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COWELL JADE PROVINCE: DETAILED GEOLOGICAL MAPPING AND DIAMOND DRILLING OF JADE AND ORNAMENTAL MARBLE OUTCROPS, 1982-1987.

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GEOLOGICAL SURVEY

by

D.J. FLINT

and

E.A. DUBOWSKI

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ABSTRACT

The Cowell Jade Province, 20 km north of Cowell, is Australia's premier source of high-quality jade. Since discovery in 1965, by Mr H.A. Schiller, 116 separate jade outcrops have been identified. Inferred resources of jade to 10 m were estimated to be 80 000 tonnes in 1987.

Detailed mapping between 1982 and 1987 of 48 jade outcrops has clearly identified many of the factors which control nephrite formation. Geological investigations included diamond drilling of three jade outcrops and 2 ornamental marble prospects.

Country rocks are Early Proterozoic, Hutchison Group sediments apparently from: banded calc-silicate gneiss at base of Warrow Quartzite, Katunga Dolomite, and carbonate facies of ?Lower or Upper Middleback Jaspilite. In all cases, host rocks are dolomitic marble and massive M_1/M_2 diopside.

Nephrite formed by several mechanisms:

- Metasomatism of dolomitic marble along D_4 fractures.
- Metasomatism of dolomitic marble along the margins of ?early-D_4 pegmatite. Pegmatite also metasomatised to produce two characteristic styles of hybrid pegmatite. Emplacement is not along the main set of D_4 joints and dissolution planes.
- Retrogression of massive M_1/M_2 diopside.

Nephrite is often foliated with a partly-sigmoidal S_4 foliation interpretable in terms of simple shearing during D_4, but with varying degrees of intensity and sense of movement.

INTRODUCTION

The Cowell Jade Province, of about 20 km^2, is located 20 km north of Cowell and contains 116 known separate nephrite jade outcrops. With inferred resources of 80 000 tonnes to 10 m depth, the deposits are of world significance. The potential has been recognised since discovery in 1965, but a thriving local jade industry is yet to be established. Government assistance has included several mapping, drilling and trial mining programs. This report presents detailed mapping, drilling and petrography of 48 jade outcrops, one talc deposit and three possible deposits of ornamental green and white marble, from the 1982-1987 mapping program.

In January 1987, Cowell Jade Pty Ltd became a public company and changed its name to Gemstone Corporation of Australia Ltd, which was listed on the Australian Stock Exchange in October 1987. As at December 1988, all 22 Mining Leases were held by the Gemstone Corporation.

Terminology of jade has been a source of confusion. The term, JADE, has been used for both the amphibole and pyroxene varieties, nephrite and jadeite, as well as for simulants (Hobbs, 1982). Jade at Cowell is **NEPHRITE**. For the purpose of this report, the term jade is used in a general sense and to denote outcrops e.g. Jade Outcrop No. 69. However, outcrops invariably contain material with a range of quality and texture. Terms used specifically to denote grades in this report are:

- nephrite
- semi-nephrite
- massive tremolite (coarse-grained) grading to tremolite schist,

These terms are used qualitatively as the range of material is transitional from one class to another. Nephrite is the highest grade of material, being suitable for polishing and use in high quality carvings of jewellry. Some semi-nephrite can be used in applications such as carvings, bookends, paper weights etc. Massive tremolite is coarser grained, occasionally microscopic grain size, but usually visible to the naked eye, is opaque and does not take a good polish. Tremolite schist is strongly foliated, coarse grained, parts readily along the schistosity and has limited gemmological application. Additional petrographic terms, are used to describe microscopic texture such as sheaves, mat tremolite, wispy tremolite, shred-like tremolite, schistose tremolite and porphyroblastic tremolite. These terms are used independently of the mineralogical classification and do not imply any specific grade.

No attempt was made to quantify the percentage of each grade of material outcrops mapped, as material quality shows considerable variation even on the scale of a few centimetres. Experience in New Zealand, Canada and Taiwan indicates that only about 10% of jade boulders collected or mined is of nephrite grade. (Leaming, 1978; Tan et al., 1978; Barnes et al., 1987 and 1988). Assessment of jade reserves (Barnes et al., 1986) assumed 26% saleable as various grades with the remainder classified as `seconds and ornamental'. That figure is now considered optimistic.

Many of the colours for jade and ornamental marble are accurately recorded by use of Munsell colours hence hue, value and chroma or saturation are detailed e.g. jade may range from greyish-green (5G 5/2) to dusky green (5G 3/2). Where no Munsell colour is noted then the colour terms used (e.g. dark green, grey-green, green-black and black) are informal and only approximate.

PREVIOUS INVESTIGATIONS

The S.A. Department of Mines and Energy (SADME) has conducted geological investigations at Cowell since the discovery, in late 1965, of nephrite by local farmer and prospector Mr H.A. Schiller. Nephritic jade was first identified by AMDEL report MP 633/67, 11 October 1966, a copy of which is included as Appendix A. The discovery outcrop was later designated Outcrop 42.

Prior to the discovery, the area subsequently identified as Outcrops 37 and 38 was mapped for ornamental marble by Steel in August 1965, but jade was not observed (Steel, 1967). Mason (1968, 1970) re-examined the site in 1968 following a request for geological assistance from Mr Schiller. At that time, the nephrite outcrops had been identified and polished samples of marble and jade had been shown to potential buyers.

The period from discovery to 1973 involved disputes and changes in tenement ownership rather than development of the jade industry. Details are recorded in Olliver (1984). Geological investigations during this period included diamond drilling of 14 holes by Analytical Exploration Pty Ltd (Hopwood, 1970; Hopwood and Coles, 1971) and by Centamin N.L. in 1973. Some of the early mineralogical/chemical investigations are detailed in Appendix B and SADME Envelope 5209.

The main phase of Government involvement began in 1974 and followed a request from the Premier's Department for SADME to evaluate the potential of the area for commercial production. Nichol (1974 a & b, 1975, 1977) geologically mapped the province, identified 91 individual outcrops of jade and reviewed the origin, quality, mining and processing of jade.

The next involvement was in 1976 when a trial mining program was conducted, in association with carving at the O'Halloran Hill College of Further Education, to evaluate the range of colours and textures (Scott et al., 1978). The carvings and jewellery were purchased by SADME for promotional displays. Funds for the program were supplied by the Director of Development. Total outcrops identified had increased to 100.

In 1979, the Miltalie jade deposit, 11 km northwest of Cowell was investigated (Scott, 1983). This is the only known significant jade outcrop outside of the Cowell Jade Province. Another prospect at Ullabidinie, 9 km west of Cowell, is at best only semi-nephrite, but provided important data on the structural and metamorphic controls to jade formation (Parker, 1981). All previous geological investigations are summarised in Barnes et al. (1980).

In an attempt to rationalise the industry in 1980, an area of about 20 km^2 comprising sections 111, 116 and 123 and including a road reserve were reserved from Parts IV to VIII of the Mining Act. Tenure was effectively restricted to 30 leases. Following cancellation and lapsing, current Mineral Leases (MLs) total 22 and are held by the Gemstone Corporation of Australia Ltd. Reservation of this area prevents pegging of new Mineral Claims (MCs) and granting of Exploration Licences (ELs) and remains in force at the time of writing.

This investigation commenced in September 1982 with detailed mapping, surveying and diamond drilling of numerous jade outcrops (including all quarries) and possible deposits of ornamental green and white marble. Geological mapping was assisted by:

- Mohammed Sahl, Mohammed Rehaili and Abdulazziz Ziab of the Directorate General of Mineral Resources, Jeddah, Saudi Arabia in 1982, and
- Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata of the Directorate General of Mineral Resources, Bandung, Indonesia in 1987.

A total of 116 individual jade outcrops are plotted on Figure 1. Production of all grades of jade to December 1988 totals 1 513 tonnes (Fig. 2).

This report documents the detailed observations at 48 outcrops where many of the factors which control jade formation are now well established. Previous geological investigations are included where appropriate, but in many cases full details are available only in the original reference. This report concentrates on mapping data and petrography and briefly discusses chemical aspects of jade formation. XRD data are detailed in Appendix D with petrographic descriptions for SADME samples collected from the area since 1980 in Appendix E, including descriptions by Farrand (1985) of samples from DDH 14 at Outcrop 15.

Progress review reports were compiled as Flint et al. (1984), Flint (1988) and Flint and Dubowski (1988). Diamond drilling of DDH 1-17 was compared with surface geology in a paper presented at the 8th Australian Geological Convention (Flint and Dubowski, 1986). Jade reserves were re-assessed in 1986 (Barnes et al., 1986). An extensive bibliography of nephrite jade (Flint and Dubowski, 1987) was prepared as part of a world review of the geology, production and reserves of nephrite jade (Barnes et al., 1987 & 1988). New scanning electron microscope (SEM) and transmission electron microscope (TEM) data from the CSIRO are partly compiled in Flint et al. (1989).

However, this report does not include all data from the 1982-1987 program and uncompiled data include:

- 1:10 000 mapping of the Cowell Jade Province
- illustration of petrographic features by photomicrographs
- additional outcrops mapped and sampled but not surveyed
- additional SEM and TEM studies by Hans Jaeger, CSIRO - Melbourne. This is partly available as SADME Slide Nos. 36656-36675 and in Flint et al. (1989).
- Some samples included in tables 1 and 2 which have not been described or located on the plans.

GEOLOGICAL SUMMARY

Detailed descriptions of site geology, including lithology and structure for the 48 outcrops examined in detail comprise Appendix G in Volume II of this report. Dates of mapping are given in the Geological maps, stereorgaphic plots and logs of diamond drill holes are presented on plans which comprise volumes III and IV. Locations of the jade and marble outcrops and geological maps and tenements are shown on figure 1 in this volume. A schematic representation of fold styles and geochronology as presented on figure 3 in this volume.

The following geological summary has been compiled from the large amount of data presented in volumes II, III and IV.

Host rocks to nephrite at Cowell are dolomitic marble, massive diopside and banded calc-silicate gneiss of the Early Proterozoic, Hutchison Group. Jade is apparently developed at several stratigraphic horizons - basal banded calc-silicate gneiss unit of Warrow Quartzite, Katunga Dolomite and dolomitic facies of Middleback Jaspilite. Most of the jade outcrops are hosted by dolomitic marble and massive diopside within the calc-silicate gneiss unit at the base of Warrow Quartzite.

High-grade metamorphics and abundant migmatites were produced during the first and second deformational events (D_1 and D_2) of the Kimban Orogeny. In dolomitic marble, typical first-phase metamorphic assemblages consist of coarse-grained dolomite, forsterite, diopside and calcite. Massive monomineralic diopside rocks were also formed. During D_2 isoclinal folding, M_2 assemblages were very similar to or of slightly lower grade than M_1 assemblages, with partial replacement of diopside by tremolite. Coarse-grained tremolite schists are occasionally found as precursors to jade and were probably formed either during D_2/M_2 retrogression or subsequently during D_3.

Retrogression was extensive during the third deformation (D_3) - a phase of macroscopic and mesoscopic folding and mylonitisation. Axial planar structures consist of schistosities, crenulations and locally a mylonitic schistosity. Mylonite zones were mapped near Outcrops 9-12 and 55 but are more extensive and common. Stratigraphic interpretations are complicated, not only by the complex interaction of D_2 and D_3 folds, but also by abundant small blocks of stratigraphy separated by mylonite zones.

Retrograde reactions in dolomitic marble during D_3 involved extensive serpentinisation of olivine and partial uralitisation of diopside. Calc-silicate interbeds were partially converted to assemblages containing combinations of epidote, zoisite, clinozoisite, chlorite, tremolite and actinolite, as well as phlogopite. D_3 retrogressive assemblages are, in places, mylonitised. Many, but not all, nephrite lenses are found within extensive zones of D_3 retrogression, even though nephrite formation was later. Such preconditioning is also often found overseas for jade lenses within serpentinised ultramafics.

Later broad cross-warping during D_4, about 1600Ma, also produced narrow zones of intense D_4 strain with widespread jointing, fracturing and displacement (Plates 9-14 and Figure 3). Dykes of porphyritic adamellite and pegmatite were also emplaced during early D_4 and are in turn jointed and folded during D_4. Metasomatism of dolomitic marble and massive diopside adjacent to these long, linear, fracture zones and pegmatite dykes is crucial to nephrite formation. Additional alteration assemblages of tremolite and nephrite, as well as talc, chlorite, epidote and serpentine were formed as solutions percolated along layering and away from the fracture. Gneissic amphibolite is often completely retrogressed to massive and schistose Ti-rich chlorite rocks which often form hanging and footwall contacts to jade lenses (Plates 12, 25 and 26).

The main mechanism of nephrite formation, suggested by Parker (1981), is replacement of dolomitic marble during D_4 metasomatism. The sequence of events is:

1. Introduction of $Si0_2$ along D_4 fractures (oriented N-S and SE-NW).
2. Diffusion of $Si0_2$ into dolomitic marble.
3. Reactions of the form:

dolomite + silica + water =
tremolite + calcite + carbon dioxide.

4. Calcite removed along D_4 fractures.

However although there are 116 known jade lenses and numerous smaller occurrences, quartz veining along D_4 fractures is observed only rarely and this is apparently a major rate-controlling factor to jade formation. However, early-D_4 pegmatites are probably the main source of silica but are in turn metasomatised themselves (e.g. see Plates 30-34). Although variously referred to as hybrid pegmatite, altered granite, altered intrusive, leucogranite, feldspar-chlorite rock or P-G rock their importance to nephrite formation was recognised since the early geological mapping of Hopwood (1970) and Hopwood & Coles (1971). The best examples are at Outcrops 32, 52, 53, 69 and 76.

D_4 structures reveal an extended period of brittle and ductile deformation and at least one foliation is often represented in jade lenses as well as adjacent chlorite-rich and talc-rich zones, but not in host dolomitic marble. The penetrative foliation apparently developed by simple shear in a ductile shear zone. The foliation, as a tremolite, nephrite, chloritic or talcose schistosity, represents the plane of flattening during shearing. Plate 16 illustrates the typical relationships between D_4 fracture planes and the S_4 foliation developed by synchronous simple shear. As the bulk strain increases,

- the schistosity is more strongly developed
- the schistosity is more asymptotic to the fracture surfaces
- and the angular difference between the schistosity and fracture surface is reduced from 20-40^o to only 10-20^o.

The foliation pattern is sigmoidal, but not the outcrop pattern of jade. Repeated ductile simple shearing in narrow zones of higher bulk strain, also caused additional foliations and folding of the earlier S_4 schistosity. The dominant D_4 foliations and fractures trend SE with a consistent sinistral sense of shear. Significantly D_4 kink folds are exposed at Outcrops 53, 99-100 and 116. The sense of shear is dextral in the south near Outcrops 46-53, 99-100 and 116 where it is associated with dextral faults that displace those outcrops from the same horizon at Outcrops 55-83. A N-S D_4 foliation is also sporadically developed, particularly in proximity to the N-S Ulbana Shear, and is referred to as either S_4 or S_5. Outcrops containing the N-S foliation are 24, 52, 53, 99-100 and 116 with open N-S folds, interpreted as D_4, also at Outcrops 35 and 114. The N-S foliation strikes in the range 000-020^{o}M and often merges with the retrogressive D_3 schistosity striking in the range 010-035^{o}M and interpretations are at times ambiguous. At Outcrop 116, the N-S phase clearly overprints the more typical SE-trending S_4 foliation.

Although most jade formed by the above model from metasomatism of dolomitic marble, precursors to jade also consisted of:

- massive M_1/M_2 diopside e.g. parts of Outcrops 15 and 55 (Plates 18-22), and
- coarse-grained tremolite schists with either an S_2 or S_3 schistosity e.g. part of Outcrop 15 (Plate 38).

Where nephrite is massive, the timing is difficult to establish but in many cases the nephrite formed from these precursors is also foliated with an S_4 schistosity produced by simple shearing.

Granitic intrusives and pegmatite synchronous with D_4 provide an opportunity to directly date jade formation, either by Rb-Sr (total rock) or U-Pb analyses on zircons. Outcrops 53 and 116 provide the best examples with clear, unambiguous relationships of a porphyritic adamellite to D_4 structures.

The Cowell Jade Province apparently corresponds to an area of favourable host rocks, intense D_4 fracturing and syn-D_4 intrusion of quartz veins, pegmatite and porphyritic adamellite. Apparently comparable host rocks and D_4 structures are extensive in the Cowell-Cleve area (Parker, 1983a and b) but, by comparison, other jade outcrops are scarce except for scattered semi-nephrite occurrences such as Ullabidinie and Miltalie. The controlling factor is apparently the same as within the Cowell Jade Province - the necessity for synchronous emplacement of quartz veins, pegmatite and granitic intrusives.

The Cowell Jade Province contains chlorite-rich rocks as well as the tremolite-rich jade lenses and these are often observed in contact with each other. Both have potential to be mined for industrial mineral applications. Tremolite powder from saws in the workshops have been used experimentally for glazing.

CHEMISTRY

Suites of samples have been analysed to further elucidate characteristics of jade as well as the rocks from which jade has been derived i.e. dolomitic marble and massive diopside. Previous chemical analyses of nephrite, semi-nephrite and host dolomitic marble are presented in Parker (1981) for the Ullabidinie area and in Nichol (1974 a & b, 1977) for the Cowell Jade Province. Data from the 1982-1987 mapping program are indexed in Tables 1 and Tables 3-10. Analyses of nephrite, semi-nephrite and coarser-grained tremolite rocks are collated in Tables 3-5. Original data are presented in Appendix C.

Interpretation presented here is limited by availability of data; most analyses being from impure samples, either with phases such as chlorite present or with the almost ubiquitous dusty opaque minerals lining D_4 fractures and foliations.

Analyses of Cowell nephrite were compared with theoretical tremolite (Table 3) and indicate that:

- SiO_2 content of Cowell nephrite is variable
- MgO is generally lower and obviously partly substituted by Fe
- CaO is also variable
- selected samples (nephrite with lowest abundance of other phases) were analysed for FeO and Fe_2O_3 and indicate that a substantial proportion of Fe is present as Fe_2O_3. However, ubiquitous dusty opaque and translucent Fe/Mn oxides/ hydroxides lining fractures probably contain most of the Fe_2O_3.

Several samples were apparently anomalous in zinc (Table 4) with 100-240ppm but some check analyses by Billiton (Appendix C, Comlabs Report COM 850537) failed to duplicate the anomalies.

As outlined in Nichol (1975) and Flint et al (1988 and 1989), Cowell jade commonly has yellow-green hues rather than vivid green, but in a very dark tone. The low content of Cr (<10-100 ppm) and Ni (<10-70 ppm) apparently determine the hue to be yellow-green rather than bright green. A similar conclusion was reached by Tan and Tsui (1978) for Fengtien nephrite (Taiwan) based on samples with a much wider range of Cr and Ni contents.

Iron has also been considered an important colour control, but Tan and Tsui (1978) found that white and green nephrite can contain the same amount of FeO. Cowell nephrite has a very dark tone and is often described as black and green black with a yellow-green hue. High iron content, as in jade from outcrops 15, 69 & 76 has been considered responsible for the dark tone (Nichol, 1975; Flint et al., 1988 and 1989). Earlier analyses M1-M4 and P100/73 (Nichol, 1974a) were all of jade from Outcrops 32-36 and colour was described as ranging from light green to very dark greyish green. Total iron contents (expressed as Fe_2O_3) ranged from 1.4% to 7.9%. To date, analyses have not been carried out on the darkest tone black or premium black jade from Outcrops 15,44 or 69. Hence the possibility exists that nephrite with higher iron content will be found. Dark green black nephrite/semi-nephrite at Outcrop 69 along a D_4 joint contained 4.75% FeO and 2.18% Fe_2O_3.

All nephrite/semi-nephrite analyses of this survey have a similar range to that found by Nichol (1975) except that several analyses here are of nephrite with less than 1% FeO + Fe_2O_3. In particular, the pale greenish yellow semi-nephrite from Outcrop 52 (ie 6230RS343 and about Munsell 10Y 9/1) contains only 0.60% FeO and 0.05% Fe_2O_3. A semi-nephrite dump sample (6230RS350), from Outcrop 52 is also low in iron with only 0.52% FeO and 0.36% Fe_2O_3. Similar pale greenish yellow semi-nephrite from Outcrop 53 (ie 6230RS426) was not analysed but is expected to contain less than 1% total iron. The pale greenish-yellow nephrite/semi-nephrite apparently developed on the margins of quartz veins crossing dolomitic marble, where retrogressive gneissic amphibolite, the probable source of iron, was absent.

Grudinin et al. (1979) demonstrated by use of optic, infrared and electron paramagnetic resonance spectroscopy that colour in Russian nephrite is connected with Fe^{2+}, Ni^{2+} and Cr^{3+} in distorted octahedral positions at the Mg^{2+} site, but did not distinguish attributes of the colour i.e. hue, tone and chroma or saturation.

However, controls to colour are more involved than just Fe, Cr and Ni contents. Flamini et al (1978) demonstrated for Taiwanese nephrite with diverse shades of green colour and cat's-eye effect, but with identical chemical and mineralogical composition, that colour was related to different arrangements of the fibres. Equivalent detailed analysis has not been carried out on Cowell nephrite, but it is probable that the numerous textural variations influence colour and perhaps also translucency. Cowell nephrite often exhibits colour mottling with `orange peel' polishing characteristics, which is demonstrably due to different arrangement and grain size of tremolite fibres (Plates 35-40).

Controlled laboratory experiments to study induced changes in colour of Russian nephrite have been conducted by Medvedev et al (1984). Nephrite was hydrothermally reworked at 300-500°C, total pressures of 500-1000 atmospheres and under oxidising or reducing conditions with starting H_2 or O_2 concentrations of 5-10 mole percent. Under oxidising conditions, rims of coarser grained fibres, 5-10 times thicker than in starting samples, were developed and secondary alterations to texture, colour (brown and dirty green hues) and translucency (lower) are evident. Under reducing conditions, texture became more homogeneous and translucency increased. Reducing conditions were interpreted to inhibit broad tremolite prisms. Both Medvedev et al (1984) for Russian nephrite and Farrand (1985) for Cowell nephrite suggested that late-stage penetration of oxidising fluids have caused formation of broad prismatic tremolite in the matrix of fine, felted fibres.

Dorling and Zussman (1987) found that small amounts of aluminium influence the morphology by suppressing formation of amphiboles with an asbestiform habit. Detailed TEM studies of the texture of jade have been conducted by Dorling and Zussman (1985) for two nephrite (tremolite) samples from Sweetwater and Lander, Wyoming and one white nephrite (richterite) from California.

Similar TEM studies have been conducted on Cowell nephrite by Hans Jaeger, CSIRO Division of Materials Science and Technology, Melbourne. Results are very similar to the TEM work of Dorling and Zussman (1985 and 1987) but are largely uncompiled at this stage. Preliminary observations are presented in Flint et al. (1989, Plates 19-23) and Lai et al. (1988) and additional slides of TEM and SEM views are available as SADME Slides nos 36656-36675.

Spear and Kimball (1984) presented a Fortran-IV program (RECAMP) for estimating Fe^{3+} contents in amphiboles where analyses record only total iron. RECAMP uses nine different normalisation procedures to calculate the amphibole formula using the analysis and stoichiometric constraints. Stoichiometric restrictions used in the program are:

- Si is recognised only in the tetrahedral sites
- only Si and Al are contained in the tetrahedral sites
- only K and Na can be in the A site
- Ca must be in the M_4 site
- octahedral Na is permitted only in the M_4 site
- there are no vacancies in the tetrahedral or octahedral sites
- K is assigned only to the A site

Tremolite and actinolite should follow that behaviour. However, results on Cowell, Taiwanese and New Zealand nephrite show that a large number of samples are non-stoichiometric tremolite. Presumably this is either caused by or contributed to by the abundant triple-chain structures in nephrite rather than the typical amphibole double-chain structure. The triple chain defects (and predicted non-stoichiometry) were found by Hutchison et al. (1976), Mallinson et al. (1977), Jefferson et al. (1978), Mallinson (1980) and Mallinson et al. (1980) and have also been found in Cowell nephrite by Hans Jaeger (Flint et al., 1989).

The model of Parker (1981) is for nephrite to form by metasomatism of impure dolomitic marble, based on the occurrence of semi-nephrite at Ullabidinie. As detailed elsewhere in this report, detailed mapping confirms this hypothesis for many of the outcrops within the Cowell Jade Province, but there are some which suggest that the precursor to nephrite is diopside and numerous examples exist of diopside uralitised to tremolite schist, semi-nephrite and occasionally nephrite. Samples were analysed to test the range of possible precursors i.e. impure dolomitic marble, massive dolomite and assorted banded calc-silicate gneiss.

Metasomatism of dolomitic marble requires introduction of substantial silica, removal of calcite and P_{H2O} must be $>>P_{CO2}$. Reactions are of the form:

1. Serpentine + 2 dolomite + $6SiO_2$ = tremolite + $4CO_2$ + H_2O
2. 5 dolomite + $8SiO_2$ +H_2O = tremolite + 3 calcite + $7CO_2$

Quartz veins and pegmatite dykes are rarely observed along D_4 fractures and silica availability is apparently the key rate-determining factor for nephrite formation by this mechanism. However, there is little doubt that nephrite does form by this mechanism though the source of silica is more likely to be the hybrid pegmatite (or feldspar-chlorite rock of Hopwood (1970) and Hopwood and Coles (1971)). This is well illustrated at Outcrop 69 and to lesser extents at Outcrops 32, 52, 53 and 76.

Direct retrogression of M_1/M_2 diopside to nephrite and semi-nephrite is common and is probably nearly of equal significance to metasomatism of dolomitic marble. Plots of CaO v MgO v SiO_2 (not reproduced here) for a range of possible precursors illustrate that nephrite formation from diopside involves less metasomatism than that required for dolomitic marble. The reaction may be of the form:

5 diopside + $3CO_2$ + H_2O = tremolite + 3 calcite + SiO_2.

This would imply that P_{C02} was greater than P_{H20} and that any silica produced would be free to react with dolomitic marble as proposed for the alternative model.

Nephrite apparently formed by both mechanisms. Both models predict calcite formation which is observed occasionally as veins (e.g. at Outcrops 35-36) and as calcite-rich pods as at Outcrop 99 (6230 RS 490) but overall, free calcite is rare.

Host rocks with very high Mg contents and perhaps where magnesite was originally present, contain phlogopite, anthophyllite, cummingtonite and chlorites (?clinochore/ pycnochlorite). More calcic and alumina-rich lithologies produce nephrite with epidote, clinozoisite and zoisite. Perhaps the best examples of these are from petrography of diamond drill core from Outcrops 15, 32 and 35.

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- R.S. Robertson and D.A. Young (Mineral Resources Branch, SADME).

D J FLINT	E A DUBOWSKI
SENIOR GEOLOGIST	SENIOR GEOLOGIST

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TABLE 1: Petrography Map Sheet 6230

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS2405/81	30969	303	Thulite	ML 5255			
GS3146/80	42889	304	Semi-Nephrite	Miltalie			Miltalie nephrite deposit
	42890	305	Semi-Nephrite	Miltalie			Miltalie nephrite deposit
	42891	306	Quartzite	Miltalie			Miltalie nephrite deposit
GS2477/83	44821	320	Calc-Silicate	Regional			
	44822	321	Amphibolite	Regional			
	44823	322	?Gneiss	Regional			
	44824	323	Calc-Silicate	Regional			
	44825	324	Calc-Silicate	Regional			
	44826	325	Nephrite	ML 4577	83		Analysis
	44828	326	Schist	ML 4386			
	44829	327	Granodiorite Gneiss	Regional			
	44830	328	Aplite Dyke	Regional			
	44836	329	Semi-Nephrite	ML 4217	32	88-86	Analysis
	44837	330	Tremolite/Dolomite	ML 4217	32	88-86	
GS2476/83	44803	331	Calc-Silicate	Regional			
	44804	332	Tremolite Schist	(ML4525)			
	44805	333	Calc-Silicate	Regional			
	44806	334	Schist	Regional			
	44807	335	Granodiorite Gneiss	Regional			
	44808	336	Calc-Silicate	Regional			
	44809	337	Schist	Regional			
	44810	338	Amphibolite	Regional			
	44811	339	Granodiorite Gneiss	Regional			
	44812	340	Granodiorite Gneiss	Regional			
	44817	341	Chert	Regional			

GS5231/83	39682	343	Semi-Nephrite	ML 4783	52	88-90	Analysis
	39689	344	Semi-Nephrite	ML 4381	35	88-86	Analysis
	39690	345	Dolomite	ML 4381	35	88-86	
	39691	346	Semi-Nephrite	ML 4381	35	88-86	Analysis
	39692	347	Foliated Nephrite	ML 4217	24	88-84	Analysis
	39693	348	Foliated Semi-Nephrite	ML 4217	24	88-84	Analysis
	39694	349	Foliated Nephrite	ML 4783	52	88-90	Analysis
	39695	350	Semi-Nephrite	ML 4783	52	88-90	Analysis
	39696	351	Semi-Nephrite	ML 4783	52	88-90	Analysis
GS5930/84	40866	352	Tremolite	(ML4522)	112		Analysis
	40868	353	Tremolite Schist	ML 4533	75		Analysis
GS6238/84	41460	354	Calc-Silicate	Regional			
	41461	355	Granite	Regional			
	41463	356	Granodiorite Gneiss	Regional		88-89	Analysis
	41465	357	Calc-Silicate	ML 4381		35/36	Not located on outcrop plan 89-86
	41466	358	Altered Intrusive	ML 4381		35/36	Not located on outcrop plan 89-86
	41467	359	Calc-Silicate	ML 4381		35/36	Not located on outcrop plan 89-86
	41468	360	Semi-Nephrite	ML 4578	51	88-90	Analysis
	41469	361	Calc-Silicate	(ML 4522)		88-89	
	41464	362	Sericite Schist	ML 4339			
		387	Nephrite	ML 4217	24		Analysis only
		405		(ML 4534)	76	89-182	No sample description available
		406		(ML 4534)	76	89-182	No sample description available
		407		(ML 4534)	76	89-182	No sample description available
		408		(ML 4534)	76	89-182	No sample description available
		409		(ML 4534)	76	89-182	No sample description available
		410		(ML 4534)	76	89-182	No sample description available
		411		(ML 4534)	76	89-182	No sample description available
		412		(ML 4534)	76	89-182	No sample description available
		413	Nephrite	ML 4217	32		Analysis only; Not located
GS 2622/87		414		(ML 4568)		89-181	XRD Analysis only
		415		ML 4783	52		Not located, plan 88-90

GS6795#5G	48685	416	Semi-Nephrite	ML 4783	52	88-90		
	48686	417	Tremolite	ML 4783	52	88-90		
	48687	418	Altered Intrusive	ML 4783	52	88-90		
	48699	419	Granitic Gneiss	ML 4217	32			
	48700	420	?Semi-Nephrite	ML 4217	32		Analysis; Not located	
	48703	421	Tremolite Schist	ML 4217	114	89-184	Analysis	
		422	Amphibolitic Gneiss	(ML 4554)	76		Analysis only	
GS6795#5G	48705	423	Chlorite-Tremolite Schist	(ML 4524)	53		Not located	
		424		(ML 4524)	53		Not located; No sample description	
GS2622/87		425		(ML 4524)	53		Not located; No sample description	
		428		(ML 4524)	53		No sample description available	
		429		(ML 4524)	116	89-181		
		431		ML 4783	52			
		432		ML 4217	32			
		433		ML 4217	32			
		434		ML 4217	32			
		435		ML 4217	32			
		436		ML 4217	32			
		437		ML 4217	32			
		438		ML 4217	32			
		489		(ML 4568)		99-100		
		490		(ML 4568)		99-100		
		491		(ML 4568)		99-100	89-181	See also 89-183; No sample description available
		492		(ML 4524)	116	89-181	See also 89-185; No sample description available	

TABLE 2: Petrography Map Sheet 6231

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS3146/80	42887	24	Nephrite	ML 4132	69		Not located
	42888	25	Nephrite	ML 4132	69		Not located
GS3786/81	31695	77	Talc	ML 4576			
	31696	78	Talc	ML 4576			
GS2477/83	44827	79	Gneiss	Regional			
	44831	80	Gneiss	Regional			
	44832	81	Granodiorite Gneiss	Regional			
	44833	82	Granodiorite Gneiss	Regional			
	44834	83	Granodiorite Gneiss	Regional			
	44835	84	Granodiorite Gneiss	Regional			
GS2476/83	44814	85	Calc-Silicate	Regional			
	44815	86	Gneiss	Regional			
	44816	87	Chert	Regional			
	44818	88	Granodiorite Gneiss	(MC 4966)			
	44819	89	Gneiss	ML 4634	15	88-83	
	44820	90	Calc-Silicate	ML 4634	15	88-83	Surface sample prior to expanded mine operation
	44813	91	Calc-Silicate	ML 4217			
GS5231/83	39683	92	Altered Intrusive	(ML 4597)	14	88-82	
	39684	93	Altered Intrusive	(ML 4597)	14	88-82	
	39685	94	Granodiorite Gneiss	(ML 4597)	14	88-82	
	39686	95	Tremolite	(ML 4597)	14	88-82	Analysis
	39687	96	Semi-Nephrite	(ML 4597)	14	88-82	Analysis
	39688	97	Granodiorite Gneiss	(ML 4597)	14	88-82	
	39697	98	Altered Intrusive	ML 4132	69	88-93	
	39698	99	Nephrite	ML 4132	69	88-93	Analysis

GS5930/84	40845	100	Calc-Silicate	(ML 4597)	14	88-82	
	40846	101	Altered Intrusive	(ML 4597)	14	88-82	
	40847	102	Gneiss	Regional			
	40848	103	Calc-Silicate	(ML 4668)	88		
	40849	104	Gneiss	Regional			
	40851	106	?Pegmatite	Regional			Analysis
	40852	107	Sericite Schist	Regional			
	40853	108	Sericite Schist	Regional			

GS5930/84	40854	109	Gneissic Granite	Regional			
	40855	1210	Granodiorite Gneiss	Regional			
	40856	111	Amphibolite	Regional			
	40857	112	Semi-Nephrite	ML 4129	1		Analysis
	40858	113	Semi-Nephrite	ML 4129	92		Analysis
	40862	117	Quartzite	Regional			
	40863	118	Migmatite	Regional			
	40864	119	Granodiorite Gneiss	Regional			
	40865	120	Tremolite	ML 4338	115	88-431	Analysis
	40867	121	Sericite Schist	Regional			
	40869	122	Semi-Nephrite	ML 4132	70		Analysis
	40870	123	Amphibolite	Regional			
	40871	124	Nephrite	ML 4131			Analysis
	40872	125	Tremolite	(MC 733)			Analysis
	40873	126	Calc-Silicate	(MC 733)			
	40874	127	?Quartzite	Regional			
	40875	128	Granodiorite Gneiss	Regional			
	40876	129	Hornblende Gneiss	Regional			
	40877	130	Dolerite	Regional			
	40878	131	Gneiss	Regional			
	40879	132	Sericite Schist	Regional			
	40880	133	Iron Formation	Regional			
	40881	134	Calc-Silicate	Regional			
	40882	135	Garnet Gneiss	Regional			
	40883	136	Garnet Gneiss	Regional			
	40884	137	Tremolite	Regional			Analysis
	40885	138	Gneiss	Regional			
	40886	139	Gneiss	Regional			

	40887	140	Calc-Silicate	Regional			
	40888	141	Dolomite	Regional			
	40889	142	Dolerite	Regional			
	40890	143	Dolerite	Regional			
	40891	144	Granitic Gneiss	Regional			
	40892	145	Altered Intrusive	Regional			Analysis
	40893	146	Quartzite	Regional			
	40894	147	Semi-Nephrite	Regional	113		Analysis
	40895	148	Granite	Regional			
	40896	149	Calc-Silicate	Regional			
GS6238/84	41462	150	Altered Intrusive	ML 4132	69		Analysis; Not located
GS4653/85		192		ML 4576			XRD Analysis only
		195		ML 4130	55		Not located; No sample description
		196		ML 4130	55		No sample description available
		197		ML 4130	55		No sample description available
		198		ML 4130	55		No sample description available
		199		ML 4130	55		No sample description available
GS6795#5G	48684	200	Granodiorite Gneiss	ML 4217		89-177	
	48688	201	Gneiss	ML 4415			
	48689	202	Gneiss	ML 4415	107	88-430	
		203		ML 4130	55	88-429	No sample description available
GS6795#5G	48691	204	Iron Formation	ML 4130	55	88-429	
	48692	205	Serpentinised Marble	ML 4130	55	88-429	
	48693	206	Iron Formation	ML 4130	55	88-429	
	48694	207	Chlorotoid Schist	ML 4338	115	88-431	
	48695	208	Gneiss	ML 4130	56	88-429	
	48696	209	Tremolite	ML 4130	56	88-429	
	48697	210	Semi-Nephrite	ML 4130	56	88-429	
	48698	211	Semi-Nephrite	ML 4130	57	88-429	
	48701	212	Tremolite Schist	ML 4217	21	88-423	Analysis
	48702	213	Tremolite Schist	ML 4217	21	88-423	Analysis
	48704	214	Chloritic Dolomite	ML 4217	27		Analysis
		215					

216		ML 4532	9-12	88-422	No sample description available
217		ML 4532	9-12	88-422	No sample description available
218		ML 4532	9-12	88-422	No sample description available
269	Iron Formation	Regional			Same as 6231 RS133; No sample description
270		ML 4532	11		Not located; No sample description

APPENDIX A

NOTES AND PETROGRAPHY OF DISCOVERY SAMPLE

AMDEL Report MP 633/67; Sample P998/66

JADE (AUSTRALIA) PTY. LIMITED

28 GOVER STREET, NORTH ADELAIDE, SOUTH AUSTRALIA 5006

Miners — Gem Merchants

A00001

H.A.Schiller
[redacted] 'P.O.Box 43,
'Cowell 5602
S.A 6

/

Discovery of Nephrite Jade.

In the latter part of 1965 while prospecting I was intrigued by a heavy, hard, coarse rock weighing about 8 lbs lying alongside of a white marble outcrop.
Mr Swain who was interested in white marble was visiting the area at my invitation. He pegged two claims over the white marble bed. On his second visit early in 1966 I handed him the rock mentioned above. He said he would take it to Adelaide for identification.
He returned several days latter, saying that it had been identified as Nephrite by the Adelaide University.
I also had an identification made by the Museum by Dr Corbit through a friend in Whyalla.
The first official identification made of the nephrite was made by A.M.D.L. through the Mines Dept on the 11th Oct for myself (copy enclosed)

H A Schiller

Per Elders to Queen. town

March 1973.

A00002

COPY

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

PARKSIDE, S.A.
11th October, 1966

MP 1/16/0

REPORT MP633-67

YOUR REFERENCE: Application dated 5/9/66

MATERIAL: Green Rock Specimen

LOCALITY: Minbrie Hd. Sec. 116

IDENTIFICATION: P998/66

DATE RECEIVED: 6/9/66

WORK REQUIRED: Identification

Investigation and Report by: I.F. Scott

Officer in Charge, Mineralogy Section: H.W. Fander

P.A. YOUNG
Director

P998/66: TS18157

This rock is a very compact, finely fibrous mass of amphibole crystals.

The ampibole has the following properties:

a. light green colour

b. no obvious pleochroism

c. Ny= 1.61

d. length fast

e. fibrous habit

The optical properties and occurrence of this mineral indicates it is nephritic jade.

APPENDIX B

MINERALOGY AND CHEMISTRY OF SAMPLES M1-M4

by McPhar Geophysics Pty Ltd

for Jade (Australia) Pty Ltd,
1973

Mineralogical Report 1286
Mineralogical Report 1326
Batch CH 4990

B00001

McPHAR GEOPHYSICS PTY. LTD.
TELEPHONE 72 2133
50-52 MARY STREET, UNLEY, SOUTH AUSTRALIA
POSTAL ADDRESS: P.O. BOX 42, UNLEY, SOUTH AUSTRALIA 5061
CABLE "PHARGEO" ADELAIDE
TELEX "PHARGEO" AA82623

MINERALOGICAL REPORT NO. 1286

by: I.R. Pontifex 30th July, 1973.

TO:	Mr. K.D. Price, Director, Jade (Australia) Pty. Ltd., 197 Port Road, QUEENSTOWN. S.A. 5014
YOUR REFERENCE:	Referred to the Petrology Laboratories by Dr. Beevers, Chief Chemist, McPhar Geophysics.
MATERIAL:	Four samples of jade.
IDENTIFICATION:	1, 2, 3, 4.
WORK REQUESTED:	Petrographic examination, description of composition and texture of each sample.
SAMPLES & SECTIONS:	Retained at McPhar, available on request.

McPHAR GEOPHYSICS PTY. LTD.

I.R. PONTIFEX
Chief Mineralogist.

INTRODUCTION:

The four samples of "jade" submitted were examined in thin section under a petrological microscope. Petrologically the samples are seen to consist of nephrite, which is defined as a massive, tough, compact variety of extremely fine fibrous to lamellar-form amphibole, having a composition between actinolite $Ca_2(FeMg)_5\ (OH)_2\ (Si_4O_{11})_2$ and tremolite $Ca_2(MgFe)_5\ (OH)_2\ (Si_4O_{11})_2$. Generally it is far more tremolite-rich than actinolite-rich.

Each sample is essentially mono-mineralic, consisting exclusively of nephrite. The microscopic differences between samples is textural, i.e. in the size and distribution of the amphibole crystals and this represents various stages of crystallisation (or recrystallisation) of the nephrite mass.

The same four samples were analysed chemically and these results have been reported separately (batch no. CH 4990). Slight variations in these analyses indicates marginal differences in the composition of the tremolite. These compositional differences however, cannot be identified under the microscope.

INDIVIDUAL PETROGRAPHIC DESCRIPTIONS

No. 1:

Colour: very dark greyish green.

This has the finest grain size and most homogeneous texture of all four samples. It consists entirely of nephrite, i.e. a compact mass of intimately intergrown or matted tremolite.

The coarsest size of individual tremolite crystals is represented by well defined prisms measuring 0.65 x 0.025 mm; and relatively diffuse, irregular shreds of fibro-lamellar form prisms, which are optically continuous over areas measuring up to 1.2 mm x 0.15 mm. Tremolite within this grain size forms about 20% of the section examined.

This coarser tremolite has one dominant preferred optical orientation, and one subordinate preferred orientation. It occurs in a matrix of matted fibrous tremolite having an average individual crystal size of about 0.025 mm.

No. 2:

Colour: light green (a darkish lime-green).

This is the next most fine grained sample of the four in the suite; the texture of the nephrite mat is less homogeneous than in no. 1 but far more homogeneous than in no. 3 and no. 4.

Tremolite prisms generally about 0.5 mm x 0.2 mm but rarely up to 3 mm x 1.5 mm have a rather ragged outline, and a random distribution. Commonly they occur in localised loose aggregates within a finer tremolite matrix, and they form some 30% of the section examined.

Fibro lamellar-form (commonly shred-like) tremolite crystals from this size down to the average matrix size of 0.08 mm appear to be optically oriented in at least two preferred directions.

Rare tremolite veinlets, 0.1 mm wide and 3 cm long cut the nephrite mat at random.

No. 3:

Colour: very marginally darker shade of green than in sample No. 2; i.e. light to mid green.

This rock has the coarsest grain size and the most heterogeneous texture of any other in the suite (although the texture of No. 4 is almost as heterogeneous).

Highly irregular, ragged, plate-like prisms of tremolite are optically, but not necessarily physically continuous over areas measuring 20 mm x 10 mm. These form some 60% of the rock and they have a random orientation within a finer matrix of shred-like tremolite crystals and matted fibres, with an average size of 0.1 mm. This matrix appears to invade and replace random areas within the coarser prisms.

No. 4:

Colour: dark, slightly greyish green; approximately mid-way between no. 3 and no. 1.

This section has the second most coarsest grain size, its texture is more heterogeneous than nos. 1 and 2, and marginally less than the texture in no. 4.

The tremolite forming the nephrite mat assumes three fairly distinct forms, as compared with generally two (less distinct) forms in the other samples. These are:

(a) vaguely defined, irregular, large tremolite prisms (40%), optically and generally physically continuous over areas of about 3 mm x 2 mm. These have a random distribution and their margins grade imperceptibly into the microcrystalline tremolite mat of (c) below. These are equivalent to the large plate-like crystals of tremolite in no. 3.

(b) relatively well defined fibro lamellar-form prisms and small sheafs of tremolite, (10-12%), average size 0.4 mm x 0.08 mm. These occur in groups which have a random distribution through the rock.

(c) the microcrystalline tremolite matrix (50%) of intricately interlocking fibres, and sheafs of these, average grain size 0.1 mm. This is equivalent to the matrix in the other samples.

B00007

McPHAR GEOPHYSICS PTY. LTD

TELEPHONE 72 2133

50-52 MARY STREET, UNLEY, SOUTH AUSTRALIA
POSTAL ADDRESS, P.O. BOX 42, UNLEY, SOUTH AUSTRALIA 5061

CABLE
"PHARGEO" ADELAIDE
TELEX
"PHARGEO" AA82623

MINERALOGICAL REPORT NO.1326

by: I.R. Pontifex 7th September, 1973.

TO:	Mr. K. D. Price, Jade (Australia) Pty. Ltd., 197 Port Road, QUEENSTOWN S.A. 5014.
YOUR REFERENCE:	Personal communication
MATERIAL:	Rock sample
IDENTIFICATION:	No number.
WORK REQUESTED:	Identification of rock type, particularly light green components.
SAMPLES & SECTIONS:	Retained by McPhar.

McPHAR GEOPHYSICE PTY. LIMITED

I R Pontifex

I. R. PONTIFEX
Chief Mineralogist.

tremolite - quartz - epidote rock

The sample was examined in thin section where it is seen to consist of a coarse highly irregular granoblastic aggregate of essentially 3 minerals:

epidote	55 - 65%
quartz	30 - 40%
tremolite	5 - 7 %

The epidote is the pale green mineral seen in hand specimen. It is generally granular but some areas appear to pseudomorph former fibro-lamellar-form aggregates, probably actinolite-tremolite.

The quartz forms highly irregular patches through the epidote, it is fairly extensively stressed.

Tremolite occurs as very fine, randomly scattered needles and prisms.

This is a quartzose calc-silicate rock of metomorphic origin. Quite likely it originally consisted of quartz-amphibole but has been reconstituted by retrograde metamorphism to its present composition.

SYDNEY

McPhar Geophysics Pty. Ltd.
48-52 MARY STREET
UNLEY, S.A. 5061
P.O. BOX 42
UNLEY, S.A. 5061
PHONE: 72 2133
CABLE: "PHARGEO"
ADELAIDE
TELEX: "PHARGEO"
AA82623

McPHAR

GEOCHEMICAL RESULTS

Samples from: CLIFFMINEX
Area:
Samples of: NEPHRITE
Preparation: PULVERISED
Batch No.: CH 4990

Sheet No.: 1
Date: 24-7-73

SAMPLES WILL BE DISPOSED OF AFTER TWO MONTHS UNLESS WE ARE OTHERWISE ADVISED

Sample Description	F ppm.
M1	750
M2	1300
M3	1400
M4	1850

* F by specific ion electrode method

SYDNEY

B00010

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48-52 MARY STREET
UNLEY, S.A. 5061
P.O. BOX 42
UNLEY, S.A. 5061
PHONE: 72 2133
CABLE: "PHARGEO"
ADELAIDE
TELEX: "PHARGEO"
AA82623

GEOCHEMICAL RESULTS

Samples from:
Area:
Samples of:
Preparation:
Batch No.: CH

Sheet No.: 2
Date: 24-7-73

SAMPLES WILL BE DISPOSED OF AFTER TWO MONTHS UNLESS WE ARE OTHERWISE ADVISED

Sample Description	CaO %	MgO %	Fe_2O_3	Al_2O_3	K_2O	SiO_2	Na_2O
M1	12.4	20.3	7.91	0.78	0.16	56.0	0.067
M2	14.0	23.5	1.38	0.72	0.07	58.2	0.084
M3	13.8	23.3	1.40	0.69	0.09	57.4	0.089
M4	14.2	22.9	2.31	0.97	0.16	56.6	0.081

	LOI	TOTAL
M1	1.89	99.6
M2	1.55	99.7
M3	1.92	98.8
M4	1.32	98.7

APPENDIX C

CHEMICAL ANALYSES

Extracted from Amdel Reports:

AC4545/84, AC2776/85
AC4694/85, AC3510/87.

Also Comlabs Report COM 850537

TABLE 3 : Nephrite/Tremolite Analyses

MAP SHEET	RS No.	ROCK TYPE	O/c No.	SiO2	TiO2	Al2O3	FeO	Fe2O3	MnO	MgO	CaO	K2O	Na2O	P2O5	H2O+	H2O-	LOI	TOTAL
		THEORETICAL TREMOLITE		56.52						23.70	13.19							
6230	325	Nephrite	83	56.10	0.06	1.12	5.62	1.85	0.18	20.20	11.70	0.13	0.11	<0.01	2.50	0.62		100.19
	329	Semi-Nephrite	32	58.00	0.02	0.82	1.35	0.60	0.11	23.20	13.10	0.06	0.13	0.02	2.15	0.47		100.03
	343	Semi-Nephrite	52	57.20	<0.01	0.57	0.60	0.05	0.06	23.70	14.60	<0.05	0.10	0.04	2.45	0.22		99.59
	344	Semi-Nephrite	35	47.90	0.02	0.26		1.78	0.14	17.70	21.20	<0.05	0.04	<0.01			10.30	99.34
	346	Semi-Nephrite	35	57.20	0.02	0.72	4.26	1.22	0.11	21.00	13.30	<0.05	0.08	0.02	2.00	0.26		100.19
	347	Foliated Nephrite	24	56.30	0.02	1.05	1.80	2.65	0.11	22.50	13.20	0.07	0.13	0.01	2.20	0.30		100.34
	348	Foliated Semi-Nephrite	24	57.60	0.04	1.05	1.49	0.42	0.11	23.00	13.50	0.05	0.06	<0.01	2.25	0.34		99.91
	349	Foliated Nephrite	52	57.90	<0.01	0.47	2.26	0.63	0.08	22.70	13.60	<0.05	0.06	0.04	2.05	0.35		100.14
	350	Semi-Nephrite	52	58.10	0.01	0.86	0.52	0.36	0.07	23.90	13.60	0.12	0.08	0.03	2.20	0.34		100.19
	351	Semi-Nephrite	52	56.90	0.05	1.46	3.12	0.89	0.13	21.30	13.80	0.05	0.09	0.04	2.15	0.24		100.22
	352	Tremolite	112	55.80	0.07	1.50	4.48	1.62	0.40	20.40	12.90	0.16	0.17	0.03	2.15	0.29		99.97
	353	Tremolite Schist	75	57.80	0.01	0.70	2.63	0.74	0.11	22.00	13.10	<0.05	0.10	0.05	2.25	0.39		99.88
	360	Semi-Nephrite	51	57.60	<0.01	0.58	0.77	0.29	0.08	23.60	14.40	<0.05	0.08	0.02	1.99	0.46		99.87
	370	Tremolite Schist	DDH 15	48.90	0.11	6.45		7.20	0.14	22.80	9.60	0.15	0.23	0.03			4.80	100.41
	373	Semi-Nephrite	DDH 16	56.00	0.05	1.83		2.54	0.19	23.60	12.70	0.49	0.15	0.02			2.64	100.21
	374	Semi-Nephrite	DDH 16	56.30	0.05	1.63		2.50	0.18	23.60	12.80	0.35	0.15	<0.01			2.54	100.10
	375	Semi-Nephrite	DDH 16	55.00	0.05	2.34		2.60	0.17	24.20	12.10	0.71	0.14	0.02			3.12	100.45
	387	Nephrite	24	56.50	0.01	1.52	1.25	0.50	0.13	23.40	13.80	0.08	0.14	<0.01	2.55	0.27		100.15
	413	Nephrite	32	56.70	0.10	2.14		2.54	0.16	22.30	12.00	0.67	0.21	<0.01				96.82
	420	?Semi-Nephrite	32	58.10	0.05	1.20		1.90	0.09	23.10	13.10	0.44	0.24	<0.01				98.22
	421	Tremolite Schist	114	54.50	0.06	3.34		2.14	0.12	22.30	11.20	0.31	0.31	<0.01				94.28
6231	95	Tremolite	14	55.30	0.14	2.60		4.22	0.12	21.30	13.50	0.08	0.20	0.04			1.23	98.73
	96	Semi-Nephrite	14	57.10	0.05	1.20	3.28	0.09	0.14	22.30	13.10	0.10	0.16	0.03	2.10	0.40		100.05
	99	Nephrite	69	56.50	0.02	0.60	4.75	2.18	0.11	20.10	11.60	0.10	0.11	0.15	3.37	0.59		100.18
	112	Semi-Nephrite	1	55.10	0.01	0.45	2.41	5.80	0.05	22.00	10.30	0.07	0.22	0.12	2.65	1.24		100.42
	113	Semi-Nephrite	92	57.40	0.01	0.51	4.39	1.17	0.09	21.60	11.40	<0.05	0.09	0.07	2.45	0.58		99.76
	115	Nephrite	102	57.20	0.01	0.55	2.61	1.18	0.31	22.00	13.50	0.06	0.06	0.13	2.05	0.26		99.92
	116	Nephrite	102	57.50	0.02	0.58	2.58	0.63	0.20	22.20	13.50	<0.05	0.06	0.09	2.15	0.35		99.86
	120	Tremolite	115	57.40	0.03	0.77	1.47	0.87	0.06	23.90	12.60	<0.05	0.05	0.02	2.35	0.47		99.99
	122	Semi-Nephrite	70	56.20	0.02	1.06	5.02	1.02	0.17	20.80	13.20	0.10	0.10	0.02	2.00	0.34		100.05
	124	Nephrite		57.20	0.03	0.50	4.67	1.41	0.09	20.60	12.40	0.05	0.08	0.06	2.30	0.59		99.98
	125	Tremolite		53.50	0.12	1.93		8.15	0.82	13.80	21.10	0.07	0.36	0.06			0.92	100.83
	137	Tremolite		55.40	0.06	1.77		11.00	0.38	17.00	14.00	0.06	0.26	0.07			1.01	101.01
	147	Semi-Nephrite	113	54.00	0.08	2.26	7.27	3.00	0.11	17.60	12.80	0.08	0.21	0.05	2.15	0.43		100.04
	154	?Semi-Nephrite	DDH 17	51.20	0.10	4.34		7.00	0.09	22.40	8.90	<0.05	0.15	0.04			4.90	99.12
	155	Semi-Nephrite	DDH 17	53.80	0.06	2.60		6.45	0.09	21.70	10.20	<0.05	0.15	0.03			3.92	99.00
	156	Semi-Nephrite	DDH 17	56.60	0.01	1.01		5.85	0.10	21.20	11.70	<0.05	0.11	<0.01			2.68	99.26
	160	Tremolite Schist	DDH 17	34.40	0.10	3.66		1.48	0.08	17.20	24.90	<0.05	0.06	0.01			17.40	99.29
	181	Semi-Nephrite	DDH 14	56.90	0.01	1.11		2.06	0.11	22.90	13.40	<0.05	0.16	0.03			2.06	98.74
	182	Semi-Nephrite	DDH 14	54.50	0.01	2.16		2.36	0.13	22.50	13.00	0.06	0.19	0.02			3.48	98.41
	212	Tremolite Schist	21	56.80	0.03	0.75		3.70	0.07	22.10	11.70	0.27	0.16	<0.01				95.58
	213	Tremolite Schist	21	57.40	0.03	1.23		5.00	0.12	21.50	12.10	0.17	0.14	<0.01				97.69

TABLE 4 : Nephrite/Tremolite - Geochemistry

MAP SHEET	RS No.	ROCK TYPE	O/c No.	Ba	Ce	Co	Cr	Cs	Cu	La	Mo	Nb	Ni	Pb	Rb	Sr	Th	U	V	Y	Zn	Zr
6230	325	Nephrite	83	30	<20	20	<10	<20	<10	60	<20	<4	20	<50	8	<10	<4	<4	20	<10	50	<20
	329	Semi-Nephrite	32	<20	20	<20	<10	<20	70	<20	<20	<4	20	<50	<2	<10	<4	<4	30	<10	110	<20
	343	Semi-Nephrite	52	<20	<20	<20	<10	<20	40	<20	<20	<4	50	<50	<2	<10	6	<4	10	<10	40	<20
	344	Semi-Nephrite	35	<20	35	<20	<10	<20	40	<20	<20	<4	10	<50	<2	<10	<4	<4	<10	<10	<20	<20
	346	Semi-Nephrite	35	<20	30	<20	<10	<20	60	50	<20	<4	20	<50	<2	<10	<4	<4	20	<10	40	<20
	347	Foliated Nephrite	24	<20	20	<20	<10	<20	100	20	<20	<4	20	<50	2	<10	<4	<4	10	<10	70	<20
	348	Foliated Semi-Nephrite	24	<20	<20	<20	<10	<20	60	20	<20	<4	20	<50	<2	<10	<4	<4	20	10	100	<20
	349	Foliated Nephrite	52	<20	<20	<20	<10	<20	40	20	<20	<4	20	<50	<2	<10	<4	<4	10	<10	50	<20
	350	Semi-Nephrite	52	<20	25	<20	<10	<20	50	<20	<20	<4	30	<50	4	<10	<4	<4	20	<10	90	<20
	351	Semi-Nephrite	52	40	20	<20	<10	<20	70	40	<20	<4	30	<50	<2	<10	<4	<4	20	10	150	<20
	352	Tremolite	112	20	20	<20	30	<20	20	70	<20	<4	40	<50	7	<10	8	<4	40	<10	90	<20
	353	Tremolite Schist	75	90	<20	<20	<10	<20	40	40	<20	<4	20	<50	<2	<10	<4	<4	20	<10	40	<20
	360	Semi-Nephrite	51	<20	20	<20	<10	<20	20	<20	<20	<4	<10	<50	<2	<10	<4	<4	10	<10	60	<20
	370	Tremolite Schist	DDH 15	<20	<20	50	60	<20	250	50	<20	<4	60	70	<2	<10	4	<4	60	20	90	110
	373	Semi-Nephrite	DDH 16	40	40	40	60	<20	80	40	<20	<4	40	80	15	<10	6	<4	40	10	110	80
	374	Semi-Nephrite	DDH 16	30	45	40	70	<20	280	50	<20	<4	50	60	14	<10	8	4	40	20	110	90
	375	Semi-Nephrite	DDH 16	40	20	50	50	<20	650	60	<20	<4	40	120	30	<10	<4	<4	40	20	120	90
	387	Nephrite	24	<20	20	<20	<10	<20	40	30	<20	<4	50	<50	<2	<10	<4	<4	10	<10	110	<20
	413	Nephrite	32	40		<20	<10	<20	2550	<20	<20	<50	20	<50	24	<10	8	4	30	<10	150	30
	420	?Semi-Nephrite	32	40		40	40	<20	290	50	30	200	70	210	<2	<10	<4	<4	70	<10	240	110
	421	Tremolite Schist	114	20		20	30	<20	50	<20	<20	<50	<10	<50	<2	<10	<4	<4	20	<10	160	<20
6231	95	Tremolite	14	60	30	<20	10	<20	70	30	<20	<4	30	<50	2	<10	<4	<4	40	10	120	<20
	96	Semi-Nephrite	14	<20	35	20	30	<20	40	40	<20	<4	40	<50	<2	<10	<4	<4	50	<10	110	20
	99	Nephrite	69	<20	<20	<20	<10	<20	60	70	<20	<4	20	<50	8	<10	<4	<4	10	<10	100	<20
	112	Semi-Nephrite	1	410	30	<20	<10	<20	20	90	<20	<4	30	<50	<2	<10	<4	<4	10	20	40	<20
	113	Semi-Nephrite	92	100	<20	<20	<10	<20	20	60	<20	<4	40	<50	<2	<10	<4	<4	80	<10	40	<20
	115	Nephrite	102	<20	<20	<20	100	<20	40	40	<20	<4	70	<50	<2	<10	<4	<4	10	<10	90	<20
	116	Nephrite	102	<20	20	<20	<10	<20	60	40	<20	<4	20	<50	<2	<10	<4	<4	<10	<10	90	<20
	120	Tremolite	115	<20	25	<20	<10	<20	100	30	<20	<4	20	<50	<2	<10	<4	<4	10	10	20	<20
	122	Semi-Nephrite	70	<20	30	30	50	<20	40	60	<20	<4	40	<50	3	<10	<4	<4	20	<10	60	<20
	124	Nephrite		60	<20	20	<10	<20	30	60	<20	<4	70	<50	<2	<10	<4	4	10	<10	30	<20
	125	Tremolite		20	25	40	<10	<20	20	80	<20	4	70	<50	4	70	<4	<4	30	<10	90	40
	137	Tremolite		80	25	40	<10	20	<10	100	<20	<4	40	<50	5	20	<4	<4	40	10	150	<20
	147	Semi-Nephrite	113	90	30	30	10	<20	30	100	<20	<4	20	<50	7	50	4	<4	20	<10	50	<20
	154	?Semi-Nephrite	DDH 17	<10	<20	50	30		<10	140	<4	<4	<10	<2		<10	6	6	10	<10	70	<20
	155	Semi-Nephrite	DDH 17	<10	<20	50	40		<10	130	<4	<4	<10	4		<10	<4	<4	<10	<10	60	<20
	156	Semi-Nephrite	DDH 17	<10	<20	50	30		<10	130	4	<4	<10	28		<10	<4	<4	<10	<10	70	<20
	160	Tremolite Schist	DDH 17	<10	<20	40	30		40	100	4	<4	<10	<2		<10	<4	6	10	<10	40	<20
	181	Semi-Nephrite	DDH 14	20	25	60	40		<10	120	<4	<4	<10	7		<10	<4	6	10	<10	50	<20
	182	Semi-Nephrite	DDH 14	<10	<20	140	40		20	130	4	<4	20	5		<10	<4	4	10	<10	70	<20
	212	Tremolite Schist	21	200		<20	<10	<20	2590	<20	<20	<50	<10	100	<2	<10	<4	<4	20	<10	540	30
	213	Tremolite Schist	21	<20		<20	<10	<20	50	<20	<20	<50	<10	<50	<2	<10	<4	<4	<10	<10	160	<20

TABLE 5 : Nephrite/Tremolite - Additional Geochemistry

MAP SHEET	RS No.	ROCK TYPE	O/c No.	Ag	As	Bi	Cd	Ga	Ge	In	S	Sb	Se	Sn	Ta	Te	T1	W
6230	413	Nephrite	32	<1	<50	<4	<20	3	<4	<10	3000	<50	<2	<50	90	<10	<10	<50
	420	?Semi-Nephrite	32	<1	110	<4	<20	3	<4	<10	2900	200	2	70	430	<10	<10	340
	421	Tremolite Schist	114	<1	<50	<4	<20	<2	<4	<10	1100	<50	<2	<50	<50	<10	<10	<50
6231	154	?Semi-Nephrite	DDH 17		<2	<4						6		<4				<10
	155	Semi-Nephrite	DDH 17		<2	<4						<4		<4				<10
	156	Semi-Nephrite	DDH 17		<2	<4						<4		<4				<10
	160	Tremolite Schist	DDH 17		2	<4						<4		4				<10
	181	Semi-Nephrite	DDH 14		<2	<4						<4		6				<10
	182	Semi-Nephrite	DDH 14		<2	<4						<4		<4				<10
	212	Tremolite Schist	21	<1	<50	<4	<20	<2	<4	<10	5200	<50	<2	<50	90	<10	<10	<50
	213	Tremolite Schist	21	<1	<50	8	<20	2	<4	<10	4000	<50	<2	<50	<50	<10	<10	<50

TABLE 6 : Regional Rock Sample Analyses

MAP SHEET	RS No.	ROCK TYPE	0/c No.	Si02	Ti02	A1203	Fe0	Fe203	Mn0	Mg0	Ca0	K20	Na20	P205	H20+	H20-	LOI	TOTAL
6230	356	Granodiorite Gneiss		70.70	0.58	13.50		5.10	0.07	1.49	1.31	3.80	3.30	0.13			0.73	100.71
	361	Calc-Silicate		72.70	0.14	14.80		1.42	0.06	0.26	8.65	0.20	2.22	0.07			0.26	100.78
	422	Amphibolitic Gneiss	76	49.50	1.31	13.50		14.80	0.19	5.50	10.20	0.57	1.18	0.07				96.82
6231	106	?Pegmatite		57.90	0.02	25.80		0.14	0.07	0.40	3.32	4.08	6.30	0.29			2.26	100.58
	145	Altered Intrusive		55.20	0.66	21.70		2.60	0.03	7.10	1.82	0.37	7.50	0.03			3.40	100.41
	150	Altered Intrusive	69	59.40	0.17	18.60		3.68	0.05	5.70	0.60	2.80	7.95	0.13			1.10	100.18
	214	Chloritic Dolomite	27	33.80	0.02	0.44		1.08	0.04	30.10	12.90	0.14	0.04	<0.01				78.56

TABLE 7 : Regional Rock Sample - Geochemistry

MAP SHEET	RS No.	ROCK TYPE	0/c No.	Ba	Ce	Co	Cr	Cs	Cu	La	Mo	Nb	Ni	Pb	Rb	Sr	Th	U	V	Y	Zn	Zr
6230	356	Granodiorite Gneiss		610	85	40	10	<20	70	80	<20	12	30	<50	145	110	14	<4	50	30	40	240
	361	Calc-Silicate		170	70	30	<10	<20	40	40	<20	8	40	<50	5	920	36	<4	<10	40	20	<20
	422	Amphibolitic Gneiss	76	100		30	40	<20	3970	<20	<20	<50	40	<50	14	120	6	<4	230	<10	140	100
6231	106	?Pegmatite		440	25	<20	<10	<20	70	<20	<20	<4	40	<50	150	360	<4	<4	<10	<10	20	<20
	145	Altered Intrusive		210	35	<20	50	<20	40	20	<20	14	70	<50	12	620	22	<4	70	10	20	290
	150	Altered Intrusive	69	110	65	<20	<10	<20	80	50	<20	4	30	<50	145	60	32	<4	10	<10	40	80
	214	Chloritic Dolomite	27	<20		<20	10	<20	1070	<20	<20	<50	<10	<50	<2	<10	<4	<4	<10	<10	240	<20

TABLE 8 : Regional Rock Samples - Additional Geochemistry

MAP SHEET	RS No.	ROCK TYPE	0/c No.	Ag	As	Bi	Cd	Ga	Ge	In	S	Sb	Se	Sn	Ta	Te	T1	W
6230	422	Amphibolitic Gneiss	76	<1	<50	<4	<20	16	<4	<10	700	<50	<2	<50	<50	<10	<10	<50
6231	214	Chloritic Dolomite	27	<1	<50	4	<20	<2	<4	<10	3100	<50	<2	<50	<50	<10	<10	<50

TABLE 9 : Diamond Drill Hole Silicate Analyses

OUTCROP	DDH No.	TS No.	RS No.	DEPTH(m)	ROCK TYPE	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	K2O	Na2O	P2O5	LOI	TOTAL
15	14	42269	166	5.89	Calc-Silicate												
		42270	167	6.24	Calc-Silicate	52.90	0.15	4.78	4.18	0.16	16.50	18.00	<0.05	0.22	0.03	1.74	98.66
		42271	168	6.59	?Semi-Nephrite	53.70	0.18	3.46	4.26	0.12	21.70	11.70	<0.05	0.21	0.04	3.32	98.69
		42272	169	7.69	?Calc-Silicate	54.90	0.16	3.18	5.20	0.13	19.20	12.50	0.11	0.37	0.03	2.84	98.62
		42273	170	14.87	Gneiss	70.10	0.61	14.10	3.90	0.03	1.96	0.87	0.81	5.30	0.21	1.36	99.25
		42274	171	17.48	Calc-Silicate	46.50	0.54	13.70	7.05	0.09	12.30	15.70	0.12	0.41	0.11	2.86	99.38
		42275	172	17.74	Massive Tremolite	52.80	0.10	4.22	5.05	0.10	20.90	11.20	0.15	0.42	0.01	3.60	98.55
		42276	173	22.20	Serpentinised Marble	12.00	<0.01	0.23	1.86	0.08	18.00	29.90	<0.05	<0.01	<0.01	36.10	98.17
		42277	174	23.15	Serpentinised Marble	18.20	0.01	0.78	1.69	0.08	17.40	29.60	<0.05	<0.01	<0.01	30.30	98.06
		42278	175	24.23	Tremolitic Diopside	47.90	0.14	5.15	2.62	0.10	20.50	18.00	<0.05	0.09	0.05	4.78	99.33
		42279	176	26.96	Serpentinised Marble	18.50	0.05	1.73	0.84	0.05	17.60	29.80	<0.05	<0.01	<0.01	29.90	98.47
		42280	177	27.36	Marble	31.60	0.10	4.46	1.08	0.09	18.00	25.50	0.06	0.02	0.02	18.20	99.13
		42281	178	29.29	Tremolitic Marble	40.60	0.10	3.08	1.72	0.07	18.70	22.10	<0.05	0.05	0.03	11.90	98.35
		42282	179	31.18	Serpentinised Marble	7.65	0.01	0.22	0.88	0.08	19.00	30.00	<0.05	<0.01	0.02	40.20	98.06
		42283	180	31.40	Tremolite-Diopside	42.70	0.02	0.48	1.85	0.13	16.10	27.00	<0.05	0.08	0.01	10.60	98.97
		42284	181	31.66	Semi-Nephrite	56.90	0.01	1.11	2.06	0.11	22.90	13.40	<0.05	0.16	0.03	2.06	98.74
		42285	182	31.70	Semi-Nephrite	54.50	0.01	2.16	2.36	0.13	22.50	13.00	0.06	0.19	0.02	3.48	98.41
		42286	183	31.88	Brecciated Diopside	53.30	0.07	2.32	2.12	0.12	17.80	21.40	<0.05	0.20	0.03	1.58	98.94
		42287	184	33.20	Mylonitised Calc-Silicate	45.00	0.86	25.30	3.36	0.04	3.58	11.20	3.90	1.68	0.10	3.26	98.28
		42288	185	34.04	Mylonitised Calc-Silicate	45.00	1.07	18.70	7.70	0.06	4.50	17.60	0.16	1.68	0.25	1.82	98.54
		42289	186	35.30	Altered Intrusive	64.10	0.86	14.70	4.16	0.04	3.84	3.00	0.37	5.60	0.13	1.81	98.61
		42290	187	36.51	Quartzite	73.50	0.19	13.90	0.90	<0.01	0.21	1.47	0.15	7.50	0.06	0.54	98.42
35	15	43740	364	7.13	Calc-Silicate	54.50	1.73	15.10	6.10	0.10	7.65	8.95	0.96	4.04	0.19	1.28	100.60
		43741	365	9.80	Altered Intrusive	36.10	3.54	19.60	8.90	0.09	16.30	5.75	0.12	1.88	0.35	7.25	99.88
		43742	366	13.38	Semi-Nephrite	55.10	0.23	2.34	6.35	0.12	21.60	12.90	0.06	0.20	0.04	1.58	100.52
		43743	367	13.38	Semi-Nephrite	56.90	0.04	0.72	4.92	0.11	22.40	13.80	<0.05	0.08	<0.01	1.59	100.56
		43744	368	14.18	Calc-Silicate	36.30	1.47	25.00	8.80	0.08	5.75	19.10	0.12	0.13	0.07	3.88	100.70
		43745	369	15.61	Calc-Silicate	36.40	1.20	25.10	8.80	0.09	6.40	18.40	0.08	0.18	0.07	4.10	100.82
		43746	370	16.40	Tremolite Schist	48.90	0.11	6.45	7.20	0.14	22.80	9.60	0.15	0.23	0.03	4.80	100.41
		43747	371	18.75	Granite	53.10	0.66	21.70	4.18	0.04	2.38	11.80	0.50	5.00	0.09	1.29	100.74
32	16	43748	372	10.05	Chlorite-Tremolite Schist	47.00	0.07	8.55	3.68	0.17	25.60	7.65	1.69	0.14	<0.01	4.62	99.17
		43749	373	10.63	Semi-Nephrite	56.00	0.05	1.83	2.54	0.19	23.60	12.70	0.49	0.15	0.02	2.64	100.21
		43750	374	10.95	Semi-Nephrite	56.30	0.05	1.63	2.50	0.18	23.60	12.80	0.35	0.15	<0.01	2.54	100.10
		43751	375	11.09	Semi-Nephrite	55.00	0.05	2.34	2.60	0.17	24.20	12.10	0.71	0.14	0.02	3.12	100.45
		43752	376	11.21	Dolomitic Marble	4.12	0.02	0.76	1.76	0.20	21.30	28.90	0.06	0.02	<0.01	43.20	100.34
		43753	377	11.71	?Calc-Silicate	37.50	0.73	24.60	6.45	0.09	7.00	18.60	1.56	0.03	0.10	3.74	100.40
		43754	378	12.09	Chlorite Breccia	34.20	0.08	17.90	4.84	0.16	29.90	1.19	1.96	0.12	0.02	9.73	100.10
		43755	379	14.42	Altered Intrusive	57.50	0.14	21.10	2.02	0.05	4.02	7.35	1.23	5.80	0.38	1.44	101.03
15	17	42254	151	6.72	Chlorite	28.30	1.15	19.30	13.80	0.12	24.20	0.58	<0.05	<0.01	0.10	10.60	98.15
		42255	152	7.86	Massive Tremolite	56.10	0.03	1.05	5.60	0.15	21.20	12.30	<0.05	0.10	<0.01	2.14	98.67
		42256	153	8.34	Tremolite-Chlorite	41.20	0.47	10.70	9.55	0.09	23.40	4.94	<0.05	0.25	0.04	8.55	99.19
		42257	154	8.69	?Semi-Nephrite	51.20	0.10	4.34	7.00	0.09	22.40	8.90	<0.05	0.15	0.04	4.90	99.12
		42258	155	9.05	Semi-Nephrite	53.80	0.06	2.60	6.45	0.09	21.70	10.20	<0.05	0.15	0.03	3.92	99.00
		42259	156	10.52	Semi-Nephrite	56.60	0.01	1.01	5.85	0.10	21.20	11.70	<0.05	0.11	<0.01	2.68	99.26
		42260	157	10.69	Dolomitic Marble	13.50	<0.01	0.24	2.48	0.13	18.20	28.00	<0.05	<0.01	<0.01	35.50	98.05
		42261	158	12.25	Diopside	52.70	0.03	2.08	2.98	0.10	17.60	21.60	<0.05	0.10	<0.01	2.16	99.35
		42262	159	14.61	Diopside	51.00	0.06	2.24	3.76	0.16	17.20	21.90	<0.05	0.13	<0.01	2.46	98.91
		42263	160	15.89	Tremolite Schist	34.40	0.10	3.66	1.48	0.08	17.20	24.90	<0.05	0.06	0.01	17.40	99.29

TABLE 9 : Diamond Drill Hole Silicate Analyses

OUTCROP	DDH No.	TS No.	RS No.	DEPTH(m)	ROCK TYPE	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	Na_2O	P_2O_5	LOI	TOTAL
15	17	42264	161	16.07	Altered Diopside	42.60	0.18	5.85	2.44	0.08	19.90	19.40	<0.05	0.07	0.04	8.65	99.21
		42265	162	17.68	Diopside-Tremolite	52.90	0.07	2.36	2.68	0.09	20.10	17.80	<0.05	0.14	0.02	3.00	99.16
		42266	163	18.20	Altered Diopside	54.90	0.04	1.77	2.78	0.09	18.50	19.20	<0.05	0.17	<0.01	1.65	99.10
		42267	164	18.95	Mylonitic Diopside	52.90	0.04	3.96	3.36	0.07	17.40	19.10	<0.05	0.24	0.03	1.71	98.81
		42268	165	20.05	Altered Intrusive	59.40	0.46	19.20	1.75	0.02	4.70	2.78	0.24	8.60	0.05	2.20	99.40

TABLE 10 : Diamond Drill Hole Geochemistry

OUTCROP	DDH No.	TS No.	RS No.	DEPTH(m)	ROCK TYPE	As	Ba	Bi	Ce	Co	Cr	Cs	Cu	La	Mo	Nb	Ni	Pb	Rb	Sb	Sn	Sr	Th	U	V	W	Y	Zn	Zr
15	14	42269	166	5.89	Calc-Silicate																								
		42270	167	6.24	Calc-Silicate	<2	<10	<4	<20	50	40		2170	100	<4	<4	<10	13		<4	8	160	12	10	20	<10	<10	100	<20
		42271	168	6.59	?Semi-Nephrite	<2	25	<4	<20	50	40		130	110	<4	<4	<10	13		<4	6	<10	6	6	40	<10	<10	110	40
		42272	169	7.69	?Calc-Silicate	2	15	4	<20	50	50		<10	120	<4	<4	30	8		<4	6	20	<4	6	30	<10	<10	90	30
		42273	170	14.87	Gneiss	<2	240	<4	65	70	70		70	160	4	24	20	7		6	8	60	14	14	50	<10	30	30	200
		42274	171	17.48	Calc-Silicate	<2	10	4	90	50	80		<10	400	<4	10	20	6		<4	6	670	22	8	70	<10	20	60	160
		42275	172	17.74	Massive Tremolite	<2	15	<4	<20	40	40		220	120	<4	<4	<10	6		<4	<4	<10	<4	4	20	<10	<10	100	20
		42276	173	22.20	Serpentinised Marble	<2	<10	<4	<20	30	20		520	100	4	<4	<10	13		<4	<4	<10	4	<4	<10	<10	<10	70	<20
		42277	174	23.15	Serpentinised Marble	<2	<10	4	20	30	30		250	100	<4	<4	<10	6		<4	10	<10	<4	6	<10	<10	<10	30	<20
		42278	175	24.23	Tremolitic Diopside	<2	<10	<4	<20	50	60		<10	100	<4	<4	20	15		<4	<4	<10	6	4	10	<10	<10	90	<20
		42279	176	26.96	Serpentinised Marble	9	<10	<4	20	30	30		<10	120	4	<4	<10	29		<4	4	<10	<4	4	<10	<10	<10	40	<20
		42280	177	27.36	Marble	<2	15	<4	20	40	30		80	90	<4	<4	<10	16		<4	<4	<10	6	<4	<10	<10	<10	60	<20
		42281	178	29.29	Tremolitic Marble	<2	<10	<4	25	170	50		140	120	<4	<4	10	5		<4	6	<10	<4	4	10	<10	<10	60	<20
		42282	179	31.18	Serpentinised Marble	<2	<10	4	<20	40	30		<10	110	<4	<4	<10	11		<4	<4	<10	<4	4	<10	<10	<10	10	<20
		42283	180	31.40	Tremolite-Diopside	<2	<10	<4	20	50	40		<10	130	<4	<4	<10	2		<4	<4	<10	<4	<4	<10	<10	<10	20	<20
		42284	181	31.66	Semi-Nephrite	<2	20	<4	25	60	40		<10	120	<4	<4	<10	7		<4	6	<10	<4	6	10	<10	<10	50	<20
		42285	182	31.70	Semi-Nephrite	<2	<10	<4	<20	140	40		20	130	4	<4	20	5		<4	<4	<10	<4	4	10	<10	<10	70	<20
		42286	183	31.88	Brecciated Diopside	<2	<10	4	<20	50	30		20	130	<4	<4	<10	8		<4	18	<10	10	4	20	<10	<10	90	20
		42287	184	33.20	Mylonitised Calc-Silicate	<2	550	<4	130	50	140		30	210	<4	26	40	20		<4	8	850	48	8	50	<10	30	30	250
		42288	185	34.04	Mylonitised Calc-Silicate	<2	20	<4	230	70	60		<10	300	<4	22	30	33		<4	8	920	60	6	220	<10	40	20	300
		42289	186	35.30	Altered Intrusive	<2	30	<4	130	100	90		30	220	<4	22	30	4		4	6	220	42	12	80	<10	30	20	410
		42290	187	36.51	Quartzite	<2	10	<4	130	140	40		40	230	<4	14	20	16		<4	<4	150	92	18	30	<10	20	<10	190
35	15	43740	364	7.13	Calc-Silicate		180		85	80	70	<20	90	70	<20	8	80	160	31			440	155	56	310		40	80	230
		43741	365	9.80	Altered Intrusive		30		550	60	80	<20	100	310	<20	20	80	<50	<2			330	115	20	430		50	110	360
		43742	366	13.38	Semi-Nephrite		<20		25	50	40	<20	120	50	<20	<4	40	60	2			<10	84	8	120		10	70	90
		43743	367	13.38	Semi-Nephrite		<20		20	40	80	<20	420	<20	<20	<4	60	<50	<2			<10	28	<4	70		<10	11700	70
		43744	368	14.18	Calc-Silicate		50		130	70	200	<20	590	100	<20	26	100	<50	3			1550	50	10	140		40	70	580
		43745	369	15.61	Calc-Silicate		20		130	50	150	<20	250	90	<20	18	60	<50	<2			1740	42	4	120		40	80	370
		43746	370	16.40	Tremolite Schist		<20		<20	50	60	<20	250	50	<20	<4	60	70	<2			<10	4	<4	60		20	90	110
		43747	371	18.75	Granite		130		150	50	110	<20	100	130	<20	16	70	70	10			660	50	10	80		30	30	460
32	16	43748	372	10.05	Chlorite-Tremolite Schist		120		<20	40	50	<20	100	20	<20	<4	40	100	80			<10	<4	<4	40		10	170	80
		43749	373	10.63	Semi-Nephrite		40		40	40	60	<20	80	40	<20	<4	40	80	15			<10	6	<4	40		10	110	80
		43750	374	10.95	Semi-Nephrite		30		45	40	70	<20	280	50	<20	<4	50	60	14			<10	8	4	40		20	110	90
		43751	375	11.09	Semi-Nephrite		40		20	50	50	<20	650	60	<20	<4	40	120	30			<10	<4	<4	40		20	120	90
		43752	376	11.21	Dolomitic Marble		<20		<20	30	40	<20	110	40	<20	<4	40	100	<2			<10	<4	<4	30		<10	20	80
		43753	377	11.71	?Calc-Silicate		110		190	40	100	<20	130	130	<20	18	50	<50	72			430	38	<4	80		50	90	200
		43754	378	12.09	Chlorite Breccia		110		20	50	70	<20	120	70	<20	<4	60	<50	88			<10	4	<4	50		20	240	100
		43755	379	14.42	Altered Intrusive		300		45	60	60	<20	80	80	<20	10	50	60	46			620	16	4	40		20	30	150
15	17	42254	151	6.72	Chlorite	<2	<10	<4	85	70	90		<10	240	<4	20	<10	5		<4	4	<10	20	<4	90	<10	30	130	210
		42255	152	7.86	Massive Tremolite	<2	<10	4	<20	50	40		<10	130	<4	<4	10	6		<4	4	<10	6	<4	20	<10	<10	50	<20
		42256	153	8.34	Tremolite-Chlorite	<2	<10	4	35	50	60		<10	170	<4	8	<10	4		4	<4	<10	4	<4	40	<10	10	90	90
		42257	154	8.69	?Semi-Nephrite	<2	<10	<4	<20	50	30		<10	140	<4	<4	<10	<2		6	<4	<10	6	6	10	<10	<10	70	<20
		42258	155	9.05	Semi-Nephrite	<2	<10	<4	<20	50	40		<10	130	<4	<4	<10	4		<4	<4	<10	<4	<4	<10	<10	<10	60	<20
		42259	156	10.52	Semi-Nephrite	<2	<10	<4	<20	50	30		<10	130	4	<4	<10	28		<4	<4	<10	<4	<4	<10	<10	<10	70	<20
		42260	157	10.69	Dolomitic Marble	<2	<10	4	<20	40	<10		130	90	<4	<4	<10	5		<4	<4	<10	4	8	<10	<10	<10	<10	<20
		42261	158	12.25	Diopside	2	<10	<4	35	70	50		<10	90	<4	<4	<10	<2		6	<4	<10	<4	<4	<10	<10	<10	80	<20
		42262	159	14.61	Diopside	<2	<10	<4	35	50	30		<10	80	<4	<4	<10	<2		<4	4	<10	8	4	<10	<10	<10	30	<20
		42263	160	15.89	Tremolite Schist	2	<10	<4	<20	40	30		40	100	4	<4	<10	<2		<4	4	<10	<4	6	10	<10	<10	40	<20

TABLE 10 : Diamond Drill Hole Geochemistry

OUTCROP	DDH No.	TS No.	RS No.	DEPTH(m)	ROCK TYPE	As	Ba	Bi	Ce	Co	Cr	Cs	Cu	La	Mo	Nb	Ni	Pb	Rb	Sb	Sn	Sr	Th	U	V	W	Y	Zn	Zr
15	17	42264	161	16.07	Altered Diopside	<2	<10	<4	25	50	50		500	110	<4	4	30	<2		4	4	<10	8	<4	20	<10	<10	70	<20
		42265	162	17.68	Diopside-Tremolite	2	15	<4	25	1270	30		<10	90	<4	<4	<10	14		<4	4	<10	<4	<4	<10	<10	<10	60	<20
		42266	163	18.20	Altered Diopside	<2	10	<4	<20	110	50		60	100	4	<4	<10	<2		<4	<4	<10	<4	6	30	<10	<10	90	<20
		42267	164	18.95	Mylonitic Diopside	<2	<10	<4	<20	110	60		370	120	4	<4	<10	7		<4	4	140	4	<4	30	<10	<10	140	<20
		42268	165	20.05	Altered Intrusive	<2	40	<4	65	50	60		30	120	<4	20	<10	27		<4	<4	240	30	6	40	<10	10	30	350

APPENDIX D

MINERALOGY BY XRD

1. Amdel Report G2622/87:
   Samples 6230 RS 414
   6230 RS 425
   6230 RS 426

2. Amdel Report G 4653/85:
   Sample 6230 RS 192

amdel
technology and enterprise
Amdel Limited - Inc. in S.A.

Amdel
31 Flemington Street,
Frewville, S.A. 5063

Telephone: (08) 372 2700

Address all correspondence to:
P.O. Box 114,
Eastwood, S.A. 5063

Telex: AA82520
Facsimile: (08) 79 6623

29 May 1987

South Australian Department of
Mines & Energy,
P.O. Box 151,
EASTWOOD, S.A. 5063

ATT: MR. D.J. FLINT

REPORT G 2622/87

YOUR REFERENCE: Application dated 8/5/87. Refs. EX-638, 12/03/249.
Recharge 86 G37 M01 344000

IDENTIFICATION: 6230 RS414, 425 and 426

MATERIAL: Three mineral samples

LOCALITY: Hutchison Group, Gawler Craton

DATE RECEIVED: 8 May 1987

WORK REQUIRED: Determination of mineralogy by XRD.

Investigation and Report by: Dr Roger Brown

Manager - Geological Services: Dr Keith J Henley

Keith Henley

for Dr William G Spencer
General Manager
Applied Sciences Group

bp

MINERALOGY OF THREE SAMPLES BY X-RAY DIFFRACTION

1. INTRODUCTION

Three rock samples received from the South Australian Department of Mines & Energy were to be examined by XRD for determination of mineralogy.

2. PROCEDURE

Subsamples were pulverised and used to produce XRD scans which were interpreted.

3. RESULTS

The results are tabulated below, the minerals being listed in order of decreasing abundance, using the semiquantitative abbreviations given.

6230 RS414		6230 RS425		6230 RS426	
Epidote*	D	Microcline	D	Amphibole†	D
Quartz	SD	Clinozoisite*	SD	Quartz	Tr-A
		Quartz?	Tr		

* Epidote and clinozoisite are of course closely related, and are difficult to differentiate by XRD. The mineral in both cases is probably intermediate in composition between epidote and clinozoisite but the available evidence, which is meagre, suggests compositions tending towards the designated end-member in each case.

† Common monoclinic amphibole of tremolite-actinolite type.

SEMIQUANTITATIVE ABBREVIATIONS:

D = Dominant. Used for the component apparently most abundant, regardless of its probable percentage level.

SD = Sub-dominant. The next most abundant component(s) providing its percentage level is judged above about 20.

A = Accessory. Components judged to be present between the levels of roughly 5 and 20%.

Tr = Trace. Components judged to be below about 5%.

The Australian
Mineral Development
Laboratories

amdel

Flemington Street, Frewville,
South Australia 5063
Phone Adelaide (08) 79 1662
Telex AA82520

Please address all
correspondence to
P.O. Box 114 Eastwood
SA 5063

31 May 1985

In reply quote: GS 1/16/0

Your Ref: 12/03/171 EX-360

Director General
Department of Mines & Energy
PO Box 151
EASTWOOD SA 5063

Attention: Mr. D. Flint
Mineral Resources

REPORT G 4653/85

YOUR REFERENCE:	Application dated 17 May 1985
IDENTIFICATION:	6231 RS 192 Mining lease 4576
MATERIAL:	One rock sample
LOCALITY:	Cowell jade province
DATE RECEIVED:	21 May 1985
WORK REQUIRED:	Determination of mineralogy using X-ray diffraction

Investigation and Report by: Michael Till

Chief, Geological Services Section: Dr Keith J Henley

Keith Henley

for Dr William G Spencer
Manager, Mineral & Materials Sciences Division

fs

Head Office:
Flemington Street, Frewville
South Australia 5063
Telephone (08) 79 1662
Telex: Amdel AA82520
Pilot Plant:
Osman Place
Thebarton, S.A.
Telephone (08) 43 5733
Telex: Amdel AA82725
Branch Laboratories:
Melbourne, Vic.
Telephone (03) 645 3093
Perth, W.A.
Telephone (09) 325 7311
Telex: Amdel AA94893
Sydney, N.S.W.
Telephone (02) 439 7735
Telex: Amdel AA20053
Townsville
Queensland 4814
Telephone (077) 75 1377

EXAMINATION OF ROCK SAMPLE USING X-RAY DIFFRACTION

1. INTRODUCTION

One rock sample was received from Mr. D. Flint of the South Australian Department of Mines and Energy, Eastwood with a request for determination of the mineralogy. The rock was labelled 6231 RS 192 and was taken from the Cowell jade province mining lease 4576.

2. PROCEDURE

A portion of the sample was analysed by X-ray powder diffractometry. The presence of smectite was confirmed by mixing with glycerol and re-analysing.

3. RESULTS

This green rock sample consists of talc with a trace to minor amount of smectite (?montmorillonite) and a trace amount of quartz.

APPENDIX E

PETROGRAPHY - as microfiche

EXTRACTED FROM:

AMDEL REPORTS	GS 3146/80
	GS 2405/81
	GS 3786/81
	GS 2476/83
	GS 2477/83
	GS 5231/83
	GS 5930/84
	GS 6238/84
	G 6794#5G

SADME Report Book 85/20, M.G. Farrand and descriptions from the authors.

SOUTH AUSTRALIA

DEPARTMENT OF MINES AND ENERGY

OPEN FILE ENVELOPE NO. 8267

COWELL JADE PETROGRAPHIC DESCRIPTIONS AND CHEMICAL ANALYSIS - DATA

Submitted by

Flint, D. and Dubowski, E.

1990

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Petrography Map Sheet 6230

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS2405/81	30969	303	Thulite	ML 5255			
GS3146/80	42889	304	Semi-Nephrite	Miltalie			Miltalie nephrite deposit
	42890	305	Semi-Nephrite	Miltalie			Miltalie nephrite deposit
	42891	306	Quartzite	Miltalie			Miltalie nephrite deposit
GS2477/83	44821	320	Calc-Silicate	Regional			
	44822	321	Amphibolite	Regional			
	44823	322	?Gneiss	Regional			
	44824	323	Calc-Silicate	Regional			
	44825	324	Calc-Silicate	Regional			
	44826	325	Nephrite	ML 4577	83		Analysis
	44828	326	Schist	ML 4386			
	44829	327	Granodiorite Gneiss	Regional			
	44830	328	Aplite Dyke	Regional			
	44836	329	Semi-Nephrite	ML 4217	32	88-86	Analysis
	44837	330	Tremolite/Dolomite	ML 4217	32	88-86	
GS2476/83	44803	331	Calc-Silicate	Regional			
	44804	332	Tremolite Schist	(ML4525)			
	44805	333	Calc-Silicate	Regional			
	44806	334	Schist	Regional			
	44807	335	Granodiorite Gneiss	Regional			
	44808	336	Calc-Silicate	Regional			
	44809	337	Schist	Regional			
	44810	338	Amphibolite	Regional			
	44811	339	Granodiorite Gneiss	Regional			
	44812	340	Granodiorite Gneiss	Regional			
	44817	341	Chert	Regional			
GS5231/83	39682	343	Semi-Nephrite	ML 4783	52	88-90	Analysis
	39689	344	Semi-Nephrite	ML 4381	35	88-86	Analysis
	39690	345	Dolomite	ML 4381	35	88-86	
	39691	346	Semi-Nephrite	ML 4381	35	88-86	Analysis
	39692	347	Foliated Nephrite	ML 4217	24	88-84	Analysis
	39693	348	Foliated Semi-Nephrite	ML 4217	24	88-84	Analysis
	39694	349	Foliated Nephrite	ML 4783	52	88-90	Analysis
	39695	350	Semi-Nephrite	ML 4783	52	88-90	Analysis
	39696	351	Semi-Nephrite	ML 4783	52	88-90	Analysis

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Petrography Map Sheet 6230 (Cont'd)

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS5930/84	40866	352	Tremolite	(ML4522)	112		Analysis
	40868	353	Tremolite Schist	ML 4533	75		Analysis
GS6238/84	41460	354	Calc-Silicate	Regional			
	41461	355	Granite	Regional			
	41463	356	Granodiorite Gneiss	Regional		88-89	Analysis
	41465	357	Calc-Silicate	ML 4381		35/36	Not located on outcrop plan 89-86
	41466	358	Altered Intrusive	ML 4381		35/36	Not located on outcrop plan 89-86
	41467	359	Calc-Silicate	ML 4381		35/36	Not located on outcrop plan 89-86
	41468	360	Semi-Nephrite	ML 4578	51	88-90	Analysis
	41469	361	Calc-Silicate	(ML 4522)		88-89	
	41464	362	Sericite Schist	ML 4339			
		387	Nephrite	ML 4217	24		Analysis only
		405		(ML 4534)	76	89-182	No sample description available
		406		(ML 4534)	76	89-182	No sample description available
		407		(ML 4534)	76	89-182	No sample description available
		408		(ML 4534)	76	89-182	No sample description available
		409		(ML 4534)	76	89-182	No sample description available
		410		(ML 4534)	76	89-182	No sample description available
		411		(ML 4534)	76	89-182	No sample description available
		412		(ML 4534)	76	89-182	No sample description available
		413	Nephrite	ML 4217	32		Analysis only; Not located
GS 2622/87		414		(ML 4568)		89-181	XRD Analysis only
		415		ML 4783	52		Not located, plan 88-90
GS6795#5G	48685	416	Semi-Nephrite	ML 4783	52	88-90	
	48686	417	Tremolite	ML 4783	52	88-90	
	48687	418	Altered Intrusive	ML 4783	52	88-90	
	48699	419	Granitic Gneiss	ML 4217	32		
	48700	420	?Semi-Nephrite	ML 4217	32		Analysis; Not located
	48703	421	Tremolite Schist	ML 4217	114	89-184	Analysis
		422	Amphibolitic Gneiss	(ML 4554)	76		Analysis only
GS6795#5G	48705	423	Chlorite-Tremolite Schist	(ML 4524)	53		Not located
		424		(ML 4524)	53		Not located; No sample description

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Petrography Map Sheet 6230 (Cont'd)

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS2622/87		425		(ML 4524)	53		Not located; No sample description
		428		(ML 4524)	53		No sample description available
		429		(ML 4524)	116	89-181	
		431		ML 4783	52		
		432		ML 4217	32		
		433		ML 4217	32		
		434		ML 4217	32		
		435		ML 4217	32		
		436		ML 4217	32		
		437		ML 4217	32		
		438		ML 4217	32		
		489		(ML 4568)		99-100	
		490		(ML 4568)		99-100	
		491		(ML 4568)		99-100	89-181See also 89-183; No sample description available
		492		(ML 4524)	116	89-181	See also 89-185; No sample description available

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Petrography Map Sheet 6231

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS3146/80	42887	24	Nephrite	ML 4132	69		Not located
	42888	25	Nephrite	ML 4132	69		Not located
GS3786/81	31695	77	Talc	ML 4576			
	31696	78	Talc	ML 4576			
GS2477/83	44827	79	Gneiss	Regional			
	44831	80	Gneiss	Regional			
	44832	81	Granodiorite Gneiss	Regional			
	44833	82	Granodiorite Gneiss	Regional			
	44834	83	Granodiorite Gneiss	Regional			
	44835	84	Granodiorite Gneiss	Regional			
GS2476/83	44814	85	Calc-Silicate	Regional			
	44815	86	Gneiss	Regional			
	44816	87	Chert	Regional			
	44818	88	Granodiorite Gneiss	(MC 4966)			
	44819	89	Gneiss	ML 4634	15	88-83	
	44820	90	Calc-Silicate	ML 4634	15	88-83	Surface sample prior to expanded mine operation
	44813	91	Calc-Silicate	ML 4217			
GS5231/83	39683	92	Altered Intrusive	(ML 4597)	14	88-82	
	39684	93	Altered Intrusive	(ML 4597)	14	88-82	
	39685	94	Granodiorite Gneiss	(ML 4597)	14	88-82	
	39686	95	Tremolite	(ML 4597)	14	88-82	Analysis
	39687	96	Semi-Nephrite	(ML 4597)	14	88-82	Analysis
	39688	97	Granodiorite Gneiss	(ML 4597)	14	88-82	
	39697	98	Altered Intrusive	ML 4132	69	88-93	
	39698	99	Nephrite	ML 4132	69	88-93	Analysis
GS5930/84	40845	100	Calc-Silicate	(ML 4597)	14	88-82	
	40846	101	Altered Intrusive	(ML 4597)	14	88-82	
	40847	102	Gneiss	Regional			
	40848	103	Calc-Silicate	(ML 4668)	88		
	40849	104	Gneiss	Regional			
	40851	106	?Pegmatite	Regional			Analysis
	40852	107	Sericite Schist	Regional			
	40853	108	Sericite Schist	Regional			

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Petrography Map Sheet 6231 (Cont'd)

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS5930/84	40854	109	Gneissic Granite	Regional			
	40855	1210	Granodiorite Gneiss	Regional			
	40856	111	Amphibolite	Regional			
	40857	112	Semi-Nephrite	ML 4129	1		Analysis
	40858	113	Semi-Nephrite	ML 4129	92		Analysis
	40862	117	Quartzite	Regional			
	40863	118	Migmatite	Regional			
	40864	119	Granodiorite Gneiss	Regional			
	40865	120	Tremolite	ML 4338	115	88-431	Analysis
	40867	121	Sericite Schist	Regional			
	40869	122	Semi-Nephrite	ML 4132	70		Analysis
	40870	123	Amphibolite	Regional			
	40871	124	Nephrite	ML 4131			Analysis
	40872	125	Tremolite	(MC 733)			Analysis
	40873	126	Calc-Silicate	(MC 733)			
	40874	127	?Quartzite	Regional			
	40875	128	Granodiorite Gneiss	Regional			
	40876	129	Hornblende Gneiss	Regional			
	40877	130	Dolerite	Regional			
	40878	131	Gneiss	Regional			
	40879	132	Sericite Schist	Regional			
	40880	133	Iron Formation	Regional			
	40881	134	Calc-Silicate	Regional			
	40882	135	Garnet Gneiss	Regional			
	40883	136	Garnet Gneiss	Regional			
	40884	137	Tremolite	Regional			Analysis
	40885	138	Gneiss	Regional			
	40886	139	Gneiss	Regional			
	40887	140	Calc-Silicate	Regional			
	40888	141	Dolomite	Regional			
	40889	142	Dolerite	Regional			
	40890	143	Dolerite	Regional			
	40891	144	Granitic Gneiss	Regional			
	40892	145	Altered Intrusive	Regional			Analysis
	40893	146	Quartzite	Regional			
	40894	147	Semi-Nephrite	Regional	113		Analysis
	40895	148	Granite	Regional			
	40896	149	Calc-Silicate	Regional			

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Petrography Map Sheet 6231 (Cont'd)

AMDEL RPT.	TS NO.	RS NO.	ROCK TYPE	LOCATION	O/C NO.	PLAN NO.	COMMENT
GS6238/84	41462	150	Altered Intrusive	ML 4132	69		Analysis; Not located
GS4653/85		192		ML 4576			XRD Analysis only
		195		ML 4130	55		Not located; No sample description
		196		ML 4130	55		No sample description available
		197		ML 4130	55		No sample description available
		198		ML 4130	55		No sample description available
		199		ML 4130	55		No sample description available
GS6795#5G	48684	200	Granodiorite Gneiss	ML 4217		89-177	
	48688	201	Gneiss	ML 4415			
	48689	202	Gneiss	ML 4415	107	88-430	
		203		ML 4130	55	88-429	No sample description available
GS6795#5G	48691	204	Iron Formation	ML 4130	55	88-429	
	48692	205	Serpentinised Marble	ML 4130	55	88-429	
	48693	206	Iron Formation	ML 4130	55	88-429	
	48694	207	Chlorotoid Schist	ML 4338	115	88-431	
	48695	208	Gneiss	ML 4130	56	88-429	
	48696	209	Tremolite	ML 4130	56	88-429	
	48697	210	Semi-Nephrite	ML 4130	56	88-429	
	48698	211	Semi-Nephrite	ML 4130	57	88-429	
	48701	212	Tremolite Schist	ML 4217	21	88-423	Analysis
	48702	213	Tremolite Schist	ML 4217	21	88-423	Analysis
	48704	214	Chloritic Dolomite	ML 4217	27		Analysis
		215					
		216		ML 4532	9-12	88-422	No sample description available
		217		ML 4532	9-12	88-422	No sample description available
		218		ML 4532	9-12	88-422	No sample description available
		269	Iron Formation	Regional			Same as 6231 RS133; No sample description
		270		ML 4532	11		Not located; No sample description

DESCRIPTION OF PINK MINERAL

Sample: 6230 RS 303; TSC30969

E00001

Location:

Near Cowell in the Cleve Metamorphics

Hand Specimen:

The rock appears coarse grained and has crystals or aggregates 5-10 mm in size which vary in colour from a pale rose pink to pinkish-cream. Some of these appear sub-rectangular to almost square in section. They are separated by zones of translucent pale grey quartz. Identification of the pink mineral was requested.

X-ray Diffraction:

Material was collected from an area of a specimen where a concentration of the pink mineral was present. It was hand-picked to remove as much quartz as possible, powdered and used to produce an X-ray powder diffractometer scan which was interpreted.

The main mineral was found to be clinozoisite. Additional diffraction peaks were present which were interpreted as possibly due to a proportion of admixed zoisite, but this cannot be asserted with confidence.

Thin Section:

The area sectioned contains about equal proportions of quartz and a mineral belonging to the epidote group. There is a minute trace of sericite.

The zones which are pale pink in the hand specimen are composed of intergrown crystals of clinozoisite, many of them between 0.5 and 1 mm long, and in many places there are radiating aggregates of these crystals some of which are almost fibrous. The optical properties vary slightly, in some zones the mineral shows very low anomalous interference covers with greys and ultra-blues but there are other zones showing higher polarization covers possibly indicating the presence of a little iron in the mineral. In some of the fibrous and radiating aggregates, the mineral apparently has straight extinction and it is possible that there is zoisite present as well as the clinozoisite identified by X-ray diffraction as the dominant epidote-group mineral. When the section is examined under very low magnification it is clear that the clinozoisite and other epidote-group minerals which may be present have pseudomorphically replaced some sub-rectangular crystals which, in the area sectioned, vary in size from 4-8 mm. These could well have been crystals of feldspar but, as there are no internal relict textures, this would be very difficult to confirm with certainty. There is one elongate zone about 6 mm long and 1 mm thick in which the mineral has higher polarization colours and could more accurately be classified as epidote. This is intergrown with a trace of chlorite and it could be interpreted as showing poorly preserved relict micaceous texture. It is possible that this was once a very large flake of biotite which was replaced by an epidote-group mineral containing slightly more iron than that which probably replaced the feldspar. There are two metamict ?zircon grains in this elongate aggregate of epidote.

Interstices between the sub-rectangular aggregates of clinozoisite and ?zoisite contain mainly quartz which varies in grain size up to about 4 mm but some of this has been strained and granulated. There is one area containing a little plagioclase intergrown with the quartz and this has also been granulated. In this area there is no clear evidence of a relationship between the epidote-group mineral and the plagioclase.

Conclusion:

The pink mineral is a member of the epidote group and predominantly clinozoisite with possibly some intergrown zoisite. This member of the epidote group has replaced relatively large crystals which were probably feldspar (?plagioclase) but this cannot be proved with certainty.

Thulite is reported to be a pink variety of zoisite, however, as this mineral is probably a mixture of clinozoisite and zoisite it would be reasonable to classify it as thulite.

Sample: 6230 RS 304; TS42889

Location: Jade deposit on Section 12, Hd Miltalie.

Rock Name:
Nephrite jade

Hand Specimen:
A massive, medium to dark green coloured rock which has a much paler green colour along some weathered surfaces. The rock also contains smaller dark green patches up to several millimetres in size which have a slightly more coarsely crystalline character.

Thin Section:
An optical estimate of the constituents gives the following:

	%
Amphibole	98
Biotite/phlogopite	Trace-1
Opaques and semi-opaques	1

This is an essentially monomineralic rock comprised of amphibole which forms crystals up to 0.3 mm long with a slightly prismatic character and an interlocking nature. Locally, the rock contains patches of more coarsely crystalline amphibole up to several millimetres in size. Within these patches the amphibole has a somewhat prismatic character and forms crystals up to 1 mm long. All of the amphibole crystals have a somewhat random orientation.

Minor biotite is present as small, fibrous flakes located interstitially between the coarser amphibole crystals. The biotite has a very pale brown, weakly pleochroic colour and could, in fact, be phlogopite. Minor opaques and translucent, semi-opaque material are disseminated through the rock as anhedral grains and granular aggregates up to 0.1 mm in size.

This sample of nephrite jade consists of interlocking amphibole crystals generally about 0.15 mm in length, although it does contain coarser-grained patches of amphibole up to several millimetres in size.

Sample: 6230 RS 305; TS42890

Location: Jade deposit on Section 12, Hd Miltalie.

Rock Name:
Nephrite jade

Hand Specimen:
A massive, medium to dark green coloured rock.

Thin Section:
An optical estimate of the constituents gives the following:

	%
Amphibole	80
Phlogopite	20
Opaques	Trace-1

This rock is comprised mainly of prismatic amphibole crystals which exhibit a moderately well developed nematoblastic foliation, although a significant proportion of the amphibole crystals exhibit a somewhat random orientation to produce an interlocking texture. Most of the amphibole crystals are about 0.1-0.3 mm in length but the rock contains some much larger crystals up to about 1.5 mm long. The amphibole is a clear, non-pleochroic variety.

The interstitial regions between the larger amphibole crystals are filled with a very pale brown, weakly pleochroic phyllosilicate which is believed to be phlogopite, although the optical distinction of phlogopite from biotite is difficult. The pale brown weakly pleochroic colour as well as the very small 2V of this phyllosilicate suggests phlogopite.

Minor opaques are disseminated through the rock as anhedral grains up to 0.1 mm in size.

This is a jade sample containing a significant proportion of a phyllosilicate believed to be phlogopite.

Sample: 6230 RS 306; TS42891

Location: Jade deposit on Section 12, Hd Miltalie.

Rock Name:
Amphibole-veined quartzite

Hand Specimen:
A massive, medium-grey coloured rock containing some paler greenish-grey coloured patches and discontinuous bands and veinlets.

Thin Section:
An optical estimate of the constituents gives the following:

	%
Quartz	65
Amphibole	35
Limonite	1
Opaques	Trace

This sample is comprised of an intensely deformed quartz mosaic veined with fibrous amphibole. The quartz mosaic has a typical grain size between 0.3 and 0.5 mm and the quartz itself is extensively deformed showing undulose extinction as well as vague, deformational lamellae which generally have a slightly bent character. Most of the quartz mosaic is comprised of somewhat lenticular quartz grains which have a subparallel orientation defining a foliation direction. Locally, the quartz exhibits slightly sutured grains margins, but for the most part the grain margins have a somewhat straight, unsutured character.

Fibrous amphibole occurs mainly as vein-like structures with the amphibole fibres oriented transversely. The amphibole is a clear, non-pleochroic variety and at least locally forms somewhat larger, prismatic to acicular crystals. Limonite tends to be concentrated in the amphibole-rich bands as irregular patches up to 0.3 mm in size, although minor limonite also occurs as interstitial fillings within the granular quartz. Traces of opaques are disseminated through the rock as anhedral grains and granular aggregates up to 0.1 mm in size.

This is a quartz-rich rock with a highly deformed, recrystallized texture containing fibrous amphibole veins and patches.

2. PETROGRAPHY

Sample: 6230 RS 320; TS44821

Applicant's No.: DJF 1

Rock Name:
Epidote-quartz schist

Hand Specimen:
This is a fine-grained, greyish-green coloured metamorphic rock which shows a weak fabric on the broken surface. On the cut surface the sample shows prominent compositional banding with a subparallel to parallel schistosity.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	45
Epidote	35
?Plagioclase	10
Biotite	6
Chlorite	2
Opaques	2
Muscovite	trace

In thin section this rock shows a prominent compositional banding that is a consequence of variations in the relative proportions of quartz and epidote.

The quartz occurs in two grain sizes. The coarser-grained quartz forms lenticular granoblastic aggregates with an individual average grain size of 0.04 to 0.08 mm in diameter. Grain contacts are straight to gently-curved with most grains showing undulose extinction. These coarser quartz aggregates are parallel with the main fabric and in places, there is a suggestion that they represent attenuated veins. The finer-grained quartz forms mosaics with an average grain size of 0.01 mm. It is probable that there is some untwinned feldspar associated with these fine mosaics. Staining of the cut slab with sodium cobaltinitrite shows that the feldspar is probably plagioclase but the exact composition is uncertain.

The epidote ranges in grain size up to 0.1 mm in diameter, but for the most part is of the order of 0.01 to 0.04 mm. It is generally concentrated into bands which also contain fine quartz mosaics. In addition it forms stringers within the quartz-rich bands.

Micaceous minerals are present in minor amounts. Green pleochroic biotite is evident, as is chlorite and there are small amounts of muscovite. The biotite flakes are orientated parallel to the compositional banding and are of the order of 0.05 mm in length.

Minor, generally amorphous opaque material is also present.

This is an epidote-quartz schist that was probably formed through low-grade metamorphism of a clay-rich sandstone. There is evidence to suggest that an early veining of this rock has been attenuated during a subsequent deformation.

Sample: 6230 RS 321; TS44822

Applicant's No.: DJF 2

Rock Name:
Amphibolite

Hand Specimen:

This is a dark green coloured metamorphic rock which has a prominent foliation. It is medium to fine-grained. There are several elongate felsic patches which form stringers in the foliation and these probably represent attenuated folding.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Hornblende	55
Plagioclase (unaltered)	15
Epidote/sericite (after plagioclase)	28
Quartz	1
Opaques	1

This rock has an equigranular granoblastic texture and consists dominantly of amphibole and plagioclase, or the alteration products of plagioclase. The prominent foliation noted in hand specimen is a consequence of the preferred orientation of elongate amphibole grains.

The amphibole grains range up to 2 mm in length but are usually of the order of 0.5 mm. They show pale green to olive-green pleochroism and an amphibole cleavage well developed. Hornblende is the probable composition. Alteration of the hornblende to ?chlorite is rare and tends to occur along cracks or fissures.

The plagioclase is of a similar grain size to the hornblende and is elongated in the foliation. Unaltered plagioclase shows multiple lamellar twinning, however, for the most part the plagioclase has been extensively saussuritised and sericitised. The fine secondary epidote and sericite aggregates predominate over the unaltered plagioclase.

The elongate felsic stringers noted in hand specimen can be seen to consist of altered plagioclase. In one instance a chain of altered plagioclase grains clearly defines a relict fold hinge. This suggests an earlier segregation of the plagioclase followed by two subsequent deformation events: one which results in folding and the other which attenuates that folding.

Quartz is a minor constituent occurring as discrete equant grains. It is also present as thin veins both oblique and parallel to the foliation.

Blocky to anhedral opaque grains are another minor constituent. These are approximately 0.2 mm in diameter. There is possibly some rutile present.

The rock is a well-foliated amphibolite that was formed through low to middle amphibolite-grade metamorphism of either a basic igneous rock or a sandy marl. There is evidence to suggest two deformation events followed by a younger low-grade alteration.

Sample: 6230 RS 322; TS44823

Applicant's No: DJF 3

Rock Name:
Altered, folded, sericitic-muscovite-biotite-plagioclase-quartz schist

Hand Specimen:
This is a folded schistose rock with a prominent compositional banding due to the interlayering of micaceous material and quartzo-feldspathic material. The rock appears to be moderately altered in hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	30
Plagioclase	20
Sericite and fine muscovite	20
Coarse muscovite	10
Biotite	10
Opaques "primary"	2
"secondary"	5
Chlorite	3
Zircon	trace
Apatite	trace

The compositional banding observed in hand specimen is clearly evident in the thin section. Quartz and plagioclase bands are interlayered with biotite and muscovite bands, and some sericite and fine muscovite bands. The rock as a whole is extensively altered with a moderate amount of secondary opaques (ferruginisation).

Quartz occurs as equant to elongate grains that range up to 4 mm in length. The coarser relict grains show strongly undulose extinction and considerable sub-grain developments. One such grain can be seen to be folded around a fold hinge. The finer-grained quartz also shows undulose extinction but the grains tend to be more equant in outline.

The plagioclase commonly occurs as strongly cracked grains with abundant secondary opaque material along the cracks. Multiple lamellar twinning is present but a high proportion of the plagioclase is untwinned. There may be some cordierite present that has herein been termed plagioclase, but positive identification of the cordierite was not possible.

Both muscovite and biotite appear to be the early metamorphic micas which parallel the folded fabric. The biotite ranges up to 1 mm in length and there is a minor amount of chloritisation. The muscovite occurs both interstratified with the biotite and as discrete grains.

Associated with the micaceous bands are sericitic bands. Some fine muscovite and biotite was also present. The sericite is secondary in origin and probably replaced an earlier metastable metamorphic phase, possibly an alumino silicate.

The primary opaques are generally irregular in outline and range up to 0.5 mm in length. They appear to be more prevalent as relicts within the sericitic bands. The secondary opaques are mainly fine-grained to amorphous and occur along cracks and fissures. Chlorite can also be seen in late-stage cracks and fissures as well as replacing the biotite and muscovite.

Zircon is present in trace amounts and there is rare apatite.

The rock is an altered, folded, sericite-muscovite-biotite-plagioclase-quartz schist. It was probably formed through low amphibolite facies metamorphism of a pelitic sediment. The rock has subsequently been folded and a low grade alteration superimposed.

Sample: 6230 RS 323; TS44824

Applicant's No.: DJF 4

Rock Name:
Clinozoisite-amphibole schist

Hand Specimen:
This is a banded green to pale green coloured metamorphic rock. The cut surface shows interlayered dark green and pale green bands with thin felsic veins. The felsic veins are discontinuous, consistent with attenuation of early-formed folds. Some relict fold hinges are evident in hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Amphibole (?edenite)	60
Clinozoisite	25
Sericite (minor muscovite)	5
Fine clays	5
Zircon/monazite	1
Opaques (goethite)	1
Sphene	trace
Chlorite	trace
Calcite	trace

The prominent colour banding noted in hand specimen appears in thin section to be due to thin clinozoisite-rich bands in an otherwise amphibole-rich rock.

The amphibole is generally colourless and its optical properties imply an edenite composition although the possibility of cummingtonite cannot be excluded.

The amphibole occurs in a variety of morphologies that may relate to differing metamorphic episodes. The early-formed amphibole appears as coarse elongate grains which range up to 5 mm in length. These grains are typically poikilitic and appear to enclose clinozoisite, which may be after early-formed plagioclase. Rare inclusions of plagioclase are evident. Recrystallisation of the amphibole results in a finer, more elongate aggregate of grains with an average grain size of 0.3 mm. These elongate grains give the rock its prominent schistosity. Associated euhedral prismatic amphibole is also prominent and this appears to be forming in the poikilitic coarse grains as well as in the more clearly recrystallised zones.

The clinozoisite-rich bands consist of aggregates of clinozoisite and fine amphibole with variable amounts of chlorite, sericite and fine clays. The clinozoisite occurs as granular anhedral aggregates that are interstitial to the amphibole. The average grain size of the clinozoisite is generally less than 0.1 mm. Sericite and fine clays appear to be sedondary products after plagioclase and the chlorite may be a result of alteration of a minor mica or amphibole phase.

Accessory phases observed are zircon and/or monazite, and sphene. Opaques are also present tending to be anhedral to blocky in outline after pyrite. In one corner of the thin section there is some prominent secondary ferruginisation. Traces of secondary calcite occur as interstitial infillings in some places.

The rock is a clinozoisite-amphibole schist that may have been formed through middle amphibolite grade metamorphism of a basic igneous rock.

Sample: 6230 RS 324; TS44825

Applicant's No.: DJF 5

Rock Name:
Amphibole-epidote-quartz schist

Hand Specimen:
This is a well layered metamorphic rock consisting of generally thick pale green to cream coloured bands up to several centimetres in thickness, interlayered with thin dark green bands. There are also several patches of darker green material and in one instance there appears to be boudinaging of the layering about one such patch.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	35
Epidote	35
Amphibole	24
Chlorite	5
Opaques	1
Zircon	trace
Sphene	trace

The compositional banding noted in hand specimen can be seen to be due to a crude alternation of quartz-rich and epidote amphibole-rich bands. There is a subparallel foliation evident, which is a consequence of the parallel alignment of the elongate quartz and amphibole grains, and to a lesser extent epidote grains.

Quartz occurs as elongate grains which show undulose to strongly undulose extinction and sub-grain developments. The grains range up to 1.5 mm in length but are typically of the order of 0.5 mm or so in length. Within the quartz-rich bands epidote and amphibole are also present. Grain margins to the quartz are cuspate or serrated in most instances. Adjacent to the amphibole grains there are sometimes projections of radiating fibres into the quartz. These are considered to represent late growth of fibrous amphibole.

The epidote forms colourless aggregates of high relief and high maximum birefringence. Grains are usually equant to elongate in outline and of the order of 0.5 mm in diameter, although some of the epidote ranges up to 5 mm. It is probable that there is some zoisite or clinozoisite present in addition to the more dominant epidote. In places the epidote appears to be forming at the expense of amphibole.

Two or even three generations of amphibole growth may be present in this thin section. Early-formed coarse-grained knots of pleochroic pale green amphibole are a minor constituent. These grains form the cores of boudins noted in hand specimen. They are up to 4 mm in diameter and show well-developed amphibole cleavage. It is possible that the amphibole in this case is actinolitic in composition.

The second amphibole development is weakly pleochroic and colourless to pale green in colour. It is finer-grained, of the order of 0.5 mm in length, with the amphibole cleavage not as well developed. The composition in this case is possibly in the actinolite-tremolite range. Rare inclusions of zircon show pleochroic haloes. This secondary amphibole commonly forms aggregates and intergrowths with the epidote, and in places interfingering epidote and amphibole is observed. As noted above, late-stage fibrous amphibole has developed in the quartz and this may represent a third stage of amphibole development.

Minor amounts of chlorite are present and these appear to be forming at the expense of the amphibole. Irregular to blocky opaques are also present. There are traces of sphene and zircon.

The rock is an amphibole-epidote-quartz schist that was possibly formed by low to middle amphibolite grade metamorphism of a pelitic sandstone rich in calcium and magnesium.

Sample: 6230 RS 325; TS44826

Applicant's No.: DJF 6

Rock Name:
Tremolite rock (jade-nephrite)

Hand Specimen:
This is a fine-grained, massive dark green-coloured rock which contains disseminated coarser-grained pale green crystals. The rock has a thin crust of weathering which appears to show a ghost fabric.

Thin Section:
A visual estimate of the constituents presents gives the following:

	%
Tremolite - fine	85
- coarse	10
Biotite/chlorite	4
Opaques	1
Apatite	trace

This rock is dominated by fine aggregates of tremolite with an average grain size of 0.02 mm. The tremolite is partly fibrous, occurring as bundles of fibres in random interlocking orientation. Some radial textures are observed.

Approximately 10% of the rock consists of aggregates and discrete crystals of coarser-grained tremolite. These are the coarse pale green crystals noted in hand specimen. The tremolite in this case generally occurs as bladed crystals with, in places, euhedral cleavage fragments, and they range up to 2 mm in length.

The aggregates of coarse tremolite also contain biotite in places. The biotite appears as small randomly orientated flakes of the order of 0.2 mm in length. Chloritisation of the biotite is prominent in places. The coarse-grained tremolite also appears to have been chloritised in several instances.

Irregular elongate opaque grains are found in the coarse-grained aggregates. These range up to 0.1 mm in length. Thin irregular cracks through the rock also contain late-stage amorphous opaque development. The weathered skin noted in hand specimen can be seen to be marked by an intense ferruginisation of the otherwise fine tremolite aggregates.

One prominent grain of apatite has been observed with a grain size of 0.2 mm. Other smaller less conspicuous grains of apatite are present.

This is a tremolite rock most probably formed through amphibolite facies metamorphism of a dolomitic limestone. The rock could be jade (nephrite).

Sample: 6230 RS 326; TS44828

Applicant's No.: DJF 8

Rock Name:
Chloritic plagioclase-muscovite-sericite schist

Hand Specimen:
This is a pale green coloured schistose metamorphic rock which has a prominent crenulation or microfolding. Several dark grey porphyroblasts up to 1 cm in length are evident on a cut surface.

Thin Section:
A visual estimate of the constituents presents gives the following:

	%
Muscovite and sericite	50
?Chlorite	25
Plagioclase	20
Quartz	5
Zircon	trace
Opaques	trace

This rock is dominated by aggregates of fine-grained muscovite and sericite. The microfolding or crenulation noted in hand specimen is emphasised by the presence of folded feldspar-rich bands that are of the order of 1 mm in thickness or less. Coarse-grained muscovite flakes also reflect the deformation.

The aggregates of fine muscovite and sericite have a grain size which ranges up to 0.02 mm. These aggregates are, for the most part, formed by the flake-like mica with high birefringence. Intergrown material of similar relief but with low maximum birefringence may be a chlorite.

The coarser-grained muscovite flakes range up to 2 mm in length. These are folded about the axes of the crenulation. Material of similar relief is often intergrown with the muscovite or is found in juxtaposition with it. This micaceous mineral has anomalous interference colours and most probably represent some form of chlorite, formed through retrogradation of the muscovite.

Feldspar is a prominent constituent forming bands deformed by the folding. Multiply lamellar twinning is evident, but many grains are untwinned. The grain size ranges up to 3 mm. The plagioclase is of andesine composition. In places it has been altered to sericite or replaced by well-formed muscovite and ?chlorite.

Quartz is a minor constituent of the rock and is found in the feldspar-rich bands as irregular grains with strongly undulose extinction.

Equant to elongate grains of zircon and/or ?monazite are present in trace amounts. These sometimes show growth zoning. Traces of opaques are also present.

This is a chloritic plagioclase-muscovite-sericite schist that was probably formed through a low amphibolite-grade metamorphism of pelitic sediment. Two stages of deformation are evident and there is some retrograde metamorphism.

Sample: 6230 RS 327; TS44829

Applicant's No.: DJF 9

Rock Name:
Granodioritic gneiss

Hand Specimen:
This is a dark grey coloured quartzo-feldspathic gneiss which is generally medium-grained and has a moderate proportion of mafic minerals. Lenticular, slightly coarser-grained, aggregates of quartzo-feldspathic material lie parallel with the prominent metamorphic fabric.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	35
Quartz	30
Biotite	20
Potassium feldspar	5
Muscovite and sericite	4
Apatite	3
Opaques (including sphene)	2
Zircon	1
Colourless phyllosilicates	trace

The gneissic fabric noted in hand specimen can be seen to be due to a general parallel alignment of elongate quartz and feldspar crystals with flakes of biotite also in a similar alignment. The biotite forms semi- to discontinuous zones through the rock.

Both multiply twinned and untwinned plagioclase are present and the composition is oligoclase. The plagioclase grains are usually of the order of 0.5 to 1 mm in diameter, and tend to be more equant in outline than the quartz. Myrmekitic intergrowths with quartz are evident. There is a minor amount of potassium feldspar present, notably microcline and microcline perthite. Alteration of the plagioclase to fine muscovite and sericite is common, but variable. A low birefringent colourless phyllosilicate also appears to be an alteration product of the feldspars.

Quartz tends to be coarser-grained, and occurs as more elongate grains up to 3 mm in length, but generally less than or equal to 1 mm. The quartz shows undulose to strongly undulose extinction with the coarser more equant grains having considerable sub-grain developments. Grain margins are commonly simple curves, however, along a number of margins recrystallisation is evident and in these cases serrated or cuspate grain boundaries can be seen.

The biotite is olive-green to green-brown in colour. The flakes generally show a parallel alignment and range up to 1.5 mm in length. In some cases, particularly where in contact with plagioclase, there is a thin rim or zone of muscovite surrounding the biotite. Opaques also occur in thin rims surrounding biotite, and these include fine granular exsolved sphene.

Apatite is a common accessory phase and it usually occurs in association with the biotite, or in biotite-rich areas. The apatite grains are elongate with round terminations, and are between 0.1 to 0.5 mm in length.

The opaques also occur in association with the biotite. Thin anhedral grains are the most prominent. Zoned round elongate grains of zircon are common; some of the zircon grains are rimmed by secondary opaques.

The muscovite and sericite are late-stage development. They tend to form at the expense of plagioclase, although some may be after biotite. Trace amounts of a colourless phyllosilicate are conspicuous.

The rock is a granodioritic gneiss and may have had an igneous precursor.

Sample: 6230 RS 328; TS44830

Applicant's No.: DJF 10

Rock Name:
Granitic gneiss

Hand Specimen:
This is a medium-grained, granitic gneiss which has red discontinuous bands of feldspar interleaved with dark micaceous bands. Some of the feldspathic bands may have originally been continuous, implying attenuation of early formed isoclinal folds.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Microcline	30
Plagioclase	24
Quartz	20
Biotite	15
Opaques	5
Muscovite and sericite	5
Zircon	1
Apatite	trace
Rutile	trace

The gneissic texture noted in hand specimen can be seen to be due to a parallel alignment of elongate feldspars and quartz coupled with the parallel schistosity arising from the alignment of biotite.

Feldspar is the dominant component of this rock. Microcline and microcline perthite are more prevalent than plagioclase. The microcline shows cross-hatched twinning and often contains perthitic exsolution features. The grains tend to be more equant than elongate and range up to 2 mm in diameter. Included blebs of quartz and serrated grain margins are a common feature.

Both untwinned and multiply twinned plagioclase are present. It is of an oligoclase composition and is generally finer-grained than the potassium feldspar though grains do range up to 2 mm. Myrmekitic intergrowths of plagioclase with quartz can be seen. The plagioclase is variably altered to sericite and fine clays.

The quartz shows several stages of recrystallisation. Coarse grains have strongly undulose extinction, considerable sub-grain developments and range up to 1.5 mm in length. Through cataclastic deformation the grains break down to finer mosaics with serrated and cuspate grain margins. Equant recrystallised quartz shows mildly undulose extinction and has curved grain margins. In some places there are zones of fine quartz mosaics interstitial to coarser grains. These areas may represent zones of more intense deformation.

The biotite is olive-green to green-brown in colour. It ranges up to 1 mm in length and forms thin stringers through the rock. In a number of instances, the biotite is rimmed by fine anhedral opaques with a grain size ranging up to 0.05 mm in length. Secondary fine muscovite also forms around the margins of biotite grains.

The accessory phases observed are zircon, apatite and rutile. The zircon grains are commonly zoned and range up to 0.2 mm in length. The apatite is a trace constituent with elongate grains up to 0.1 mm.

The rock is a granitic gneiss that probably has an igneous precursor.

Sample: 6230 RS 329; TS44836

Applicant's No.: DJF 16

Rock Name:
Tremolite rock

Hand Specimen:
This is a massive pale green coloured rock which is composed of finely crystalline material. There are some sugary recrystallised overgrowths present.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
?Tremolite	98
Opaques	2
Apatite	trace

This rock is dominated by massive aggregates of a fine-grained amphibole. Under high magnification the amphibole appears to occur in fibrous aggregates with individual fibre bundles of the order of 0.02 mm in length. These fibrous bundles of amphibole form together ghost coarser domains which are of the order of 3 to 5 mm in diameter. Optical continuity is evident within each domain and some show ghost multiple lamellar twinning.

Coarser-grained amphibole, most probably tremolite in composition occurs as elongate crystals up to 0.6 mm in length. It is also probable that the finer-grained amphibole noted above is tremolite in composition.

There is a small amount of fine-grained opaque phases present. One end of the thin section shows the effects of a local ferruginisation. Overall there appears to be a slight clouding of the amphibole which may be a consequence of minute dust-like inclusions.

Several grains of apatite are present. These are round and elongate in outline ranging up to 0.2 mm in length.

This is a tremolite rock that was probably formed through amphibolite grade metamorphism of a siliceous dolomitic marble. There is evidence to suggest at least two phases of recrystallisation have occurred.

Sample: 6230 RS 330; TS44837

Applicant's No.: DJF 17

Rock Name:
Banded tremolite rock with minor dolomite-opal bands

Hand Specimen:
This is a poorly banded white and pale green coloured rock which is mostly massive and fine-grained. One surface of the hand specimen is very porous and this presumably represents a weathering crust.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Amphibole bands:	
Tremolite	90-95
Opaques	5
Sericite and calcite in porous bands	5
Carbonate siliceous band:	
Dolomite	50
Opaline silica	45
?Chalcedony	5

This rock is composed of three distinct bands. Two are dominated by amphibole comprised of distinctly different grain sizes whilst the third is a thin 1 to 3 mm band consisting of dolomite and opaline silica.

The coarse-grained amphibole band consists of tremolite which occurs mostly as elongate crystals up to 2 mm in length. Most of the tremolite is porous with minor secondary infills of calcite and/or sericite.

The finer-grained amphibole band consists of aggregates of fibrous tremolite with an average grain size of the order of 0.05 mm in length. There is a crude general alignment of the fibrous tremolite which parallels the overall banding. Some patches of coarser tremolite are present with elongate crystals ranging up to 1 mm in length. In these coarser-grained patches the individual grain margins are sometimes emphasised by the presence of interstitial dust-like opaques. Elsewhere fine opaque material is present.

Along one margin of the rock there is a band which consists of well-formed crystal outlines of dolomite set in a microcrystalline matrix. These relict dolomite crystals range up to 1 mm in length, but internal recrystallisation of the dolomite has resulted in finer granoblastic aggregates bound by the relict euhedral outline. Individual equant grains are of the order of 0.5 mm in diameter. Interstitial to the dolomite there is massive opaline silica which appears colourless and is almost isotropic. Some developments of ?chalcedony occur as round-shaped inclusions in the opaline silica. It is probable that the opaline silica and ?chalcedony is a secondary infill to the dolomite.

This is a banded tremolite rock with minor dolomite opal bands and was probably formed through amphibolite grade metamorphism of an impure dolomitic limestone.

2. PETROGRAPHY

Sample: 6230 RS 331; TS44803

Applicant's No.: E 6

Rock Name:
Retrogressively-altered diopside (?) granulite

Hand Specimen:
A crudely banded and weakly foliated inequigranular mottled green-white rock of metamorphic derivation.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Pyroxene (diopside)	∿40
Tremolite-actinolite	∿40
Talc	∿15
Epidote	2-3
Quartz	2-3
Biotite (and ?sericite)	<1
Opaques (iron oxide)	trace

A complex metamorphic history involving at least two phases has developed this rock from a protolith rich in lime and magnesia (?dolomite). Coarse granuloblastic diopside appears to have been the first metamorphic product. Individual crystals are coarse, being up to 4 or 5 mm diameter, and are grouped in clusters several centimetres across. These groups or metamorphic segregations, are surrounded by partially nematoblastic prisms of tremolite-actinolite in which individual crystals are up to 2 mm long. These have enwrapped the pyroxene segregations with a variable layer up to 1 cm thick. The two minerals together form a band 4 to 5 cm thick which is enclosed in thinner bands of more typically gneissic texture.

The thinner gneissic layers also give the impression that they were originally a mixture of pyroxene and amphibole, but appear to have been exposed to more considerable hydrothermal alteration, possibly in conjunction with minor shearing and crushing of the coarser minerals. These now show only vague pseudomorphous outlines of coarse crystals and consist of a microcrystalline mesh of talc, epidote and rare quartz-rich layers (?introduced). Some of the layers show a degree of schistose foliation which is apparently attributable to the presence of fine flakes of biotite and ?sericite, which may also be present among some of the more finely intermeshed mineral mixtures.

The rock is almost certainly a regional metasediment of high amphibolite to granulite facies, possibly produced from a slightly siliceous magnesian limestone. It appears to have been lightly sheared and retrogressively-altered accompanied by minor hydrothermal changes.

Sample: 6230 RS 332; TS44804

Applicant's No.: E 16

Rock Name:
Tremolite-andesine amphibolite

Hand Specimen:
A coarse-grained weakly foliated schistose rock consisting of bladed dull green amphibole and feldspar.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Tremolite-actinolite	∿50
Plagioclase (andesine)	20-30
Sericite	20
Titanite (sphene)	1-2

Nematoblastic prisms of tremolite-actinolite of very varied sizes up to 10 mm long, are scattered in poorly-defined wavy layers in a minor matrix of granuloblastic feldspars. The tremolite-actinolite is a very pale pleochroic yellow-green ferroan variety, with occasional polysynthetic twin lamellae. Many of these crystals are aligned with their long axes parallel to the layering, but the rock is only very superficially foliated. Elongate polygonal crystals of plagioclase are scattered among many of the amphibole layers, and in places they are concentrated into almost pure feldspar bands, alternating with the amphibole. The coarser crystals of feldspar, which are generally associated with the coarser amphiboles, are copiously twinned and their composition is estimated as a calcic andesine (Ab_{52}). Patches of densely turbid sericite (and ?clay mineral) occur scattered among the more felsic bands in particular. In places, this sericitic alteration is invading the adjacent feldspars, but it appears to have formed from a different but more amenable component, which has been totally replaced. Possibly this was a potassic feldspar. Some of the feldspathic bands also contain inclusions of a prismatic to granular mineral of high refractive index which is almost certainly titanite. The granules all are less than 0.1 mm and form clusters and trains along former grain boundaries and have apparently been recrystallised in conjunction with alteration of the feldspars.

The rock is an amphibolite facies equivalent of a shaly calc-magnesian sediment such as a dolomitic marl.

Sample: 6230 RS 333; TS44805

Applicant's No.: E 19

Rock Name:
Clinozoisite-tremolite amphibolite

Hand Specimen:
A massive fine-grained mottled green and white rock.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Clinozoisite	∿60
Tremolite-actinolite	30
Calcite	3-5
Titanite (sphene)	1-2
Feldspar	<1

This is a massive metamorphic rock in which broad irregular clusters of almost equant prismatic clinozoisite set in calcite forming groups up to 1 cm diameter, are irregularly dispersed in a finer matrix of tremolite-actinolite and clinozoisite. The clinozoisite is very abundant and is by far the most dominant component. It has the form of idioblastic to subidioblastic crystals up to 0.5 mm diameter set among the massive calcite which fills the intercrystalline interstices. It is virtually colourless even in hand specimen, and is very iron-deficient. Away from the calcite it passes into an almost pure granuloblastic clinozoisite of similar general grain size.

Quite abruptly the relatively pure clinozoisite gives way to segregations of a generally finer grained intergrowth of tremolite-actinolite and clinozoisite. Much of the tremolite-actinolite is an exceedingly fine mesh of acicular crystals which wind randomly around the granules of clinozoisite. Many of these areas also contain finely granulated titanite, several crystals showing the typical wedge-shaped form, but actually consisting of microcrystalline composites. A very few crystals of feldspar (?plagioclase) are present as sparse void fillings among the other crystals.

The rock is classified as an amphibolite facies equivalent of a lime-dominant calc-magnesian sediment such as a dolomitic limestone or marl. Clinozoisite being a rather unusual mineral but prominent in this rock, its identity was checked by X-ray diffraction analysis as it is readily confused with other members of the epidote group.

Sample: 6230 RS 334; TS44806

Applicant's No.: E 24

Rock Name:
Tremolite-labradorite amphibolite

Hand Specimen:
A strongly foliated medium-grained dark grey amphibolitic rock.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Tremolite-actinolite	>80
Plagioclase (labradorite)	5
Pyroxene (?diopside)	5-8
?Titanite (sphene)	1-2
?Epidote (saussurite)	2-3

Nematoblastic aligned subidioblastic tremolite-actinolite crystals up to 2 mm long and 1 mm wide are the dominant component of this rock. There is a considerable parallelism of the long axes of the amphibole, and as a result a marked foliated and lineated texture within the rock. Thin bands of ?diopside pyroxene are interlaminated with the tremolite-actinolite. The crystals are of irregular polygonal forms, and are smaller but more equidimensional than the amphibole. They are virtually colourless, but are quite poikiloblastic and contain an abundance of pyroxene and feldspar crystals up to 0.2 mm diameter. Their form and manner of inclusion in the diopside is quite random and suggests that the diopside is of later formation and has enveloped the other minerals. The feldspars are scattered randomly but uniformly throughout the amphibole, usually occupying sites at the junction of crystals. The crystals average 0.3 mm diameter, and the multiple twinning indicates that they are of labradorite(Ab_{50}) composition. They tend to have clear transparent cores but most crystals have a fringe of turbid ?saussuritic and/or sericitic alteration. A few minor masses of fine granular ?titanite are also present within well altered feldspathic crystals.

The rock is a typical amphibolite facies equivalent of a marl or lime-rich shale.

Sample: 6230 RS 335; TS44807

Applicant's No.: E 26

Rock Name:
Sheared microgranodiorite gneiss

Hand Specimen:
A massive grey-green medium-grained metamorphic rock with a rather contorted foliation.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	~50
Plagioclase (oligoclase)	20-30
Biotite	3-5
Sericite	15-20
Chlorite	3
Leucoxene	<1
Limonite	1-2

Xenoblastic crystals of feldspar and quartz up to 2 mm diameter are the principal part of this rock. Most of these crystals, however, show considerable strain and their boundaries are commonly occupied by a finer mass of cherty recrystallised quartz, or fissures filled with a fine mesh of phyllosilicates. The feldspar has an apparent composition corresponding to oligoclase, but most of the crystals are heavily included with scattered flakes of clay mineral and sericite.

Flakes of biotite are the coarsest mica present, but most of these flakes are bent and distorted with ragged variously altered margins merging into broad intermeshed masses of sericite which occupy most of the fissures. Several biotite masses contain clumps of opaque earthy leucoxene scattered around their margins, as though it has been exsolved during alteration. The sericite is very prominent and is even visible in the hand specimen as a system of fine random intergranular fissure fillings. In section it is so fine-grained that individual flakes are indistinguishable. It is most abundant within the fissure pattern mentioned and appears to be a product of minor tectonism and limited hydrothermal alteration. Small clusters of chlorite and chlorite/sericite mixtures also occur among the quartz grains. These appear to be more prevalent in the vicinity of biotite. Grains of limonite appear to be replacing iron oxides.

The rock is evidently sheared and altered and seems most likely to have been derived from a microgranodiorite or gneiss of equivalent composition.

Sample: 6230 RS 336; TS44808

Applicant's No.: E 39

Rock Name:
Quartz-epidote rock

Hand Specimen:
A massive pale grey-brown metamorphic rock which shows an abundance of fine fractures and shearing.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	30-40
Epidote	50-60
Titanite (?leucoxene)	2-3
Hematite	<1

This is a massive sheared and recrystallised metamorphic rock in which very vaguely defined bands of almost pure epidote alternate with bands containing a greater proportion of quartz. The quartz is clear and transparent and consists of veinlets and areas of fine to medium-grained granuloblastic texture. Odd grains are, however, dispersed among the epidote, and have a form which is constrained by the epidote.

The epidote varies texturally from fine to medium-grained granuloblastic mosaics to radial prismatic to almost acicular clusters of quite elongate (up to 1 mm) prisms. The form of these crystals is more idioblastic against the quartz, and several have sharply defined wedge-shaped outlines. The epidote is virtually colourless both in section and in hand specimen, suggesting that it is deficient in iron; its optical properties could coincide either with zoisite or epidote, so since it was a major component its identity as epidote was confirmed by X-ray diffraction.

The quartz-rich areas and bands contain a sparse scattering of almost opaque finely granulated titanite. Many of these have the typical wedge-shaped form of titanite, but actually consist of microcrystalline composites. These are white and almost earthy in oblique illumination so may be leucoxene or similar titanian oxide.

The rock is classified as an amphibolite facies metamorphic equivalent of a lime-rich siltstone or sandy marl.

Sample: 6230 RS 337; TS44809

Applicant's No. : E 46

Rock Name:
Chloritised quartzo-feldspathic gneiss

Hand Specimen:
A fine to medium-grained pale grey-green metamorphic rock with a weak foliation, and very poorly-defined compositional lamination. Some quartzo-feldspathic veining or segregation is observed at one end of the specimen.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	20-30
Plagioclase (oligoclase)	5-10
Muscovite (sericite)	40-50
Chlorite	15
Limonite	1-2
Opaques (iron oxide)	1-2

An originally medium-grained texture of aligned mica flakes up to 1 mm wide is set amongst granuloblastic mosaic of quartz and feldspars of similar dimensions in this rock. Faint relict layering of a former gneissic to schistose rock can still be seen although the alteration has obscured much of the detail. Virtually all the former feldspars are now converted to a mesh of fine flakes of muscovite (sericite), and the quartz crystals while still clear are fractured and cracked, the crevices being filled with further fine mica and traces of limonitic staining. Biotite was the principal original mica, but is now entirely chloritised, although the form and laminar structure can still be seen. The margin of each crystal is now outlined by a rim of fine granular iron oxides exsolved during the alteration process.

A small (1 × 2 cm) area of fairly pure quartz and feldspar has been segregated at one end of the sample. It is generally coarser-grained (?ptygmatic pegmatite), but can be seen in section to be partly sericitised although some areas of unaltered oligoclase are present.

A few masses of goethitic limonite are scattered throughout the rock, many of them showing clear pseudomorphous outlines after clusters of pyritohedra. Such sulphides may have been a component of the former gneissic metamorphic or else have formed at an early stage of the alteration.

The rock is an extensively hydrothermally-altered gneiss of originally granitoid composition.

Sample: 6230 RS 338; TS44810

Applicant's No.: E 51

Rock Name:
Sericitised amphibolite

Hand Specimen:
A medium-grained dark greenish-grey massive rock with a weakly defined lineation of amphibole.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	15
Sericite (?muscovite)	25-30
Amphibole (hornblende)	40-50
Epidote	10-15
Opaques (iron oxide)	3-5

Prisms of bright green to yellow pleochroic hornblende from 0.5 to 1.0 mm long are the principal part of this rock. The crystals are generally more equant than in some other amphibolites of this series, and there is only a minor parallelism of the long axes which imparts the weak lineation, together with a slight compositional layering. Slightly finer-grained granoblastic quartz and originally also feldspars are scattered among the amphibole, often in parallel layers alternating with more ferromagnesian-rich bands. The feldspars are now entirely converted to masses of fine sericite, which in places, is partially recrystallised to muscovite. Knots and clusters of fine to medium-grained granular epidote are disseminated throughout. These seem generally to follow the junctions of hornblende-rich areas with former feldspathic concentrations. Although there is some coarser granules among the epidote, suggesting a minor degree of recrystallisation, most of it is very fine and disseminated along the intergranular boundaries. This seems to indicate that, at least in part, it was a product of the sericitisation alteration process.

Clusters of granular to skeletal iron oxide opaques (?magnetite) occur disseminated throughout, having shapes suggesting that they were originally intergrown with other minerals. Most are now surrounded with granular epidote and to a lesser extent the sericitised feldspars.

The rock is a para-amphibolite derived from a sediment such as a sandy dolomitic marl, which has suffered hydrolytic alteration probably in conjunction with minor retrogressive metamorphism.

Sample: 6230 RS 339; TS44811

Applicant's No.: E 57

Rock Name:
Granodioritic gneiss

Hand Specimen:
A medium-grained pink-brown gneissic rock of dominantly quartzo-feldspathic composition foliated by thin sparse micaceous layers.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	20-30
Plagioclase (oligoclase)	40-50
Microcline	20
Biotite	1-2
Muscovite	2
Sericite	3-5
Leucoxene	<1
Limonite	1
Zircon	trace

The texture of this rock is generally granoblastic, but very inequigranular. A few xenoblasts of quartz and the feldspars are up to 1 mm diameter, but these are enveloped in a much finer, similarly xenoblastic, but almost cherty grain-sized intergrowths of quartz and feldspar. A few rare flakes of biotite and muscovite are disseminated throughout but most are concentrated along the micaceous bands which rarely exceed 1 mm in width, although there are a few knots of sericite which are up to 5 mm diameter. The micaceous bands contain relict flakes of muscovite and biotite up to 0.5 mm, but these pass into masses of sericite which envelope and appear to be partly forming from them. The biotite in particular is grossly altered and surrounded with limonite staining derived from the exsolved iron oxide. A few possibly pseudomorphous areas of ?goethite limonite may represent former sulphides, but much of the limonite has dispersed through the rock and now stains the intergranular boundaries and fissures.

Two feldspars are present in the rock. The more abundant is a coarser, multiple-twinned plagioclase which is of a composition corresponding to oligoclase. These crystals tend to be enwrapped to a greater or lesser degree by the potassic microcline, which appears to be filling veinlets between the larger components, possibly indicating that it was of later formation.

The rock shows some signs of shearing and recent retrogressive hydrothermal alteration and recrystallisation which has obscured any evidence of its origin; it seems most likely, however, to represent a metasediment such as a siliceous claystone or siltstone.

Sample: 6230 RS 340; TS44812

Applicant's No.: E 62

Rock Name:
Contorted granodioritic gneiss

Hand Specimen:
A medium-grained pink and grey laminated gneissic rock of alternating quartzo-feldspathic and micaceous layers, which has been sharply folded and contorted.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	30
Plagioclase (oligoclase)	30-40
Microcline (+ ?orthoclase)	20
Biotite	2-3
Muscovite	3-5
Chlorite	1
Sericite	~10
Opaques (limonite)	1
Apatite	trace
Zircon	trace

This is in many respects a very similar rock to the previous sample; it has, however, been obtained from a zone of flexure, and shows massive folding and distortion of the gneissic banding. The mineralogical constituents are almost identical, except that sericite is more abundant as it appears to be concentrated in the fold axes. The quartz and feldspars are much as in sample E 57, except that the coarsest crystals are up to 2 mm diameter and are separated by a lesser proportion of fine crystals. A few of the plagioclase feldspars are slightly clouded and spotted with flecks of sericite, but the microcline is comparatively clear. The composition of the plagioclase is again near oligoclase, but is perhaps marginally more calcic.

The micaceous bands consist of broad flakes of biotite and muscovite dispersed among irregular masses of fine sericite, and show various signs of alteration. Much of the biotite is partially or completely chloritised and frequently rimmed with limonite from exsolved iron oxides. The micaceous bands have obviously been a line of least resistance for tectonic fractures and shearing of various kinds which have shredded the flakes and have become channels for oxidising solutions which have stained the micas with limonite. The opaques present are fairly sparse, but appear to be entirely goethite now, and may have been derived by alteration of a minor sulphide content.

The rock is a sheared, contorted, and retrogressively-altered gneiss, which has probably been derived from a metasediment such as a siliceous claystone.

Sample: 6230 RS 341; TS44817

Applicant's No.: E 74

Rock Name:
Epidositic chert

Hand Specimen:
A fine-grained massive yellow-green cherty rock, with a faint sub-parallel colour mottling visible on the cut surface.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	∿50
Epidote	∿50
Opaques (?leucoxene)	<1

A very fine-grained cherty texture similar to the previous sample is also a feature of this rock, except that it consists of a virtually equal mixture of quartz and epidote. Both minerals are essentially fine-grained with no crystals coarser than 0.1 mm, and most are in the size range less than 20 microns. The quartz has formed a granuloblastic mosaic which encloses the more rounded granular epidotes. In a few places, the epidote granules are tending to coalesce into slightly coarser recrystallised bands, but this is still quite insignificant. The colour mottling seen in hand specimen is resolved in section as a minor compositional fluctuation in the proportions of the quartz and the epidote.

Angular patches of almost pure granuloblastic quartz are scattered randomly through the fine quartz-epidote matrix. These are composites of slightly coarser quartz crystals. Their angular form, but general alignment with the banding, suggests that they may represent siliceous pyroclastic fragments or devitrified shards. The abundance of fine epidote is also taken by most authorities as an indication that the sediment is of dominantly tuffaceous derivation. The lack of any except the slightest trace of opaques is possibly against this interpretation, as only a few white earthy granules of leucoxene are visible. As for sample E 72, there is a mesh of random fine veinlets throughout the rock. Most contain quartz, but some also contain recrystallised epidote. The rock is concluded to be a metasediment of quartz and epidote derived from a rock such as a ?tuffaceous siltstone.

2. PETROGRAPHY

Sample: 6230 RS 343; TSC39682

Applicant's No:
E52/30

Rock Name:
Tremolite rock (jade)

Hand Specimen:
This is a fine-grained, pale creamy-green coloured rock that is generally massive. The weathered surfaces are more buff-coloured and on the cut surface there appears to be some colour mottling.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	90
Opaques	8
Calcite	2
Apatite	Trace

This rock is dominated by massive aggregates of fine-grained tremolite. The tremolite is elongate in nature with an average grain size of 0.01 mm for the fine-grained aggregates. These elongate grains are generally in random orientation although there are several small domains which show a preferential orientation.

There are patches and discrete areas of coarser grains of tremolite with individual elongate grains ranging up to 1 mm in length. Within the coarser patches the tremolite is generally in random orientation. The colour mottling noticed in hand specimen appears to correspond with these coarser tremolite aggregates. In one corner of the thin section secondary calcite occurs interstitial to the coarser tremolite enveloping the ragged terminations.

The opaques are variably distributed throughout the rock. They mostly occur as very fine, dust-like inclusions in the tremolite and appear to be preferentially concentrated into zones or patches. Apatite is present in trace amounts. It occurs as ovoid grains which range in size up to 0.25 mm in length.

This is a tremolite rock or jade that was produced from middle amphibolite-grade metamorphism of a siliceous dolomitic marble. The texturally distinct tremolite varieties suggest two crystallization episodes.

Sample: 6230 RS 344; TSC39689

Applicant's No:
DJF 18

Rock Name:
Calcite-bearing tremolite rock (or jade)

Hand Specimen:
This is a pale green-coloured rock which is generally massive although a weakly-developed cleavage is evident. On the cut surface there is an apparent compositional banding which has been folded.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	70-75
Calcite	25-30
Apatite	Trace

This rock consists of tremolite and calcite which exhibit a variety of morphologies and relative times of formation.

Tremolite is the primary phase, occurring as fine-grained aggregates with an average grain size of approximately 0.01 mm. For the most part the tremolite is in random orientation although in patches slightly coarser, ?recrystallized tremolite shows a parallel orientation. Secondary calcite occurs interstitial to this fine tremolite and is of a similar grain size.

Clots consisting of coarser-grained aggregates of tremolite are also prominent with the elongate grains ranging up to 0.5 mm in length. These grains tend to be in random orientation with calcite infilling the interstices.

Tremolite also occurs as thin veins, up to 0.2 mm in thickness, consisting of fibrous tremolite aligned perpendicular to the vein direction. Single grain lengths fill the width of each individual grain.

The calcite also forms veins. These consist of granoblastic aggregates of elongate calcite with a range in grain size up to 0.7 mm. The veins show open fold hinges as noted in hand specimen, and in places there has been attenuation of the limbs. Other more diffuse bands rich in calcite, with lesser tremolite, also exhibit similar style folds. In these compositional bands the tremolite is fibrous and parallels the axial plane of the folds. It is this axial planar feature which gives the rock its indistinct cleavage noted in hand specimen.

Traces of apatite occur as round and irregular-shaped grains ranging up to 0.5 mm in length. They are disseminated throughout the specimen.

This is a calcite-bearing tremolite-rich rock or jade that shows at least three stages of tremolite development and two stages of calcite development. The rock shows broad open-style folding with an axial planar cleavage developed.

Sample: 6230 RS 345; TSC39690

Applicant's No:
DJF 19

Rock Name:
Chlorite-bearing dolomitic marble

Hand Specimen:
This is an off-white to pale green-coloured, coarse-grained rock with a gneissic fabric that is best expressed on the cut surface. On a foliation surface flakes of mica are prominent and there is some pyrite also.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Dolomite	60
Calcite	20
Chlorite (including biotite)	17
Tremolite	5
Opaques	3
Spinel	Trace

This rock is dominated by coarse granoblastic aggregates of dolomite with lesser interstitial mica and secondary calcite. The relict core dolomite grains range up to 3 mm in length, with partial to complete recrystallization resulting in finer aggregates of interstitial dolomite. Most of the coarser grains show multiple lamellar twinning and some have interpenetrating twins. Grain margins are irregular, sutured, or cuspate for the coarser grain sizes with the recrystallized finer grains showing more equant shapes with curved margins. The gneissic fabric noted in hand specimen is due to partial alignment of the elongate dolomite grains. The mica occurs interstitial to the coarser dolomite, either as discrete flakes or as clusters of flakes. Individual flakes are commonly in the size range 0.1 to 0.5 mm in length. The mica tends to lie with the long axes in subparallel orientation, emphasizing the gneissic fabric and some flakes are kinked. Biotite is the primary micaceous phase with the chlorite derived by alteration, and chlorite now forms the dominant micaceous phase.

Tremolite occurs as colourless, elongate to equant grains, 0.1 to 0.5 mm in length. The grain margins are slightly ragged in places and this is a retrograde metamorphic effect.

Calcite occurs both interstitially to the dolomite and as veins. The interstitial calcite is probably a secondary development, introduced at the time of cataclastic deformation. The calcite ranges in size up to 0.5 mm and occurs both as discrete grains and as aggregates. Vein calcite is of variable grain size and follows cracks or fissures in the dolomite,at a high angle to the metamorphic fabric.

The opaques range in size up to 0.3 mm and exhibit variable morphologies. Some are blocky and consist of pyrite. Others are more irregular and finer in grain size. In places the fine opaques occur along the cleavage traces of the mica. Rare subidiomorphic pale green spinel is also present.

This is a dolomitic marble which has secondary calcite and chlorite developments. Prograde metamorphism has reached amphibolite facies as evidenced by the presence of tremolite and ?spinel. Retrograde metamorphism and probably accompanying cataclastic deformation has formed the chlorite and finer interstitial dolomite aggregates.

Sample: 6230 RS 346; TSC39691

Applicant's No:
DJF 20

Rock Name:
Massive tremolite rock(or jade)

Hand Specimen:
This is a very fine-grained, generally massive rock which appears to have a pale green outer skin with an inner dark green core. There is an indistinct cleavage and on the cut surface some colour mottling within each colour band is evident.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	~95
?Opaques	~5

The rock dominantly consists of massive aggregates of very fine-grained tremolite which has an average grain size of less than 0.01 mm. This fine tremolite tends to show partial optical continuity within coarser, ghost domains which are of the order of 2 to 3 mm in diameter. These ghost domains are sometimes rimmed by fine dust-like material and it is these domains which are the colour mottling observed in hand specimen.

Coarser-grained tremolite is present as discrete grains or aggregates with a range in grain size up to 0.8 mm in length. Tremolite also occurs in veins or fissure developments, up to 0.1 mm in thickness. These veins consist of fibrous tremolite, either with single crystals forming the width of the vein, or with several crystals forming radiating aggregates within the vein.

Fine dust-like inclusions occur in the tremolite and also along cracks through the sample, mimicking relict domainal structures. This material is extremely fine-grained and tentatively termed opaques. They are probably ferruginous in composition.

This is a very fine-grained tremolite rock or jade, which was probably formed through amphibolite-grade metamorphism of a siliceous dolomitic marble. ?Relict domainal structures suggest that an earlier coarser-grained material has been altered or replaced by fine tremolite.

Sample: 6230 RS 347; TSC39692

Applicant's No:
DJF 21

Rock Name:
Foliated tremolite rock (or jade)

Hand Specimen:
This is a fine-grained, pale green-coloured rock that has a weakly-developed schistosity in hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	∿95
Opaques	∿5
?Apatite	Trace

This rock consists predominantly of tremolite and has a well-developed metamorphic fabric. Relict augen of coarser fibrous tremolite range up to 1.5 mm in length and lie with their long axes in the foliation direction. Within these augen the fibrous tremolite may be orientated at a high angle to the foliation, with single tremolite fibres forming the width of the augen. Interstitial recrystallized tremolite has an average grain size of less than 0.04 mm for fine-grained mats, ranging up to 0.1 mm for more massive aggregates. Much of this finer tremolite is fibrous, being aligned in the foliation direction, and wrapping around the relict coarser material.

The foliation is emphasized by subparallel cracks or wispy fissures which contain very fine secondary opaque phases, ?goethite or limonite. Irregular coarser patches of opaques and/or clays are also evident.

There are one or two coarse grains of ?apatite.

This is a well-foliated rock consisting predominantly of tremolite in a variety of grain sizes. It is a tremolite rock or jade.

Sample: 6230 RS 348; TSC39693

Applicant's No:
DJF 22

Rock Name:
Foliated tremolite rock (or jade)

Hand Specimen:
This is a fine-grained, pale green-coloured rock which appears to have an indistinct cleavage in hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	90
Opaques	∿5
Clays (?chlorite)	5

This rock predominantly consists of fibrous tremolite in a variety of grain sizes. Fine-grained mats of tremolite are the most abundant form with an internal grain size of the order of 0.01 mm. These mats appear to form optically continuous domains which are elongate in outline and give the rock its fabric. The domains are in part highlighted by fine opaque phases around the margins.

The fine tremolite grades into coarser, fibrous aggregates in places. Individual grains within these aggregates may range up to 1.5 mm in length and tend to lie with their long axes parallel to the fabric. Other aggregates contain more crystalline tremolite in random to radial orientation with a range in grain sizes up to 0.4 mm.

In places the tremolite is clouded by inclusions of dust-like material, or has been partially altered to clay. There may be some chlorite developed in these areas. Discrete anhedral opaque grains are also present averaging 0.1 mm in grain size.

This is a foliated tremolite rock or jade that appears to have formed through middle amphibolite-grade metamorphism of a siliceous dolomitic marble.

Sample: 6230 RS 349; TSC39694

Applicant's No:
DJF 23

Rock Name:
Foliated tremolite rock (or jade)

Hand Specimen:
This is a fine-grained, pale green-coloured rock which has an indistinct cleavage. On the cut surface some colour mottling is evident.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
Opaques/clays	5
Apatite	Trace
Zircon	Trace

This rock dominantly consists of fine-grained mats of fibrous tremolite with an average grain size of 0.04 mm. The fibrous tremolite shows parallel alignment and in places there appears to be crenulation of this alignment, resulting in a crenulated schistosity. The fine mats are in optical continuity,forming domains which range in size up to 5 mm. It is these domains which give the rock its colour mottling as noted in hand specimen.

Coarse-grained tremolite is present both as discrete grains and as aggregates. These grains are partly euhedral in outline and range in length up to 1.5 mm. Some of the grains show well-developed amphibole cleavage. In places the coarse grains are ragged in outline and partial recrystallization to finer-grained more fibrous tremolite is evident.

Opaques occur as fine wispy material parallel with the foliation. This material is probably goethitic in nature. Clouding of the tremolite is also evident in places and this is possibly fine opaque material or clays.

Apatite occurs as discrete elongate colourless grains which range up to 0.3 mm in length.

This is a foliated tremolite rock or jade, with a superimposed crenulation of that schistosity. The rock was probably formed through middle amphibolite-grade metamorphism of a siliceous dolomitic marble.

Sample: 6230 RS 350; TSC39695

Applicant's No:
DJF 24

Rock Name:
Tremolite rock (or jade)

Hand Specimen:
This is a green to pale green-coloured rock which for the most part is massive and fine-grained. On the broken surface there is evidence for recrystallization with a saccharoidal texture.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	90-95
Opaques	5
Apatite	∿1

This rock consists of fibrous mats of fine tremolite which for the most part form coarse relict domains of earlier grains. These domains range up to 4 mm in diameter and appear to give the rock the saccharoidal texture noted in hand specimen. Within each domain the fibrous tremolite has an average grain size of 0.01 mm and is usually in a parallel orientation. This orientation is oblique to relict ?twinned textures. In some domains the fine tremolite schistosity has been crenulated or kinked.

Aggregates and discrete coarser grains of tremolite are also present. These are elongate in outline, ranging in length up to 1.5 mm. Some of the coarser tremolite has ragged grain margins implying partial recrystallization to the finer tremolite. Others have a prismatic outline with a common grain size being between 0.1 and 0.5 mm. This more prismatic tremolite in places appears to be coeval with the crenulations or kinking and represents later recrystallization.

Opaques occur along cracks through the sample and are probably fine iron oxides. There are patches where the wispy opaque stringers are more prominent and appear to be replacing the tremolite. Apatite occurs as equant to elongate colourless grains of moderate relief with a range in grain size up to 0.5 mm.

This is a tremolite rock or jade that appears to show several stages of tremolite development. Earlier relict domains appear to have recrystallized into optically continuous fibrous mats of tremolite. These have subsequently been crenulated or kinked and there is some prismatic tremolite developed ?along the axial plane of these crenulations or kinks.

Sample: 6230 RS 351; TSC39696

Applicant's No:
DJF 25

Rock Name:
Epidote/clinozoisite-bearing tremolite rock (or jade)

Hand Specimen:
This is a fine-grained rock with a prominent cleavage and where fresh is dark green in colour. The rock has an orange-brown weathering skin.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	80
Epidote/clinozoisite	10
?Chlorite	5
Opaques	5
Apatite	Trace

This rock is dominated by fibrous mats of tremolite with scattered relict augen of coarser tremolite in a parallel orientation. The finer-grained tremolite also tends to lie in parallel orientation, giving the rock a prominent fabric equivalent to the cleavage noted in hand specimen. The average grain size for the fine tremolite is of the order of 0.01 to 0.04 mm. Relict augen structures range in size up to 4 mm in length. They consist of coarser tremolite showing variable recrystallization to finer tremolite. In most augen the coarser fibrous tremolite is orientated at a high angle to the foliation and long axes of the augen, whilst the finer tremolite tends to show kink bands or crenulations. Discrete coarser tremolite grains are also present, being elongate in shape and of the order of 1 mm in length.

Granular aggregates of turbid, high relief material occur as elongate clusters, also parallel to the foliation. These aggregates are probably epidote or clinozoisite originally, with partial alteration to chlorite and/or clays. Discrete epidote grains, pale green in colour, occur in some of these aggregates, with an average grain size of 0.05 mm. There is one patch of subhedral clinozoisite, consisting of colourless elongate grains of high relief,that are up to 0.4 mm in length. This clinozoisite is orientated in the foliation.

Opaques generally occur as fine-grained irregular masses or stringers around the margins or along the cleavage traces of relict coarse ?tremolite grains. The opaques also form along cracks as younger developments.

Apatite is prominent in trace amounts, occurring as elongate grains which range up to 0.2 mm in length.

This is an epidote/clinozoisite-bearing rock or jade that has a prominent foliation and relict augen textures. Some of the fine fibrous tremolite mats show a secondary crenulation of this foliation.

Sample: 6230 RS 352; TSC40866

Applicant's No.
DJF 49

Rock Name:
Coarse-grained tremolite rock

Hand Specimen:
This is a massive dark green coloured rock with a 1 to 4 mm thick orange-brown weathering skin. On the broken surface there is a sugary overgrowth texture.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
?Actinolite	1
Epidote	3
Clays and iron staining	1
Apatite	trace
Zircon	trace

This sample is comprised mostly of tremolite in a variety of morphologies and grain sizes. The early-formed tremolite is coarse-grained crystals ranging up to 4 mm in diameter. This coarse tremolite is generally colourless to very pale green in colour and has ragged grain margins due its breakdown into finer tremolite. Some euhedral amphibole crystals are also present, showing prismatic amphibole outlines and typical 60°-120° cleavage. This amphibole is colourless and of slightly higher relief, but is still probably of a tremolite composition. The secondary tremolite is generally finer-grained aggregates of fibrous amphibole with a range in grain sizes, grading down from the coarser early-formed tremolite.

There are minor but prominent patches of darker, higher relief material which in the centre can be seen to consist of fine granular epidote. The epidote has an average grain size of 0.02 mm and is surrounded by a thin rim of darker coloured fibrous amphibole which may be actinolitic in composition. Some alteration is associated with the epidote and fine clays can be seen. The fine clays and iron staining are also evident along cracks and fissures through the sample, clouding the adjacent amphibole. Trace amounts of apatite and ?zircon can be seen.

This is a tremolite rock or jade, which is atypical in that it contains abundant coarse tremolite developments which are recrystallised into the more typical fine tremolite aggregates.

Sample: 6230 RS 353; TSC40868

Applicant's No.
DJF 51

Rock Name:
Crenulated tremolite rock

Hand Specimen:
This is a green to pale green coloured, medium to fine-grained rock which has a prominent foliation. On the cut surface crenulation of that foliation is evident.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
Clays (and iron staining)	5
Apatite	trace

This sample consists mostly of fine fibrous tremolite which lies in parallel alignment giving rise to the prominent foliation noted in hand specimen. This foliation has been crenulated, and within the axial planes of the crenulations there is a moderate development of a second generation schistosity. The extent of this second deformation is variable in that in some domains the second generation schistosity is more dominant, whilst in others the crenulation is more or less insignificant and a planar earlier fabric dominates.

Coarse tremolite ranges in grain size up to 3 mm in length. Most are orientated with their long axes and cleavage traces parallel to the early schistosity. Some are elongated in the early schistosity but have their cleavage lying in the second generation schistosity. Others do not appear to show either of the above characteristics and are unstrained irregular crystals.

Trace amounts of apatite are present. There are numerous cracks and fissures through the sample which appear to contain fine clays and/or ferruginous material.

This is a crenulated tremolite rock which shows evidence for two fabric-forming events. The second deformation is not as intense as the first and results in a schistosity that it is not uniformly developed over the scale of this thin section.

3. PETROGRAPHY

Sample 6230 RS354; TSC41460; Applicant's No. DJF54

Rock Name:
Tremolite-Bearing Diopside Rock (or Calc-Silicate)

Hand Specimen:
This is a pale green to cream coloured, coarsely crystalline rock which is generally massive and consists dominantly of pyroxene occurring as well cleaved coarse crystals. There are patches and aggregates of a darker green, fibrous amphibole phase which is also coarse grained, although not as coarse as the pyroxene.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Diopside	65
Tremolite/Actinolite	25
Epidote	7
Apatite	2
Sphene	1
Zircon	Trace
?Biotite	Trace
Dolomite	Trace

This sample dominantly consists of coarse aggregates of diopside which show recrystallisation into finer granoblastic aggregates. The diopside ranges in grain size to at least 7 mm in diameter in this thin section. Many grains show multiple twinning with some twin lamellae bent or curved due to deformation. The finer grained diopside ranges down to less than or equal to 0.1 mm in diameter, occurring as equant grains with curved to straight grain margins.

Replacement of the diopside by elongate prismatic amphibole is common and probably represents retrograde metamorphism. The amphibole is mostly colourless with very weak pale green pleochroism in a few cases. It is most probably of tremolite composition with possibly some extension towards the actinolite end member. The amphibole exhibits a wide range in grain sizes, with individual elongate grains ranging up to 3 mm in length in some of the coarser aggregates. Finer grained more fibrous tremolite occurs interstitial to and replacing the diopside.

Epidote is another retrograde metamorphic phase. It occurs as clouded, anhedral grains which range up to 2.2 mm in diameter, although most are of the order of 1 mm or so. The epidote appears to post date the diopside but can be seen to have formed prior to the development to the tremolite/ actinolite.

Apatite and Sphene are prominent prograde accessory phases. The apatite occurs as round elongate to equant grains which range up to 0.5 mm in diameter. Sphene occurs as prismatic to anhedral grains which range up to 2 mm in length, mostly being less than 1 mm. Traces of zircon are also present.

Dolomite is present as a secondary phase occurring as late stage infills associated with cracks. The grain size of the dolomite is quite variable. Some grain margins within this sample have red-brown biotite developed and there are fine opaques along many grain margins.

This is a tremolite-bearing dioxide rock that was probably formed through middle amphibolite facies metamorphism of an impure sandy limestone. Retrograde metamorphism and associated fluids give rise to the epidote and amphiboles.

Sample 6230 RS 355; TSC41461; Applicant's No. DJF55

Rock Name:
Adamellite

Hand Specimen:
This is a medium grained, pale pink coloured, quartzo feldspathic rock. It has a weak foliation as seen in the alignment of darker coloured micaceous phases.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	30
Quartz	25
Potassium Feldspar	25
Biotite	5
Muscovite	5
Opaques	3
Zircon	Trace
Apatite	Trace
Sericite	5
Epidote	2

This is an even grained rock consisting mostly of granular aggregates of quartz and feldspar with lesser biotite, muscovite, and opaques. The plagioclase is slightly coarser grained, appearing as rectangular and anhedral grains ranging up to 1.5 mm in length. It is of an oligoclase to andesine composition and most grains show multiple lamellar twinning. There are some myrmekitic intergrowths with quartz. Alteration of the plagioclase is common with sericite and fine epidote formed in many grains. In some cases the plagioclase is extensively altered giving rise to well developed muscovite.

Microcline perthite and perthite are the potassium feldspars. These range in grain size up to 1.8 mm for some rectangular grains, with most occurring as more equant to anhedral grains averaging 0.5 mm in diameter. The potassium feldspar is not altered to the same extent as the plagioclase.

Quartz occurs in a range of grain sizes due to variable recrystallisation. Coarser remnant quartz grains are up to 1.5 mm in length and these show strongly undulous extinction and considerable subgrained development. The finer grained quartz shows undulous to strongly undulous extinction and curved to sutured grain margins, with very irregular grain outlines.

Biotite appears to be the primary micaceous phase, occurring as elongate to equant grains up to 0.5 mm in length. It is olive green to green-brown in colour, with some replacement by muscovite. Most of the muscovite is of a secondary nature, developed at the expense of plagioclase. Some coarser aggregates have individual flakes up to 1.5 mm in length, however most is less than or equal to 0.5 mm. The alignment of the micaceous phases seen in hand specimen is not as prominent on the micro scale, although there is some crude alignment of the biotite.

The opaques occur as blocky to anhedral grains up to 0.5 mm in diameter. The more irregularly shaped grains appear to show secondary remobilisation of the opaque phases. Zircon and apatite are primary phases which occur in accessory amounts. The zircons are typically elongate round grains. Some irregular high relief grains which are up to 0.3 mm in length may be monazite or xenotime.

Epidote is a minor but prominent secondary phase. It occurs as fine granular aggregates together with the sericite replacing plagioclase. Thin epidote veins are also present, consisting of elongate single epidote crystals up to 0.5 mm in length. There is reddish-brown coloured material developed along grain margins which is probably hydrous iron oxide phases.

This is an even grained adamellite that appears to have suffered a mild deformation resulting in the alignment of some of the micas. Secondary alteration in particular of the plagioclase gives rise to epidote and sericite, and there is some late stage epidote veining.

Sample 6230; RS 356; TSC41463; Applicant's No. DJF57

Rock Name:
Biotite Quartzofeldspathic Gneiss (or Granodioritic Gneiss)

Hand Specimen:
This is a grey to dark grey coloured, medium grained, quartzofeldspathic gneiss. Coarse 1 to 3 mm thick feldspathic veins and pods are elongated in the main foliation. On a foliation surface there appears to be an abundance of mica.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	40
Quartz	25
Potassium Feldspar	15
Biotite	15
Muscovite	3
Sericite	3
Opaques	2
Zircon	Trace

This rock has an inequigranular granoblastic texture consisting of coarser relict feldspar and quartz grains which are elongate in nature and have a subparallel alignment. Biotite is a prominent constituent and is preferentially concentrated into discontinuous stringers which together with the alignment of the quartzofeldspathic material give the rock its gneissic texture.

Both twinned and untwinned plagioclase are present and in one large elongate plagioclase grain, 4.5 mm in length, the twin lamellae are curved due to the deformation. Most of the plagioclase is finer than this grain, generally being less than or equal to 1.5 mm in length. The plagioclase is of an oligoclase composition. Some antiperthitic exsolution features are present and myrmekitic intergrowths with quartz can also be seen. Alteration to clays and sericite is evident in some plagioclase grains.

Microcline perthite and perthite are the potassium feldspars in this rock. The potassium feldspars range up to 2.5 mm in length in the feldspathic rich veins or seggregations noted in hand specimen. Elsewhere the feldspar is less than or equal to 1 mm. Quartz is similarly coarser grained in the veins or seggregations, with relict grains ranging up to 2 mm in length. Strongly undulous extinction, subgrain developments, and cuspate to curved grain margins typify the quartz throughout the rock. Within the host gneiss the quartz occurs as both core grains of similar size to the feldspars, and also as recrystallised interstitial fine aggregates.

The biotite is brown to greenish-fawn in colour with individual flakes ranging up to 1.5 mm in length. Fine grained, granular opaques occur as inclusions within the biotite or around its margins. Patches of sericite and fine muscovite occur together with the biotite, and in places these form stringers subparallel with the foliation, extending along quartz and feldspar grain margins. The larger sericite aggregates mimic the feldspar grain morphologies, implying that the micas have replaced an earlier prograde metamorphic phase.

The opaques occur as discrete anhedral grains in addition to those associated with the biotite. Individual grain sizes range up to 0.5 mm in diameter. Zircon is a prominent accessory phase, with many grains coated by opaques. Zonation of the coarser grains can also be seen.

This is a biotite bearing quartzofeldspathic gneiss which if of a granodioritic composition.

Sample 6230 RS 357; TSC41465; Jade Outcrop 34

Rock Name:

Banded Tremolite Clinozoisite Rock

Hand Specimen:

This rock is comprised of two distinct bands. One is pink to pale purple in colour and is generally massive, whilst the other is green in colour and has fibrous aggregates.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Clinozoisite	60-65
Tremolite	25-30
?Epidote	5-10
Calcite	5
Sphene	Trace

The two distinct colour bands noted in hand specimen correspond to markedly different mineralogies. The pink to pale purple band consists of massive aggregates of clinozoisite with lesser interstitial secondary tremolite. The clinozoisite is essentially colourless in thin section and is an early formed phase occurring as radiating clusters of elongate to prismatic crystals, up to 4 mm in length. More rectangular to equant crystals show multiple twinning and are approximately 0.5 to 1.5 mm in length. The clinozoisite is clouded by fine inclusions in places and appears to partly replaced or altered to a more birefringent phase which may be epidote.

Thin veins of fibrous tremolite permeate through the early formed clinozoisite. Aggregates of fibrous and prismatic tremolite occur interstitially through the clinozoisite and appear to have formed at its expense. Sphene occurs as an accessory phase within the clinozoisite with coarse aggregates of partly prismatic grains ranging in grain size up to 1 mm. Finer anhedral sphene is also present, with an average grain size of ≦0.1 mm.

The green coloured band noted in hand specimen consists dominantly of tremolite. Early formed, massive, coarse grained tremolite ranges up to 4.5 mm in length. This can be seen to be partially recrystallised giving rise to finer grained, more fibrous tremolite. The coarser grained tremolite is clouded by fine inclusions or alteration products, including secondary calcite. Near the boundary between the tremolite and the clinozoisite band there is a thin band of subhedral clinozoisite or epidote, with an average grain size of the order of 0.3 to 0.5 mm. There is interstitial fibrous tremolite and abundant secondary calcite associated with this ?epidote. Calcite also occurs in the veins through the clinozoisite bands, and these veins are up to 0.3 mm in thickness.

This is a banded tremolite clinozoisite rock that was probably formed through low to amphibolite facies metamorphism of a siliceous dolomitic limestone or a marl. Retrogradation and recrystallisation of an early coarse grained assemblage can be seen.

Sample 6230 RS 358; TSC41466; Jade Outcrop 34

Rock Name:
Hydrothermally Altered Plagioclase Rock

Hand Specimen:
This is a mottled pale green, dark green, and purple coloured rock. On the cut surface there is an indistinct banding which is cut by the colour mottling.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Seriticised Plagioclase	60-65
Tremolite/Actinolite	15-20
Epidote	10-15
Sphene	2
Apatite	2
Zircon	1
Calcite	Trace

The primary mineralogy of this sample has been extensively altered or replaced. The rock is dominated by aggregates of sericite and/or fine muscovite which appear to have replaced plagioclase. In places relict rims to original plagioclase grains can be seen and some of these show multiple lamellar twinning.

There are irregular vein-like developments of tremolite/actinolite and epidote, which are probably the dark green and purple coloured mottling noted in hand specimen. The tremolite/actinolite is pale green in colour and weakly pleochroic, hence the partly actinolitic designation. This amphibole occurs as elongate, prismatic grains which in places are fibrous, and range up to 0.6 mm in length. More equant anhedral amphibole grains occur in granular aggregates within the cores of some of these vein-like developments. In many cases essentially unaltered plagioclase occurs together with the tremolite/actinolite with the amphibole appearing to be replacing the plagioclase.

Epidote occurs in veins and irregular aggregates. The veins are up to 0.2 mm in thickness and these thin veins cut across the tremolite/actinolite development. The irregular epidote aggregates are coarser and more diffuse, often occurring together with tremolite. Individual grains range up to 0.6 mm in diameter and have ragged grain margins.

Sphene, apatite, and zircon are prominent accessory phases. Sphene occurs both as coarser more prismatic grains, up to 0.25 mm in length, and as finer anhedral grains. The sphene appears to be preferentially concentrated in the tremolite/actinolite and epidote developments. Apatite occurs as round to elongate grains, in part subhedral. The apatite ranges up to 0.25 mm in length and is found both as discrete single grains, as aggregates of two or three grains, and in semi-continuous stringers. The zircon occurs mostly as round elongate grains, some of which have subhedral overgrowths.

Calcite is present in trace amounts, and appears as a late stage phase infilling interstices within tremolite/actinolite.

This is a hydrothermally altered plagioclase rock with prominent secondary development of tremolite/actinolite and epidote.

Sample 6230 RS 359; TSC41467; Jade Outcrop 34

Rock Name:
Tremolite Clinozoisite Rock

Hand Specimen:
This is a massive pale green coloured rock with some irregular pale pink coloured veins. The rock has a sugary texture implying metamorphic recrystallisation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Clinozoisite	50-55
Tremolite	35-40
?Epidote	5
Calcite	5

This sample is dominated by coarse grained aggregates of a colourless, epidote group mineral which shows anomalous interference colours and is probably clinozoisite. The subhedral lath shape clinozoisite crystals range up to 4.5 mm in length, with most showing multiple lamellar twinning. The clinozoisite crystals are generally in a random orientation. In places there is minor recrystallisation of the clinozoisite giving rise to a more birefringent variety which may be epidote. Thin veins of secondary ?epidote cut through the early formed clinozoisite. Most clinozoisite grains are clouded by fine dust like inclusions which may represent the early stages of replacement or alteration.

The other main constituent of this rock is tremolite, which occurs in radiating aggregates of fibrous crystals. The fibrous crystals range up to 2 mm in length and can be seen to be replacing the clinozoisite, with radiating clusters and discrete prismatic crystals penetrating the massive clinozoisite aggregates.

Calcite is a late stage development. It occurs in veins and aggregates throughout the clinozoisite and appears to have partly replaced tremolite. in thin veins. Within the tremolite rich patches the calcite infills any interstices, and forms irregular vein like developments.

This is a tremolite clinozoisite rock that was probably formed through prograde middle to low amphibolite facies metamorphism of a marl, followed by hydrothermal alteration giving rise to the tremolite.

Sample 6230 RS 360; TSC41468; Jade Outcrop 32

Rock Name:
Tremolite Rock

Hand Specimen:
This is a pale green coloured, fine grained rock which appears to have an indistinct foliation on the weathered surface.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	
Fine	90-95
Coarse	5-10
Apatite	1
?Epidote	Trace
Zircon	Trace

This sample is dominated by tremolite which exhibits a variety of grain sizes. Fine grained aggregates of fibrous tremolite are abundant and occur in a type of domainal texture. Each domain is several millimetres in diameter and has internal optical continuity whilst consisting of fine grained fibrous aggregates. This fine fibrous tremolite is of the order of 0.02 mm in length. In places there is a subparallel to parallel alignment of the fibrous tremolite giving rise to the indistinct foliation noted in hand specimen. This foliation is better developed in some areas and can be seen to have been crenulated.

Coarser grained elongate tremolite grains are a minor constituent, ranging up to 1 mm in length. These occur as subhedral discrete grains or granular aggregates. In places they appear to be relict core grains, not recrystallised into the domainal fine grained aggregates noted above. The weakly developed foliation can be seen to wrap around these relict coarser tremolite grains.

Apatite is a prominent accessory phase, occurring as round to elongate grains which range up to 0.5 mm in length. Traces of zircon are present and there are rare, high relief, colourless grains which may be epidote.

This is a fine grained tremolite rock which has appears to have formed through middle amphibolite facies metamorphism of a siliceous dolomitic limestone. Early prograde coarse grained tremolite has been recrystallised into finer fibrous aggregates which in places show a parallel alignment giving rise to an indistinct foliation. There has been subsequent crenulation of that foliation.

Sample 6230 RS 361; TSC41469; Jade Outcrop 90

Rock Name:

Clinozoisite Quartz Rock

Hand Specimen:

This is a coarse to medium grained rock consisting of coarse pale pink coloured aggregates, with finer interstitial colourless and pale green aggregates. The rock is generally massive with no obvious foliation.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Quartz	55-60
Clinozoisite	30-35
?Epidote	5-10
Opaques	Trace
Apatite	Trace
Sphene	Trace

This rock principally consists of granular intergrowths of quartz and epidote group minerals. The quartz is the early formed component and shows variable extenstive recrystallisation. Coarse relict grains of quartz range up to 4 mm in length and show strongly undulous extinction, considerable subgrain developments, and cuspate grain margins. Finer grained aggregates and mosaics of quartz are a consequence of recrystallisation of the coarser material and occur interstitially to and surrounding that material.

In places there are clouded finer grains associated with the quartz which may have originally been plagioclase. However, most of this primary phase(s) associated with the quartz has been altered to or replaced by epidote group minerals.

A colourless to clouded coarse grained phase with low to anomalous interference colours is most probably clinozoisite. In place this occurs as radiating aggregates of fibrous to prismatic crystals, which range up to 3 mm in length. Elsewhere this material is not as well developed and forms granular aggregates after the primary phases it has replaced. The clinozoisite appears to be the pale pink coloured material noted in hand specimen.

A colourless to clouded very pale green phase of similar relief to the clinozoisite has a higher birefringence than that mineral and is possibly epidote. This is the pale green material noted in hand specimen. The epidote occurs as rectangular aggregates of fine elongate crystals and has a noticeably different morphology to the clinozoisite.

Irregularly shaped opaques, subhedral to anhedral sphene, and round to elongate apatite are all present in accessory amounts. The opaques appear to be late stage or remobilised. The sphene tends to be preferentially associated with the clinozoisite and epidote. The apatite generally occurs as fine inclusions within the quartz.

This is a clinozoisite quartz rock that appears to have formed through hydrothermal alteration of a granitoid or gneissic precursor. It is similar to sample 6230 RS 303 described in report GS 2405/81.

6230 RS 362

Sample ~~6231 RS 151;~~ TSC41464; Applicant's No. DJF 60

Rock Name:

Folded Gneissic Sericitic Schist

Hand Specimen:

This is a reddish-brown to grey coloured rock with a prominent gneissic texture. On the cut surface ?quartzofeldspathic seggregations emphasise the main fabric and relict limbs of folds are evident with attenuated hinge zones. The rock appears to be highly weathered.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Sericite	65
Muscovite	10
Biotite	10
Chlorite	10
Quartz	10
Opaques	5
Zircon	Trace

This sample dominantly consists of sericite with lesser biotite, muscovite, and quartz. The attenuated folded fabric noted in hand specimen is clearly evident in thin section. There is an early foliation represented by a parallel alignment of biotite, elongate quartz, and sericite rich seggregations. These have been folded and attenuated, with fold flexures seen in the biotite rich bands and sericite aggregates. The sericite aggregates appear as quartzofeldspathic bands in hand specimen. The sericite is clearly a retrograde metamorphic or hydrothermal development, probably after feldspar or an aluminosilicate. In places it grades into fine muscovite and there is evidence to suggest that the well developed muscovite has in part broken down to form some sericite.

The quartz occurs both as aggregates and single grains which range up to 1 mm in length. The grains and aggregates are elongated in the fabric or form discontinuous stringers which may be boudinaged bands. Undulous to strongly undulous extinction, some subgrain developments, and curved to cuspate grain boundaries typify the quartz.

The biotite is preferentially concentrated into bands which emphasise the folded fabric. It is green-brown in colour, is often altered to chlorite, and has opaque inclusions or rims. The flakes range up to 0.3 mm in length. Muscovite occurs together with the biotite replacing it in parts, and being of a similar grain size.

The opaques are irregular in outline and range up to 0.2 mm in diameter. Late stage ferruginisation gives rise to the abundant iron stained cracks and alteration of the primary opaques. Zircon is a prominent accessory phase.

This is a gneissic sericitic schist which has suffered at least two deformations. The high sericite content is a consequence of alteration of an original gneissic rock which may have contained an aluminosilicate phase or been rich in plagioclase.

E00056

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT BK NO:
DME NO:
DISK NO: 8

6230 RS 364 DDH 15, 7.13 m Thin section C 43740

RETROGRESSED CALC-SILICATE

Hand specimen: Distinct leopard-skin texture with off-white quartzofeldspathic zones 1-3 mm across with irregularly-shaped and disseminated aggregates of darker green chlorite and actinolite. Appears similar to retrogressed diopside of outcrop #15, but in this case is altered quartz + feldspar.

Thin section:

Original assemblage of quartz, K-feldspar, albite and actinolite has been extensively modified by sericitisation and formation of secondary actinolite, chlorite, epidote and unidentified titanate.

Estimated mineral abundances (%) are:

Sericitised K-feldspar	40
Quartz and albite	33
Actinolite	20
Epidote and titanate	6
Chlorite	1

K-feldspar is extensively sericitised whereas albite is less altered; quartz and untwinned albite difficult to distinguish. Granular with an average size of 0.2 mm which is probably a secondary grain size. Early-phase actinolite forms larger poikiloblastic porphyroblasts to over 1 mm across, but are substantially replaced by finer granular aggregates and aligned fibrous aggregates.

Tremolite fibres are aligned defining a schistosity which is also parallel with a poor to fair dimensional alignment of quartz and feldspar. Schistosity is apparently a retrogressive feature of unknown age.

Primary assemblage	Alteration assemblage
Quartz	Sericite
Plagioclase	Actinolite fibres
K-feldspar	Chlorite
Actinolite	Epidote and semi-opaque
	Titanate

Comment: Rock is probably a retrogressed calc-silicate band, 0.54 m thick within massive and schistose chlorite + tremolite rocks. However, its assemblage and massive fabric are also in keeping with a source of altered leucogranite.

6230 RS 365 DDH 15, 9.80 m Thin section C 43741

CHLORITE + FELDSPAR ROCK

Hand specimen: Massive, dark grey green and fine-grained chlorite-rich rock with a vein to 5 mm wide of dark green-black chlorite and milky white feldspar. Vein is probably an altered and contaminated leucogranite or aplite.

Thin section: Sample is a massive chlorite + sericitised feldspar rock with a pronounced dusting of fine-grained epidote and unidentified titanate.

Estimated mineral abundances (%) are:

Chlorite	45
Sericitised feldspar	40
Epidote and titanate	14
Apatite	trace - 1%

Feldspar is the only early phase but it has been intensely sericitised and also has some cores of chlorite aggregates. Feldspar is coarsest within the interpreted vein, ranging up to 2 mm across, but is also present throughout the sample.

Chlorite has two forms. Firstly, as large flakes to 1.5 mm across with epidote and titanate as thin stringers along chlorite cleavages - this chlorite probably forms from retrogression of an earlier phase, probably amphibole. Secondly and more commonly, chlorite forms blocky sheaves with slightly radiating cleavage traces, with blocky crystals averaging 0.25 mm across. Pleochroism is very pale green to very pale brown, and with very low birefringence.

Epidote and a semi-opaque titanate are abundant as stringers and a high-relief dusting; distinct grains are rare. Both phases are rare within the coarse-grained feldspar-rich vein. Yellow spotting in hand specimen is from epidote-rich aggregates.

Comment: Chlorite + feldspar rock or highly altered leucogranite. Feldspar is the only relict primary phase. Alteration has produced abundant chlorite with epidote and titanate.

6230 RS 366 DDH 15, 13.38 m Thin section C 43742

SEMI-NEPHRITE

Hand specimen: Fine-grained tremolite grading to semi-nephrite, but with a pronounced S_4 foliation. Colour is greyish green (10 GY 5/2 to 6/2) grading to pale green (10 G 6/2).

Thin section: Semi-nephrite containing two tremolite schistosities and minor tremolite porphyroblasts.

Estimated mineral abundances (%) are:

Tremolite schistosity	99
Tremolite porphyroblasts	<1
Apatite	trace

Two schistosities are equally well developed and at about 25° to each other. Both consist of fine-grained well-aligned tremolite with an average length of only 0.02 mm and with length:breadth ratios averaging 4:1. Both schistosities have identical characteristics, forming an interlocking but aligned network.

Rare coarse tremolite porphyroblasts are to 0.5 mm across and predate the schistosities.

Comment: Sample is sufficiently fine-grained to be classified as semi-nephrite. Both schistosities may have been generated during D_4.

6230 RS 367 DDH 15, 13.38 m Thin section C 43743

SEMI-NEPHRITE

Hand specimen: Fine-grained tremolite grading to semi-nephrite; colour is greyish green - about 10 GY 5/2 to 6/2. An S_4 foliation is weakly developed.

Thin section: Fine-grained tremolite but consisting of irregularly distributed areas of different grain size of fine-grained tremolite.

Estimated mineral abundances (%) are:

Tremolite matrix	>99
Tremolite porphyroblasts	trace
Tremolite veins	trace

Matrix tremolite has two forms, both of which are fine-grained and very similar, differing only in grain size. Each type is separated into broad patches and irregular zones which do not appear to form any discernible pattern.

Finest-grained zones contain equant to poorly-elongate tremolite with a length:breadth ratio averaging only about 2:1. Average length is less than 0.01 mm.

Coarser zones, which still have an average fibre length of only 0.1 mm, again show the same range in shape and elongation. Maximum fibre length is 0.2 mm.

Both zones exhibit a poor alignment defining a schistosity.

Tremolite veins, apparently formed as open fractures at the time of schistosity development, consist of tremolite fibres oriented at a high angle to the vein wall. In places, tremolite schistosity in the matrix is semicontinuous with tremolite fibres within the veins.

Comment: Semi-nephrite with two distinct grain sizes and a poorly-developed S_4 schistosity. All of the tremolite may have developed during D_4.

6230 RS 368 DDH 15, 14.18 m Thin section C 43744

CLINOZOISITE ROCK

Hand specimen: Banded light yellow and dark green rock with irregular slightly-wavy banding 1-3 mm thick. Age of banding not definitely known but is possibly S_3 as it is mylonitic and predates S_4 jointing.

Thin section: Banded epidote/clinozoisite rock with bands 1-3 mm thick which consist almost entirely of a granular mosaic of fine-grained epidote/clinozoisite.

Estimated mineral abundances (%) are:

Epidote/clinozoisite	90
Chlorite	9
Titanate	1

Banding is probably of deformational origin and is paralleled by a chlorite schistosity. Chlorite is concentrated in these mylonitic bands and exhibits a good alignment. Clinozoisite bands contain granular mosaics with no alignment but with grain size variations. Fine-grained bands have an average size of 0.05-0.1 mm while coarser bands have grains up to 0.5 mm.

Chlorite is elongate, has very low grey birefringence and always contains elongate inclusions and stringers of semi-opaque ?titanate parallel to the cleavages.

Comment: Mylonitic banding, foliation and retrogressive assemblage probably produced during D_3. No primary phase remains.

6230 RS 369 DDH 15, 15.61 m Thin section C 43745

CLINOZOISITE ROCK

Hand specimen: Sample is identical with the previous sample, RS 368, but with the addition of dark green-black chlorite-lined joints almost at right angles to the mylonitic banding. Chlorite bands are less than 1 mm wide, subparallel, aligned parallel with the drill core and classified as S_4 joints. Fractures show slight offset across the ?S_3 mylonitic banding.

Thin section: Sample is very similar to RS 368 but fabric is slightly more mylonitic. Finer-grained granulated zones are more abundant but finer-grained than in RS 368 with an average grain size of only 0.02 mm. Coarser zones average about 0.2 mm.

S_3 mylonitic assemblage	S_4 assemblage
epidote/clinozoisite	chlorite
chlorite	?adularia
titanate	ferrug. staining

Schistosity is defined by bands of aligned chlorite and stringers of semi-opaque titanate.

S_4 joints are predominantly infilled by aligned chlorite. Chlorite fibres and sheaves are aligned not along the joint, not in the S_3 schistosity but at about 45° to each. S_4 joints exhibit displacement and discontinuity across the mylonitic foliation.

?Adularia is also present within S_4 joints as grains with minute ?sericite inclusions, and range up to 0.8 mm long.

RS 370 DDH 15, 16.40 m Thin section C 43746

TREMOLITE SCHIST
(Retrogressed tremolite + diopside + phlogopite rock)

Hand specimen: Dominantly dark green and probably chloritic with lesser white tremolite forming a diffuse compositional banding, across which is developed a strongly-developed tremolite schistosity. A milky white vein of tremolite, about 3 mm thick, cuts across compositional banding and is subparallel to the schistosity.

Thin section: Compositional banding of hand specimen is too coarse and diffuse for thin section examination but appears to consist of slight concentrations of early-phase coarse-grained tremolite, phlogopite and diopside. Across the banding and largely obliterating it is a pronounced fine-grained tremolite schistosity.

Estimated mineral abundances (%) are:

primary phases		schistosity phases	
Phlogopite (chloritised)	8	Tremolite (fibrous)	80
Tremolite (coarse grained)	7	Sphene & opaques	trace
Diopside	5		

Large, clear, colourless tremolite up to 1 mm across is clearly a pre-schistosity phase with overgrowths of fine-grained, aligned, fibrous tremolite. Phlogopite forms equant blocky grains with cleavage often oriented at high angles to the schistosity and with not even a dimensional alignment in the later schistosity. Most phlogopite has been partly chloritised. Basal sections show darker yellow-brown pleochroism and with minute inclusions of acicular ?rutile. Diopside is minor, is strongly granulated and drawn out in the superimposed schistosity.

Tremolite schistosity is defined by fine-grained, well-aligned, colourless to very pale green fibres which wrap around earlier coarser phases as well as forming overgrowths.

Comments: Banding is probably S_1 or S_2 and represents an assemblage consisting of at least diopside + tremolite + phlogopite. Cross-cutting schistosity may be S_4 and is dominated by tremolite fibres.

RS 371 DDH 15, 18.75 m Thin section C 43747

EPIDOTISED GRANITE

Hand specimen: Sample is from the altered and contaminated margin of a feldspar-rich intrusive. White, milky feldspar forms a background to a superimposed light, olive-green, mylonitic schistosity composed of bands of epidote. Cross-cutting the mylonitic schistosity and banding are several veins parallel to the core axis i.e. S_4 joints and veins. The widest is 3 mm and composed of light olive green epidote whereas the others are dark greenish black and composed of chlorite and/or actinolite.

Thin section: The granite is pervasively altered with bands and disseminated epidote and pronounced recrystallisation with reduction of primary grain size. Cross-cutting S_4 veins consist entirely of either epidote or actinolite, and represent about 15% of the total sample.

Estimated mineral abundances (%) for the host altered granite are:

Feldspar	50
Epidote	35
Quartz	14
Sphene	1

All feldspars are either extensively epidotised or sericitsed and have undergone extensive partial recrystallisation reducing primary grain size of about 2 mm down to no more than 0.5 mm.

Quartz is clear and forms finer-grained aggregates apparently interstitial to feldspar. Epidote varies from large irregular grains to 1 mm across in feldspar-rich bands, to very fine grains in epidote-rich mylonitic bands where the average grain size is only about 0.05 mm and grains are often elongate in the schistosity.

Actinolite forms distinct radiating aggregates up to 2 mm across which are concentrated along very thin S_4 fractures, where the S_4 fractures are only 0.02-0.04 mm wide. A few aggregates are disseminated through the altered granite and not obviously directly related to an S_4 fracture.

Comment: Age of granite intrusion and epidotisation is not known but may be about D_3 - a known time of retrogression and mylonitisation. During D_4, radiating clusters of actinolite and bands of granular epidote formed along S_4 fractures.

RS 372 DDH 16, 10.05 m Thin section C 43748

TREMOLITE + CHLORITE SCHIST with primary PHLOGOPITE; minor nephrite

Hand specimen: Irregular mottled texture with dark green to black speckled chlorite and paler green very fine-grained tremolite.

Thin section: Dominantly a retrogressive assemblage containing chloritised phlogopite porphyroblasts in a fine-grained partly-schistose matrix of chlorite and tremolite. Tremolite-rich portions of the matrix produce the paler green zones of hand specimen, dark green zones are of chlorite-rich portions of the matrix, while speckled appearance is from phlogopite porphyroblasts.

Estimated mineral abundances (%) are:

Primary phlogopite (partly retrogressed)	15
Matrix tremolite	40
Matrix chlorite	45
Epidote	trace

The only definite primary phase is phlogopite which forms blocky grains not aligned in the superimposed schistosity. About 50% of the phlogopite has been chloritised in distinct narrow bands parallel to the cleavage, producing marked contrasts between bands of:

- high birefringence, pale brown pleochroism of phlogopite
- low birefringence, colourless chlorite.

Tremolite mats are up to 4.5 mm across and suggest another primary phase of ?dolomite or ?diopside.

Tremolite matrix has a variable texture ranging from extremely fine-grained equant matrix with a grain size of no more than 0.01 mm (i.e. nephritic), to a coarser schistosity wrappng around phlogopite. Chlorite-rich portions of the matrix are apparently completely retrogressed phlogopite or another primary phase.

RS 373 DDH 16, 10.63 m Thin section C 43749

SEMI-NEPHRITE

Hand specimen: Dark green semi-nephrite with Munsell colour of about dusky yellowish green 10 GY 3/4. Also contains thin dark streaks 1-3 mm long of iron-staining or elongate stringers of ?chlorite.

Thin section: Three generations of tremolite are evident of which only one may be a primary phase. Phlogopite shows only minor chloritisation and may also be a primary phase.

Estimated mineral abundances (%) are:

Tremolite mats	35
Tremolite prisms	30
Tremolite matrix	25
Chlorite	5
Phlogopite	5
Epidote/clinozoisite	trace
Apatite	trace

Tremolite mats range up to 4.5 mm across but consist of very fine-grained parallel and elongate bundles of aligned tremolite fibres, with bundles averaging about 0.03 mm long. The phase being replaced contained two distinct cleavages and was apparently either amphibole or calcite/dolomite.

Matrix tremolite is extremely fine-grained with an average size of only 0.01-0.02 mm. Grain boundaries are irregular and 'grains' probably consist of very-small randomly-oriented fibre bundles.

Tremolite prisms are coarser, ranging up to 0.5 mm across, but are not obviously earlier than matrix or mat tremolite. Coarse tremolite may be the same age as the other tremolite rather than representing a primary phase.

Chlorite forms aggregates containing randomly-oriented sheaves of fibres. Chlorite is colourless and with very low birefringence, and apparently formed at the same time as matrix and mat tremolite.

Comment: Up-hole or hanging wall contact zone of jade lens; sample is 8 cm inside the contact.

Primary phases are perhaps phlogopite + ?dolomite. Replacement phases are tremolite + chlorite + epidote + apatite. Only matrix tremolite is sufficiently fine grained to be classified as nephrite. Overall, sample is more appropriately classified as semi-nephrite.

RS 374 DDH 16, 10.95 m Thin section C 43750

SEMI-NEPHRITE

Sample is very similar to RS 373, but RS 374 is from the central portion of the jade lens. Matrix tremolite is more extensive with lesser tremolite mats. Cleavage traces within tremolite mats however indicate that the former phase may have been diopside. Fibrous rims on coarser tremolite prisms confirm prisms as an earlier phase. Allanite and epidote probably form at same time as matrix and mat tremolite.

Estimated mineral abundances (%) are:

Matrix tremolite	38
Mat tremolite	30
Prism tremolite	25
Chlorite	5
Epidote	1
Allanite	1

Comment: Assemblage is almost entirely retrogressive and phlogopite is absent.

Primary phases may have been diopside + tremolite. Early tremolite is partially replaced whereas diopside? is completely replaced by an assemblage of

tremolite + chlorite + epidote + allanite.

Massive and non-foliated.

6230 RS 375 DDH 16, 11.09 m Thin section C 43751

SEMI-NEPHRITE

Hand specimen: Moderately translucent dusky yellowish green (about 10GY 3/2 to 3/4) nephrite with approximately 10% brown ?phlogopite porphyroblasts. Jade sample is from within 1-2 cm of footwall contact of jade lens but actual contact not recovered in core.

Thin section: Sample is very similar to RS 373 and 374 with lesser mat tremolite but more abundant epidote and phlogopite.

Estimated mineral abundances (%) are:

Tremolite matrix	38
Tremolite prisms	35
Tremolite mats	19
Epidote and clinozoisite	3
Chlorite	2
Phlogopite	1
Allanite	trace

Spots/porphyroblasts in hand specimen are from coarse-grained tremolite, phlogopite and epidote. Tremolite is again massive with no schistosity present.

Epidote forms distinct larger aggregates - to over 1 mm across and where some consist of coarse-grained radiating clusters. Epidote, clinozoisite, allanite and phlogopite often form aggregates some of which are intergrown with tremolite.

Comments: Primary phases are probably ?diopside (now tremolite mats), coarse tremolite and probably phlogopite. Secondary retrogressive assemblage developed during jade formation is: tremolite + chlorite + epidote + clinozoisite + allanite + ?phlogopite.

6230 RS 376 DDH 16, 11.21 m Thin section C 43752

DOLOMITIC MARBLE

Hand specimen: Off-white to yellow, medium-grained dolomitic marble with minor disseminated dark green-black specks of chlorite. A grey band, about 4 mm wide, is apparently much finer grained.

Thin section: Estimated mineral abundances (%) are:

Dolomite	90
Chlorite	6
Tremolite-actinolite	3
Calcite	1
Phlogopite	trace

Dolomite forms a coarse-grained equigranular mosaic with an initial grain size of about 2 mm but which has been reduced considerably by recrystallisation etc. Grey band of hand specimen is obviously deformational and contains the finest dolomite - averaging 0.03 mm.

Chlorite can occur in large flakes and is probably after phlogopite as relict phlogopite shows at least 40% alteration to chlorite. Chlorite is pale brown with an anomalous blue birefingence.

Comment: Sample of dolomitic marble is from within 10 cm of a jade lens yet petrographically, it is typical of dolomitic marble from throughout the jade Province.

6230 RS 377 DDH 16, 11.71 m Thin section C 43753

CLINOZOISITE & PHLOGOPITE ROCK

Hand specimen: Weakly foliated rock with pale olive 'augen' (about 10Y 6/2) up to 4 mm long in a darker, weakly foliated matrix. Matrix is light olive grey (5Y 5/2) and contains about 10% dark chlorite or phlogopite.

Thin section: Specimen is dominated by clinozoisite much of which, along with phlogopite, shows a dimensional alignment defining the schistosity evident in hand specimens. The clinozoisite + phlogopite schistosity wraps around 'augens' of almost pure clinozoisite - these are more readily apparent in hand specimen.

Estimated mineral abundances (%) are:

Clinozoisite	80
Phlogopite (slightly chloritised)	19
?Titanate	1

Clinozoisite is colourless to pale brown and non pleochoic, exhibits anomalous blue birefringence and is often elongate and aligned defining a schistosity. Maximum length is 0.4 mm. Clinozoisite in contact with phlogopite aggregates is often subhedral.

Phlogopite has two forms. Larger coarser flakes are aligned parallel with clinozoisite but are still no more than 0.5 mm long. Most phlogopite is in fine-grained aggregates which are apparently interstitial to clinozoisite.

An unidentified dusting ?titanate forms the only other phase present.

Comment: An unusual assemblage with a pre-S_4 phlogopite + clinozoisite schistosity.

6230 RS 378 DDH 16, 12.09 m Thin section C 43754

CHLORITE BRECCIA

Hand specimen: Breccia with dark green-black clasts of fine-grained chlorite set in an unusually brown fine-grained matrix of unknown composition.

Thin section: Dark green clasts, evident in hand specimen, are chlorite-rich but also contain disseminated tremolite and are extremely fine-grained with an average size of no more than 0.01 mm. Matrix areas are distinctly coarser but still average no more than 0.03 mm and consist of tremolite, phlogopite and clinozoisite with only minor chlorite.

Estimated mineral abundances (%) are:

CLASTS (85%)		MATRIX (15%)	
Chlorite	75	Tremolite	45
Tremolite	25	Phlogopite + chlorite	45
Apatite	trace	Clinozoisite	10

Clasts are very fine grained and dominated by colourless, low birefringent chlorite less than 0.01 mm. Small tremolite grains, rarely reaching 0.02 mm, tend to be randomly oriented or only slightly aligned. Also present are minor disseminated slender tremolite needles to 0.3 mm long with high length:breadth ratios and which appear to form fairly late.

Matrix consists of ragged colourless clinozoisite, pale brown phlogopite, tufts of fibrous tremolite and occassional larger tremolite needles. Average grain size is about 0.03 mm with clinozoisite slightly coarser than the other phases.

Comment: Age of formation of clasts and matrix not known but trend is the same as for other outcrops i.e. an early chlorite-rich phase is followed by a more-tremolite-rich phase.

6230 RS 379 DDH 16, 14.42 m Thin section C 43755

ALTERED INTRUSIVE

Hand specimen is from the contact zone of a microcline + quartz intrusive into chlorite-rich rocks. Yellowish colour indicates epidote is present.

Thin section: Extensively altered and recrystallised granite with formation of abundant secondary epidote and acicular actinolite as well as accessory opaques, titanate and apatite. Epidote is concentrated into schistose bands whereas actinolite forms very characteristic radiating clusters along grain boundaries and fracture planes.

Estimated mineral abundances (%) are:

Primary quartz and feldspar	73
Secondary epidote	15
Secondary actinolite	10
Secondary apatite	trace-1
Secondary titanate	trace-1
Secondary opaques	trace

Primary feldspar is to in excess of 5 mm across but has been extensively sericitised and recrystallised. Some sections now consist of a fine-grained deformation/recrystallised band where the average grain size is only 0.01-0.02 mm. Grain boundaries are irregular and often lined by alteration products, particularly actinolite.

Epidote is predominantly concentrated into bands which often do not parallel actinolite bands. Alignment of epidote varies from along the band to a good alignment at about 30° to the band. Colour is pale brown to yellow brown, is non-pleochroic and has anomalous blue-yellow birefringence.

Actinolite forms radiating clusters or sheaves up to 2 mm long which are concentrated in fractures or along grain boundaries of primary fledspar. These contain actinolite needles which penetrate well into neighbouring feldspar.

Comment: As for other altered granite samples, epidote formation is followed by actinolite.

SAMPLE: 6230 RS416: TSC48685

Rock Name:
Nephritic Tremolite

Hand Specimen:
A very fine-grained and massive, greenish-grey rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	99
(?)Apatite	Tr-1
Opaques and semi-opaques	Tr-1

This is essentially a monominerallic rock comprised of fibrous tremolite forming a felted intergrowth. Much of the tremolite has a very fine grain size below 0.03 mm but larger fibrous textured tremolite crystals ranging up to 0.4 mm in length are intergrown with the finer tremolite. Approximately 30% of the sample consists of the larger tremolite crystals with most of the rest consisting of much finer, nephritic intergrowths.

Minor amounts of a very weakly birefringent mineral form disseminated grains up to 0.2 mm in size. Positive identification of this mineral is difficult but it could be apatite.

The rock is transected by very narrow fractures ranging up to 0.05 mm wide which have a discontinuous character and an essentially random orientation. Some of these fractures are lined or partially lined with opaque material which are most likely opaque, iron or manganese oxides. Some of these fractures also contain minor amounts of translucent, reddish-brown limonitic material.

This is a metamorphic rock comprised almost completely of tremolite much of which exhibits a very fine interlocking texture typical of nephrite.

SAMPLE: 6230 RS417: TSC48686

Rock Name:
Tremolite

Hand Specimen:
A dark greyish-green coloured rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	95
Carbonate	3
Clinopyroxene	1

This essentially a monomineralic rock comprised almost completely of colourless amphibole. The amphibole forms weakly prismatic to acicular or fibrous textured crystals up to 1 mm long. Most of the amphibole tends to form crystals between 0.1 and 0.3 mm in size. The amphibole typically forms a felted to interlocking mosaic.

The rock contains minor amounts of disseminated carbonate as very finely granular aggregates and narrow fracture and vein fillings. The carbonate is intimately intergrown with the tremolite and is thought to be an alteration product of tremolite.

Along one margin of the thin section minor clinopyroxene forms skeletal crystals up to 2 mm wide. These clinopyroxene crystals have highly irregular shapes showing marginal replacement by tremolite.

This is a metamorphic rock comprised almost completely of tremolite. Along one margin of the thin section there is evidence that at least some of the tremolite represents a replacement product of pre-existing clinopyroxene. The tremolite shows some alteration to finely granular carbonate.

SAMPLE: 6230 RS418: TSC48687

Rock Name:
Deformed Feldspar-Quartz Gneiss

Hand Specimen:
A coarse grained rock with a white to greenish-grey colour.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Plagioclase	35
Orthoclase	25
Quartz	20
Amphibole	15
(?)Epidote	3
Sphene	1
Opaques and semi-opaques	Tr

This sample consists mainly of a highly deformed intergrowth of quartz and feldspar. The feldpsar consists of both polysynthetically twinned plagioclase and untwinned potash feldpsar. All of the felsic minerals have strongly recrystallised and deformed appearing textures with granulation along grain margins and the development of sutured grain margins. Some larger plagioclase crystals in particular also exhibit bent and broken twin lamellae.

The amphibole tends to be concentrated along fractures where it forms acicular radiating aggregates up to 1 mm long. The amphibole typically has a pale green, weakly pleochroic colour and is most likely a member of the tremolite/actinolite group. Some irregular patches of amphibole up to about 1 mm wide are present and typically have acicular crystals radiating from their outer margins.

Minor amounts of a reddish-brown mineral form finely granular aggregates up to about 1 mm wide. This mineral has high relief and low birefringence and could be an epidote mineral. Minor sphene forms birefringent disseminated grains and granular aggregates some of which have a somewhat turbid character. Traces of sericite were noted locally as an incipient alteration product of the feldspar. Minor opaques form small disseminated grains.

This is most likely a plutonic igneous rock such as an adamellite which has been subjected to strong deformation producing an intensely deformed and recrystallised texture. Fibrous to acicular amphibole has formed as an essentially postdeformational mineral and tends to be concentrated along fractures.

SAMPLE: 6230 RS419: TSC48699

Rock Name:
Granite Gneiss

Hand Specimen:
A strongly foliated, gneissic rock with a white to grey colour.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Quartz	35
Plagioclase feldspar	30
Potash feldspar	20
Biotite	10
Muscovite	5
Zircon .	Tr
Opaques	1

This sample consists mainly of a finely granular quartz and feldspar mosaic with a typical grain size of 0.1 to 0.2 mm intergrown with larger feldspar crystals and finely divided mica flakes. The mica exhibits a well-developed lepidoblastic foliation and tends to be concentrated within discontinuous, undulose stringers intergrown with the finely granular quartz and feldspar. This finely granular matrix has a granulated and slightly recrystallised appearing texture. The larger feldspar crystals have angular broken to irregular shapes and appear to be remnants which locally show some marginal granulation.

The feldspar consists of both plagioclase and potash feldspar including at least some grid-iron twinned microcline. Some of the large plagioclase crystals have a zoned character containing slightly altered cores now comprised mainly of finely divided sericite/clay.

The mica consists of biotite and muscovite both of which form small flakes below 0.15 mm long. The biotite is intensely pleochroic in shades of brown.

Minor opaques are disseminated through the rock as anhedral grains up to 0.1 mm wide. Traces of zircon were noted as small disseminated crystals up to 0.1 mm wide.

This is thought to be a metamorphosed and deformed plutonic igneous rock possibly of adamellitic composition.

SAMPLE: 6230 RS420: TSC48700

Rock Name:
Nephritic Tremolite

Hand Specimen:
A very fine-grained and massive, black rock.

Thin Section:
This is essentially a monomineralic rock comprised almost completely of fibrous tremolite which forms a finely felted mosaic. Within localised regions slightly larger tremolite crystals up to 1 mm in length are present and these usually exhibit a lamellar texture probably due to deformational effects. Minor opaque to translucent iron oxides tend to be concentrated within narrow, undulose fractures which exhibit a vague preferred orientation defining a weakly developed foliation.

SAMPLE: 6230 RS421: TSC48703

Rock Name:
Tremolite Schist

Hand Specimen:
A very fine-grained massive rock with a grey colour.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	98
Epidote	1
Opaques and semi-opaques	Tr-1

This sample consists mainly of very fine, fibrous tremolite which forms an essentially nephritic intergrowth. Much of the fibrous tremolite has a whorled and contorted texture but a vague preferred orientation of the fibrous tremolite defines a foliation direction. Some larger fibrous aggregates of tremolite up to 0.5 mm in size are disseminated through the rock. A few weakly prismatic crystals of tremolite up to 0.3 mm long are also locally present.

Epidote is disseminated through the rock as subidiomorphic crystals and aggregates up to 0.8 mm in size. Some of the epidote tends to form vaguely radiating aggregates. Minor opaques form disseminated grains and aggregates below 0.1 mm wide. Some opaque to translucent iron oxides occur locally as very narrow linings along foliation lamellae.

This is a tremolite-rich rock comprised mainly of fibrous, nephritic textured intergrowths.

SAMPLE: 6230 RS423: TSC48705

Rock Name:
Chlorite-Tremolite Schist

Hand Specimen:
A greyish-green foliated rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Chlorite	70
Tremolite	25
Plagioclase	1
Zircon	Tr
Opaques and semi-opaques	4

This sample consists mainly of a fibrous, chloritic matrix through which elongate prismatic amphibole crystals are disseminated. A well-developed foliation is defined by a preferred orientation of the amphibole crystals as well as a preferred orientation of much of the chlorite. A vague mineralogical banding is also defined by a tendency for the amphibole to be concentrated in discontinuous weakly developed bands.

The chlorite is a fibrous variety with a pale green, weakly pleochroic colour and low anomalous birefringence. The amphibole is a colourless variety and forms elongate, prismatic crystals up to 3 mm in length.

Traces of zircon form small disseminated crystals up to 0.1 mm wide. Opaques are disseminated through the rock as anhedral to euhedral grains and aggregates up to 0.5 mm in size. Some of the tremolite in particular shows incipient alteration to reddish-brown iron oxides.

This is a metamorphic rock with a strongly foliated character comprised mainly of elongate tremolite crystals in a well foliated chloritic matrix.

Sample: 6231 RS 24; TS42887, PS28340

Location: Outcrop 69, Section 113, Hd Minbrie.

Rock Name:

Nephrite jade

Hand Specimen:

A dark green coloured rock with a paler coloured weathering rind which appears to penetrate approximately 1 cm into the rock. For most of this depth the rock has a paler green colour but the outermost 1 mm has a dull white colour. Reddish-brown limonitic staining is also evident on the outermost surface of the very narrow coating.

Thin Section:

In thin section this rock can be seen to consist of very finely divided, somewhat fibrous-appearing, amphibole which forms a felted, interlocking network. The largest amphibole crystals are up to about 0.3 mm long and have an essentially random orientation. Opaques are also disseminated through the rock as anhedral grains up to 0.1 mm in size. There are no obvious textural differences between the darker green coloured areas and the paler coloured rind. The outermost portion of the weathered surface contains concentrations of translucent, reddish-brown iron oxides as discontinuous, somewhat undulose, vein-like structures up to 0.05 mm wide.

Polished Section:

In polished section the narrow, 1 mm wide, white rind can be seen to have a translucent character with brilliant white interal reflections giving a colouration similar to that produced by a finely divided titanium mineral such as leucoxene. It is considered likely that the slight colouration is due to finely divided titanium, but this could not be confirmed with the electron microprobe by detecting higher titanium contents in this region. Careful scanning with the probe failed to detect any titanium in the rock, although small amounts of finely divided titanium could still produce this colouration. It is possible that other factors such as the texture of the rock and its reaction to weathering could also produce these white internal reflections.

Conclusions:

This is a nephrite jade rock with a well developed, felted texture. The white rind could be due to very finiy divided titanium although precise confirmation of this was not obtained.

Sample: 6231 RS 25; TS42888

Location: Outcrop 69, Section 113, Hd Minbrie.

Rock Name:
Nephrite jade

Hand Specimen:
A massive rock with a green colouration ranging from a somewhat dark to a somewhat pale green.

The rock is also transected by some narrow fractures lined with white material. An X-ray diffraction powder photograph of this material gave only an amphibole pattern from the host rock.

Thin Section:
This is an essentially monomineralic rock comprised of fibrous amphibole which exhibits a well developed foliation. Variations in colour observed in the hand specimen appear to be due to different amounts of finely divided, translucent, reddish-brown material which most likely represents very finely divided iron oxides. This material tends to be concentrated along slightly undulose planes oriented parallel to the foliation direction within various regions. Minor opaques and translucent, semi-opaque material (possibly a titanium mineral) are disseminated through the rock as small grains and granular aggregates generally below 0.1 mm in size.

Conclusion:
This is a sample of nephrite jade comprised of somewhat fibrous amphibole with a foliated character whose variation in colour appears to be due to variations in very finely divided iron oxides which produce a slightly translucent brown colour in thin section.

DESCRIPTION OF TALC

Sample: 6231 RS 77; TSC31695

Applicant's No.:
A

Location:
Sample from trench on Mt. Geharty Talc Deposit

Hand Specimen:
A massive, very pale greyish-green rock which is soft and has the physical properties of talc. On a freshly cut surface some variations in colour and grain size are visible and these suggest the presence of bands up to 2 cm thick but they are not very regular and there is no definite evidence to suggest the cause of this apparent banding.

Thin Section:
This rock consists practically entirely of talc and the only impurities which can be detected microscopically are traces of opaque oxide and one minute grain of sphene. Some zones of the talc, however, are very fine-grained and if any other fibrolamellar silicate minerals are present they could only be detected by X-ray diffraction.

Up to about 80% of this sample is composed of moderately coarse-grained micaceous talc and many of the individual crystals are between 0.3 and 0.6 mm in size. In the plane in which this section was cut, this talc shows only a very weakly developed preferred orientation and there is therefore no definite foliation.

At both ends of the section there are bands up to at least 15 mm thick composed of much finer grained talc and there is another zone in the rock where there are thinner streaks and interconnected bands, 2-3 mm thick, of similar very fine-grained talc. On a wet, freshly cut surface of the hand specimen, these finer grained zones appear a darker greyish-green and in the plane of the section they are at a high angle to the direction of suggested very weak or incipient foliation. In most of these finer grained zones there are a few larger, generally elongate crystals of talc which, in a few places, show some evidence of sub-parallel orientation in at least two directions which intersect at a very high angle. The reason for this is not clear and when the rock was examined under very low magnification the pattern formed by the finer grained bands did not give any clue as to their origin.

Throughout most of the areasof coarser grained talc there appears to be very fine-grained dark material along many grain boundaries and cleavage planes but it is possible that some of this dark appearance is due to internal reflection in very thin or tiny voids and is not actual inpurity. There are however, at least a few very thin films of tiny crystals of opaque material along some cleavage planes and grain boundaries. In the thin section, one tiny grain of sphene was found.

Conclusion:
The sample is practically pure talc as far as can be determined by microscopic examination and the only visible impurity is a trace of very fine-grained opaque oxide.

Sample: 6231 RS 78; TSC31696

Applicant's No.:
B

Location:
Sample from trench on Mt. Geharty Talc Deposit

Hand Specimen:
A pale, greyish-green rock which is massive but has the physical properties of talc. A freshly cut surface shows less evidence of banding than in sample A, and there are a few small dark spots which, however, are not opaque impurities. There is a poorly defined, paler-coloured vein a few millimetres thick.

Thin Section:
This sample is also composed entirely or almost entirely of talc and the only impurity detectable by microscopic examination is a trace of very fine-grained opaque material.

It differs from sample A in that throughout most of the section there is a background (or matrix) of very fine-grained talc and this contains generally between 15 and 30% of larger, commonly elongate crystals of talc, 0.4 to 0.8 mm long, which tend to be orientated mainly in two or three directions. Throughout most of the section, many of the flakes are orientated in two directions which intersect at about 90° but in places this angle is smaller and in some zones there are flakes orientated in a third direction, almost bisecting the angle between the two other directions. The directions in which these flakes are orientated are the same throughout practically the whole of the thin section and, although in places the pattern formed shows some similarity to cleavage in carbonate, it is most unlikely that this would have been a single very large crystal of carbonate with cleavage planes in the same direction throughout the whole of the sample. The reason for the orientation of these larger flakes of talc therefore remains undetermined at this stage in the investigation. There are some zones in the rock where there is a much higher proportion of larger flakes of talc and correspondingly less of the interstitial, very fine-grained talc, and in one area several millimetres in size there is practically none of the very fine-grained talc.

Impurities are similar to those in sample A and consist of some very fine-grained dark opaque material along a few cleavage planes and grain boundaries. There is a general turbidity along cleavage planes and grain boundaries in the coarser-grained talc but, as noted previously, at least some of this turbidity could be due to the presence of minute voids and films of air causing internal reflection. No other mineral grains were found in the section and if there is another fibrolamellar silicate intergrown with the talc, this could only be detected by X-ray diffraction.

Conclusion:
The sample is composed entirely or almost entirely of talc and the only impurity visible by microscopic examination is a trace of very fine-grained opaque material. This differs from sample A mainly in grain size and texture.

Sample: 6231 RS 79; TS44827

Applicant's No: DJF 7

Rock Name:

Folded biotite-plagioclase-quartz schist

Hand Specimen:

This is a biotite-rich schist with a pronounced quartzo-feldspathic content. The rock shows M or W folds with an amplitude of 4 or 5 cm and a wavelength of approximately 4 cm. These folds can be seen to be affecting an earlier schistosity marked by the prominent biotite-rich bands. There is also some crenulation of the earlier biotite schistosity which could represent a third deformation event, or form part of the event which produced the larger folds.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Quartz	30
Plagioclase	30
Biotite	25
Muscovite and sericite	10
Opaques (goethite)	3
Apatite	2
Zircon	trace
Rutile	trace

This rock has two prominent fabrics that are clearly evident in hand specimen. The earlier fabric has a compositional banding and associated layer parallel schistosity. In thin section this is seen to consist of a crude parallel alignment of elongate quartz and plagioclase-rich bands, interleaved with elongate irregular stringers or zones of biotite in the same orientation. The second fabric consists of a folding of this earlier schistosity/ compositional banding with minor recrystallisation.

The quartz generally occurs as elongate grains of variable sizes ranging up to 3 mm in length; but usually of the order of 1 mm in length. The larger quartz grains show strongly undulose extinction and considerable sub-grain developments. The finer grain sizes tend to be more equant with undulose extinction. Grain margins vary from serrated and cuspate in the coarser-grain size through to curved or straight for the more recrystallised quartz varieties. In some fold hinges large elongate quartz grains can be seen to be warped around the fold axes.

Plagioclase is co-dominant with quartz. Many grains show multiple lamellar twinning, although untwinned plagioclase is evident. The plagioclase tends to be more equant than the quartz and has an average grain size of 0.5 mm in diameter. It is of an oligoclase to andesine composition. Minor amounts of myrmekitic intergrowths with quartz have been observed.

The biotite is green-brown in colour and the flakes range up to 3 mm in length. Crenulation of the coarser flakes is evident in some instances. Most of the biotite is folded around the hinges of the second generation folds, but within these hinges there are usually one or two grains in an axial planar orientation. In places the biotite shows prominent pleochroic haloes around inclusions of zircon.

Muscovite and sericite appear to be late-stage developments. The muscovite flakes are of the order of 0.1 mm in length and these occur in association with the biotite-rich stringers or bands, possibly after the biotite. The muscovite also occurs in association with sericite as an alteration of a previous metamorphic mineral. This mineral could have been a feldspar or possibly an alumino silicate. Alteration of the plagioclase to sericite is evident but not ubiquitous, as there is a high proportion of unaltered plagioclase. The opaques show a variety of form, some are euhedral showing cubic, rectangular and even hexagonal outlines. Others are anhedral and show irregular and elongate outlines. Some rutile has been observed.

Apatite is a common accessory phase. It occurs as elongate to equant grains and is typically found in association with the biotite. Zircon is also present in trace amounts.

The rock is a folded biotite-plagioclase-quartz schist that was probably formed through low to middle amphibolite facies metamorphism of a pelitic sediment.

Sample: 6231 RS 80; TS44831

Applicant's No.: DJF 11

Rock Name:
Schistose biotite-quartz-plagioclase gneiss

Hand Specimen:
This is a gneissic rock with a high proportion of mica resulting in a very well-developed foliation. Semi to discontinuous quartzo-feldspathic segregations have been boudinaged on a small scale and several augen-like pods can be seen. The main fabric has been folded and a fold hinge can be seen in this hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	30
Quartz	25
Biotite	20
Sericite	15
Chlorite	7
Opaques (including rutile)	2
Zircon and monazite	1

This is a coarse-grained metamorphic rock consisting of bands of plagioclase and quartz, and biotite and sericite. The parallel alignment of the biotite gives the rock the prominent foliation noted in hand specimen. In addition to the biotite-rich bands, there are sympathetic sericite-rich zones which parallel the foliation.

Plagioclase commonly shows multiply lamellar twinning, but untwinned plagioclase is present. The plagioclase is oligoclase in composition and ranges in grain size up to 4 mm. The more elongate grains are aligned parallel to the foliation. Included round blebs of quartz are commonly observed. The plagioclase is little altered with only minor sericitisation.

The quartz occurs in a wide range of grain sizes which probably reflect different stages of recrystallisation. The coarse-grained quartz ranges up to 5 mm in diameter. It shows strongly undulose extinction and in places considerable sub-grain developments. Grain margins are curved to cuspate. The finer-grained quartz tends to have simpler-grained margins but still shows undulose to strongly undulose extinction.

The biotite is green to green-brown in colour and individual flakes range up to 2 mm in length. Chloritisation of the biotite is observed and there may be some replacement by muscovite. Pleochroic haloes around zircon inclusions are present and a high proportion of the biotite is rimmed by fine opaques, or has opaque inclusions along grain margins.

Conspicuous aggregates of sericite occur together with the biotite in bands. Fine-grained muscovite also occurs with the sericite and there appears to be some fine clays and/or chlorite. These sericitic aggregates do not appear to have formed at the expense of plagioclase which is generally little altered. It is probable that the sericite has replaced an earlier, metastable metamorphic mineral, possibly an alumino silicate or perhaps cordierite.

The opaques occur both as discrete anhedral grains and as fine rims and inclusions in the biotite. The discrete grains are elongate to equant in shape, although some are anhedral. They are of the order of 0.1 mm in diameter. The finer opaques associated with the biotite have a grain size of 0.01 mm or less. Some rutile is present.

Zircon occurs in accessory amounts with most grains round in outline and often zoned. The zircon grains are typically 0.1 mm or less in length. Some monazite is present.

The rock is a schistose biotite-quartz-plagioclase gneiss. The nature of its precursor is not clear from the mineralogy but it may be sedimentary in nature.

Sample: 6231 RS 81; TS44832

Applicant's No.: DJF 12A

Rock Name:
Schistose granodioritic gneiss

Hand Specimen:
This is a medium to coarse-grained, grey-green coloured schistose rock. The well developed schistosity can be seen to be crenulated and thin coarse quartzo-feldspathic segregations are also deformed.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	35
Quartz	30
Chlorite	15
Biotite	10
Sericite and muscovite	7
Opaques	2
Apatite	1
Zircon	trace
?Cordierite	trace

This rock has granoblastic aggregates of plagioclase and quartz, with the more elongate grains in a subparallel orientation, thereby giving rise to a gneissic fabric. The biotite is both aligned with this fabric and occurs in random orientation.

Multiple lamellar twinning of the plagioclase is common; however, untwinned plagioclase is also present. The plagioclase is oligoclase to andesine in composition. Grains range up to 2 mm in diameter with most being of the order of 1 mm or less. The margins to the plagioclase grains are typically straight to curved. There is variable minor sericitisation evident.

The quartz shows a wide range of grain sizes with the coarsest being 2 mm in length. The coarser grains tend to be elongate, have strongly undulose extinction and show sub-grain developments. Grain margins are curved to cuspate. The finer-grained quartz has simpler grain margins and shows undulose to strongly undulose extinction. Embayments of plagioclase in quartz and vice versa are common.

The biotite is a green to green-brown colour with flakes ranging up to 2 mm in length. It occurs in stringers with parallel orientation, hence the schistosity, but is also found in aggregates with the flakes in random orientation. The biotite has been extensively altered to chlorite and in many cases the chlorite predominates. Inclusions and rims of fine opaques and some muscovite are common features.

There are patches of aggregates consisting of sericite and fine muscovite. These are usually associated with biotite-rich areas and are formed at the expense of an early metastable metamorphic mineral, and not the plagioclase. In places, possible relict ?cordierite may be present but no cordierite has been positively identified.

Apatite is a common accessory phase. The opaques are also present in accessory amounts and occur both associated with the biotite and as discrete disseminated grains. Zircon is also present.

This is a granodioritic gneiss that probably has a sedimentary precursor.

Sample: 6231 RS 82; TS44833

Applicant's No.: DJF 12B

Rock Name:
Granodioritic gneiss

Hand Specimen:
This is a grey coloured gneissic rock which has a well flattened compositional banding. On the cut surface folding of the compositional banding can be seen. Coarse-grained feldspathic segregations are prominent and probably represent a veining.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	35
Quartz	28
Biotite	20
Sericite and muscovite	7
Microcline	5
Opaques (some rutile)	3
Zircon	1
Chlorite	1

This rock has a foliated granoblastic texture. The grain size is variable and grains range up to 2.5 mm in diameter, with most being less than or equal to 1 mm. The gneissic texture evident in hand specimen is a consequence of the parallel alignment of elongate quartz and feldspar grains. There is a high proportion of biotite which has a similar orientation.

The plagioclase commonly shows multiple lamellar twinning although untwinned plagioclase is present. It is oligoclase to andesine in composition. Included blebs of quartz are present and there are some prominent myrmekitic developments. The average grain size is of the order of 0.5 mm in diameter. Sericitisation of the plagioclase is variable but generally present in only minor amounts.

Microcline and microcline perthite are also present but represent only a small proportion of the total feldspar content. Staining of the off-cut shows the microcline is preferentially concentrated in discrete bands parallel with the foliation, and these probably represent the veining noted above. Cross-hatched twinning and exsolution features are prominent in the microcline and the potassium feldspar tends to be generally coarser-grained than the plagioclase.

Quartz displays a wide range of grain sizes ranging up to 2.5 mm in length. The coarser-grains show strongly undulose extinction and some have sub-grain developments. Grain margins are cuspate and some are very irregular with embayments of feldspar, or quartz embayed into feldspar. In some places there are fine-grained quartz mosaics and elsewhere aggregates of quartz and feldspar.

The biotite is brown to green-brown in colour. Flakes range up to 1.5 mm in length, but for the most part the biotite is less than or equal to 0.5 mm. There are pleochroic haloes around inclusions of zircon. Some of the biotite has minor rims and intergrowths of muscovite and there are some opaque rims and inclusions. Small amounts of chloritisation of the biotite is present.

Associated with biotite-rich aggregates or zones are prominent areas consisting of sericite and/or fine muscovite. The sericite/muscovite appears to have replaced an earlier metastable metamorphic mineral, possibly cordierite or an alumino silicate phase.

Discrete flakes of muscovite are also present and commonly occur interstitial to the quartz and feldspar or are associated with biotite.

The opaques show a variety of forms. Some euhedral cubic grains are evident but most are anhedral irregular in outline. The opaques range up to 0.3 mm in length. Some rutile is present.

Zircon is a prominent accessory phase occurring as simple discrete grains sometimes zoned, with a few rare compounded grains evident.

The rock is a granodioritic gneiss with possible igneous precursors, although the high biotite content does imply a sedimentary component.

Sample: 6231 RS 83; TS44834

Applicant's No.: DJF 13

Rock Name:
Granodioritic gneiss

Hand Specimen:
This is a grey coloured quartzo-feldspathic gneiss which has a fine compositional banding consisting of mafic-rich and quartzo-feldspathic-rich bands. Coarser-grained feldspathic-rich bands or veins occur parallel with the compositional banding. Both the veins and compositional banding have been folded or rotated with a second generation feldspathic vein occurring along the fold axis.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	30
Plagioclase	30
Biotite	20
Sericite and muscovite	8
Potassium feldspar	5
Opaques	5
Chlorite	1
Zircon	1

This rock has a well foliated granoblastic texture with elongate quartz and feldspar grains in parallel alignment, consistent with the orientation of the abundant biotite. A very coarse vein of quartz and feldspar is also parallel with the metamorphic fabric.

The quartz occurs in a variety of grain sizes and forms. Relict coarser quartz grains range up to 2 mm in length. These show strongly undulose extinction and considerable sub-grain developments, with many being recrystallised into finer aggregates. Grain margins are typically cuspate and embayments of quartz into feldspar and feldspar into quartz can be seen. Finer-grained quartz mosaics and fine aggregates of quartz and feldspar are present.

The vein quartz is much coarser-grained, ranging up to 1 cm in length, although partial to complete recrystallisation during deformation is observed. Undulose extinction, sub-grain developments and some quartz mosaics can also be seen in the vein quartz.

Plagioclase is the dominant feldspar. Both untwinned and multiply twinned plagioclase is evident. The plagioclase composition is oligoclase to andesine. Grain sizes are commonly less than 0.5 mm, although the plagioclase does range up to 1.5 mm. Myrmekitic intergrowths of quartz in plagioclase are present. Alteration to sericite varies from little or none to moderate amounts.

Microcline and microcline perthite occur as minor constituents throughout the rock, but are more common in the secondary veining.

The biotite is brown to green-brown in colour with individual flakes ranging up to 2 mm in length. It has abundant inclusions and rims of fine opaque grains. Individual opaques are of the order of 0.02 mm in diameter. Replacement of the biotite by muscovite and alteration to chlorite can be seen. Many biotite flakes are intergrown with thin slivers of muscovite or have muscovite borders.

Associated with the biotite are patches up to 2 mm in diameter which consist of fine aggregates of sericite and fine muscovite, with chlorite present as well. As noted with other related rock types, the sericite/ muscovite aggregates probably formed at the expense of an earlier alumino silicate phase or cordierite.

Some discrete aggregates of fine muscovite are also present. These are mostly interstitial to the quartz and feldspar or peripheral to the feldspar.

The coarser-grained opaques are blocky to anhedral in outline, ranging up to 0.7 mm in diameter with most of the order of 0.1 mm. Fine opaques also occur with the biotite as noted above. Some rutile has been observed.

Zircon occurs in accessory amounts. Round outlines are common although some complex forms are present consisting of compound round grains.

The rock is a granodioritic gneiss with a high proportion of biotite. It was probably derived from an igneous precursor although a sedimentary component cannot be excluded.

Sample: 6231 RS 84; TS44835

Applicant's No.: DJF 15

Rock Name:
Granodioritic gneiss

Hand Specimen:
This is a grey coloured, layered, quartzo-feldspathic gneiss. Quartzo-feldspathic-rich bands up to 4 mm in thickness are interlayered with more mafic-rich bands. The cut surface shows broad open folding of the compositional layering and there appears to be a superimposed axial planar fabric.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	40
Quartz	30
Microcline	10
Biotite	10
Muscovite and sericite	5
Opaques	3
Chlorite	2
Zircon	trace
Sphene	trace
Apatite	trace

This rock has an inequigranular granoblastic texture. Equant to elongate remnant core grains of quartz and plagioclase, of the order of 1 mm in length, are mantled by finer recrystallised aggregates of quartz and feldspar together with interstitial biotite. The prominent compositional banding is not as clearly evident on the scale of the thin section, however, a general alignment of elongate grains indicates the earlier-formed fabric. The biotite stringers tend to be subparallel, although follow the outline of the relict core grains. Some secondary growths can be seen and these tend to lie parallel to the fold axis seen in hand specimen.

The plagioclase ranges up to 2 mm in diameter with both multiply twinned and untwinned grains present. Some of the coarser grains have antiperthite exsolution features. Included blebs of quartz are common and some myrmekite is observed. Some of the plagioclase shows extensive alteration to sericite.

Microcline and microcline perthite are present both as discrete grains and as exsolution features in plagioclase.

The quartz ranges in grain size up to 2 mm, althlugh it is mostly of the order of 1 mm or less. The grains tend to be more elongate than the feldspars and are more prevalent as recrystallised finer aggregates. Undulose to strongly undulose extinction is evident and grain margins are cuspate. There are abundant finer aggregates of quartz and some mosaics can be seen.

The biotite is brown to green-brown in colour. It commonly occurs as interstitial grains to the coarser feldspar and ranges in grain size up to 0.6 mm in length, although mostly being of the order of 0.1 mm. Fine muscovite is associated with the biotite as are the accessory phases zircon, opaques and sphene. Some chloritisation of the biotite is associated with these accessory minerals.

The zircon grains are usually round in outline and some show growth zoning. Apatite is also an accessory phase in this thin section.

The rock is a granodioritic gneiss with a possible igneous precursor.

Sample: 6231 RS 85; TS44814

Applicant's No.: E 66

Rock Name:
Amphibolitised ?pyroxene-granulite

Hand Specimen:
A greenish-grey massive rock consisting of a medium to coarse-grained mesh of fibres and prisms of silicate minerals.

Thin Section:
A visual estimate of the constituents is as follows:

	%
?Tremolite-actinolite	~50
Pyroxene	5-10
Epidote	~20
Feldspar	2
Chlorite	20-25
Limonite	<1

A granular texture of pale green to almost colourless fibrous amphibole comprises the principal part of this rock. Crystals are up to 3 mm in length and of generally similar width. In many places the minerals appear to be altering to chlorite, which has replicated to greater or lesser degree the almost fibrous cleavage of the amphibole. Trails of fine granular to short prismatic epidote crystals follow the amphibole intergranular boundaries, and in places merge into turbid saussuritic masses. The epidote is both turbid and stained brown with what appears to be a small proportion of limonite or other exsolved iron oxide. The amphibole appears to have the composition of a weakly ferroan tremolite-actinolite, but has an unusually high birefringence. Its form suggests that it has replaced a more granuloblastic pyroxene mixture such as diopside and/or and orthopyroxene. A few relict grains of untwinned feldspar are scattered among the calc-magnesian silicates, and a few sparse concentrations of chlorite indicate the former possible location of more aluminous silicates. Because of the unusual appearance of the amphibole in this rock, the total components were confirmed by X-ray diffraction analysis. A possible derivation of this rock is from a pyroxene-feldspar granulite which has been retrogressively altered to amphibole and epidote. This may have taken place in conjunction with the formation of the chlorite, but there may also have been a degree of later hydrothermal or even metasomatic processes involved. The composition appears to be too rich in lime and deficient in iron to interpret it as an ortho-amphibolite, hence it is considered more likely to have been derived from a calc-magnesian sediment such as a siliceous dolomite.

Sample: 6231 RS 86; TS44815

Applicant's No.: E 69

Rock Name:
Biotite-feldspar-quartz schist

Hand Specimen:
A fine to medium-grained foliated rock consisting of near-white quartzofeldspathic layers alternating with thin but abundant micaceous laminations. The rock is extensively folded and crumpled.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	40-50
Feldspars	30-40
Biotite	15-20
Muscovite	<1
Leucoxene (or titanite)	2
Limonite	1-2
Zircon	trace

Strongly aligned laminations of biotite flakes of fairly fine grain size (few exceed 0.5 mm diameter) alternate with broad layers of granuloblastic quartz-feldspar intergrowths up to 5 mm wide which contain a very small proportion of mica. The quartz and feldspars in places show faint relict outlines of former detrital grains of quartzitic composites around which, there are swathes of biotite flakes. Several coarse crystals of quartz and feldspars are present up to 1 mm diameter, which may be relict detrital grains or, less likely, porphyroblasts. They are set in a generally finer to even cherty mosaic of granuloblastic quartz in which the individual crystals rarely exceed 0.2 mm. The feldspars are predominantly soda-lime varieties, and the crystals showing multiple twinning indicate a composition corresponding to oligoclase. Many feldspars are cloudy with ?clay mineral alteration products, and staining tests indicate that potassic metasomatism has taken place along a few fine transverse veinlets sparsely distributed across the rock.

The biotite-rich layers do contain a few rare flakes of muscovite, and small granular inclusions of leucoxene (or titanite) scattered among them. The schisty foliation along these layers is also the weakest direction, and there has been a tendency for the layers to separate and the fissures become filled with limonitic weathering products.

The rock is a schistose metasediment derived from an argillaceous siltstone or lithic arenite.

Sample: 6231 RS 87; TS44816

Applicant's No.: E 72

Rock Name:
Chert

Hand Specimen:
A generally dark green and pale brown banded massive fine-grained siliceous chert, with additional fine quartz veining.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	>90
Chlorite	2-3
Sericite	<1
Limonite	<1

This is a fine to very fine-grained mass of granuloblastic quartz. The laminations seen in hand specimen are revealed microscopically as consisting of varied grain sizes and clarities of almost pure quartz. Some is so fine as to be virtually cryptocrystalline, and others contain crystals up to 0.1 mm. Within the quartz veins the crystals become coarser again, being up to 0.3 mm diameter and much more transparent.

The laminations of the chert are resolved microscopically to contain a multiplicity of ultra-fine layers, some being no more than 0.1 mm thick. Most of the long axes of the quartz crystals are parallel to the laminations, and have recrystallised more completely and more coarsely where there is a paucity of other components. The finer chert layers contain fine chlorite flakes and even rarer traces of sericite. A few sparse bands are quite densely clouded with inclusions, and contain an assortment of quartz or chalcedony grains, which give the impression that they may have replaced feldspars. Some intergranular limonitic staining, and minor void fillings of the same material, are present in these bands and the adjacent quartz veins.

The rock is a chert which has been derived from a siliceous sediment. Many cherts are considered to be derived by silicification or devitrification of glassy lavas or tuffs. The relict laminations in this rock are so fine, and the ferromagnesian contaminants are so sparse that this interpretation seems unlikely. It is therefore suggested that it is a direct oceanic colloidal precipitate, such as are known to form in the vicinity of volcanic sources where additional silica is fed into the water. It may, however, contain a very small proportion of pyroclastic contaminants.

Sample: 6231 RS 88; TS44818

Applicant's No.: E 90

Rock Name:
Sheared granodiorite gneiss

Hand Specimen:
A medium-grained lineated granitoid rock.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	20-30
Plagioclase (oligoclase)	∿60
Muscovite	3
Biotite	1
Chlorite	5-8
Titanite (sphene)	<1
Zircon	trace

This rock has a well-developed boudinage structure in which aligned cylindrical masses of quartz and feldspar of rounded to elliptical cross section are enclosed in very weakly foliated clusters of micaceous minerals. The feldspar is entirely plagioclase with an oligoclase composition (Ab_{80}). Most crystals are xenoblasts of average diameter 0.5 mm, but there is a considerable proportion of smaller crystals (0.1 mm and less) distributed along the coarser crystal boundaries. Most of the quartz is also present as part of this finer mosaic separating the coarser feldspars. A few coarser quartz crystals are, however, present particularly among the micaceous components.

Muscovite flakes up to 0.5 mm diameter, intergrown with variously chloritised biotite of similar dimensions, comprise the micaceous separations between the boudins. The flakes are partially aligned and the clusters elongated with the general structure. Granular masses of titanite occur particularly within the biotite and chlorite-rich zones, and in a few places rounded prisms of zircon are also present.

The rock is classified as a gneiss which has an essentially granodioritic composition. It is an amphibolite facies metamorphic equivalent of an argillaceous siltstone or arenaceous shale.

There is one very fine hydrothermal metasomatic veinlet, which traverses the hand specimen. Some fine pink ?hematitic pigmentation has developed in the feldspars along its length, and staining tests show the presence of potassic feldspar traces which are penetrating the intergranular crevices of the plagioclase.

Sample: 6231 RS 89; TS44819

Applicant's No.: ML 4634/21

Rock Name:
Chloritised quartz-feldspar gneiss (?migmatite)

Hand Specimen:
A massive green rock with a rather crumpled and folded alternate banding of white layers or veins. There is also a very weak foliation parallel to the layering.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Quartz	15-20
Plagioclase (andesine)	∿70
Chlorite	5-10
Muscovite	1-2
Titanite (sphene)	∿1
Opaques (leucoxene)	1

A considerable diversity of grain sizes is a feature of this rock. Broad medium to quite coarse-grained quartzo-feldspathic (?pegmatite) bands occupy the white layers, while relatively fine-grained quartz, feldspars and chlorite make up the foliated green laminations. The finer-grained feldspar is untwinned, but within the coarser ?veins it shows multiple twinning and a series of perthitic-type intergrowths. The composition appears to be that of a sodic andesine (Ab_{65}). Quartz is relatively scarce within these ?veins but is more prevalent in some of the finer bands and micaceous layers. The chlorite is present as knots and layers of fine partially aligned flakes, which in a few places, alternate with patches of muscovite. Much of the chlorite is as ultra-fine inclusions in the more cherty to chalcedonic siliceous bands, and is obviously the cause of coloration in the rock. A few subidiomorphic crystals of titanite are randomly scattered, and there are drawn-out streaks and schlieren of pale cream to brown earthy opaques which follow the laminations, and appear to be a titanian oxide such as leucoxene.

This rock gives the impression that it was a micaceous schist or gneiss which has been hydrothermally chloritised and tectonically distorted during the introduction of the quartzo-feldspathic (?pegmatite) phase. Alternatively it could represent a chloritised metamorphic rock which had already been segregated such as a migmatite.

Sample: 6231 RS 90; TS44820

Applicant's No.: ML 4634/42

Rock Name:
Epidote-chlorite rock

Hand Specimen:
A medium to fine-grained yellowish-green massive rock with a very weakly defined subparallel banding.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Epidote	>80
Chlorite	10-15
Carbonate (?dolomite)	2-3

This rock is almost entirely a mass of subidioblastic pale yellow-green epidote prisms, which are up to 1 mm long and 0.5 mm wide. The crystal terminations tend to be rounded and the intergranular spaces filled with finer to even microcrystalline mesh of chlorite. Some of the chlorite has the form of fine curving swathes of flakes which wind between the epidote prisms; other larger areas consist of small rosettes of radial flakes. Although the chlorite is not very abundant, it is most concentrated along a few subparallel fractures or fissuring directions, which coincide with the banding direction and may be largely responsible for it. Even finer (less than 50 microns) crystallites of carbonate are also disseminated along these chloritic fissures, and to a lesser extent among the epidote. This carbonate appears virtually colourless, and is unaffected by the alizarin red-S agent used for staining calcite. It is assumed that it is dolomite, although siderite or ankerite are also possibilities.

This rock differs markedly from any common metamorphic composition. If the banding is a relict sedimentary texture rather than a metamorphic compositional segregation, then it could be regarded as a metasediment derived from a lime-dominant calc-magnesian marl or dolomitic shale such as for sample E 19. Alternatively, if the granular texture of the epidote is itself a relict, it could be a retrogressively and hydrothermally altered pyroxene granulite, which must itself have been derived from a dolomitic source rock. The genetic evidence in this rock is rather too vague for meaningful interpretation.

The iron content is one of the more unusual features and it seems difficult to interpret without resorting to some volcanogenic contaminant in the original sediment or introduction of one or more elements metasomatically.

Sample: 6231 RS ~~84~~ 91; TS44813

Applicant's No.: E 63

Rock Name:
Epidote amphibolite

Hand Specimen:
A fine to medium-grained massive granular yellow-green rock with faint darker mottling visible on the sawn surface.

Thin Section:
A visual estimate of the constituents is as follows:

	%
Epidote	∿50
Amphibole (tremolite-actinolite)	40-50
Titanite (sphene)	1-2

This rock consists essentially of a fibrous to prismatic amphibole enclosing granular masses of epidote. Most of the amphibole is a random fibrous mesh of very pale green to colourless tremolite-actinolite (nephrite) which winds its way between coarser (up to 1 mm long × 0.5 mm wide) prisms of the same mineral, and the granular masses of epidote.

The epidote itself occurs in trains and bands of quite coarse grain size, which are resolved microscopically as aggregates of granules which virtually never exceed 0.1 mm diameter. In places these aggregates become the dominant component and the rock is virtually monomineralic, except for inclusions of acicular tremolite-actinolite. Alternatively, in other places the amphibole is dominant, and only rare discontinuous trains of finer epidote are present.

The titanite is also rather finely granulated. Although a few crystals show partial development of the typical lozenge-shaped form, these are in some places actually microcrystalline composites. Others appear to be portions of narrow elongate crystals up to 0.5 mm long wedged among the other components and aligned with the lineation direction of the amphibole.

There is a very faint compositional banding visible in thin section alternating between the calc-aluminous epidote-rich layers and the calc-magnesian tremolite-actinolite. There is also a slight tendency for the titanite crystals to lie along definite bands, but they may have been influenced by minor fissures in the rock which appear to be of later origin.

The rock is an amphibolite facies metasediment, derived from a very calcic rock with appreciable alumina and magnesia. While there is no definite evidence that this is not an ortho-amphibolite, it is believed more likely to have been a metasediment from an argillaceous siliceous dolomitic limestone.

Sample: 6231 RS 92; TSC39683

Applicant's No:
E14/17

Rock Name:
Chlorite and muscovite-bearing plagioclase gneiss

Hand Specimen:
This is a coarse-grained feldspathic rock. On the cut surface a prominent foliation is evident due to the concentration of micas into distinct bands. This foliation shows the effects of an open folding or crenulation event.

Thin Section:
A visual estimate of the constituents gives the following:

	%
Plagioclase	55
Chlorite	15
Sericite	15
Muscovite	10
Opaques	4
Zircon and/or monazite	1
?Altered sphene	Trace

This is a plagioclase-rich rock and has a wide range in grain sizes. The plagioclase ranges in size up to 1 cm in diameter. The coarser plagioclase has antiperthitic exsolution features and some show multiple lamellar twinning but most are untwinned. It is an oligoclase in composition although there may be some albite present. There is little or no K-feldspar and there may be some quartz. Grain boundaries are ragged and sub-grain developments common, indicating at least one superimposed cataclastic deformation. The plagioclase grains are commonly clouded by fine alteration products and many have sericite/muscovite and chlorite developed within.

The muscovite also shows a wide range in grain sizes with some flakes up to 3 mm in length. The coarser muscovite flakes appear to be early metamorphic developments at the expense of feldspar and these have small-scale kinks in the cleavage traces. The sericite and finer muscovite are concentrated along zones within the rock which have suffered more intense cataclastic deformation and alteration of the feldspar. These micaceous bands are the crenulated foliation evident in hand specimen.

Associated with the muscovite is a colourless to greyish-coloured micaceous mineral with low maximum birefringence. This is probably chlorite and in places can be seen to be replacing the muscovite. As with the sericite, there are patches of finer-grained chlorite developed.

The opaques are typically irregular in outline and range in size up to 0.5 mm in length. In a number of cases the opaques occur around the margins of, and along the cleavage traces of muscovite or chlorite. These finer-grained opaques have very ragged grain margins. Zircon, and/or monazite , is a prominent accessory, ranging in grain size up to 0.1 mm with some zoned and complex composite grains evident. There are also traces of ?altered sphene.

This is a chlorite and muscovite-bearing plagioclase gneiss that has suffered at least one major cataclastic deformation and a subsequent mild crenulation or folding event.

Sample: 6231 RS 93; TSC39684

Applicant's No:
E14/37

Rock Name:
Chlorite and sericite-rich plagioclase gneiss

Hand Specimen:
This is a well-foliated rock consisting mostly of finer-grained, dark green-coloured micaceous material with coarser, white feldspathic bands or segregations. There are some very coarse clots of feldspar which are up to 5 cm in diameter. The foliation and feldspar segregations show open warps or crenulations, and in places there is some disruption along the axial plane of these warps.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	50
Sericite	20
Chlorite	15
Coarse muscovite	5
Opaques	9
Epidote	1
Goethite	Trace
Sphene	Trace
Zircon	Trace

This sample is similar to 6231 RS 92, in that it consists of plagioclase which has been altered, resulting in chlorite, muscovite and sericite.

Plagioclase in thin section exhibits a continuous spectrum in grain sizes, ranging up to 7 mm in diameter. Most of the plagioclase occurs as elongate grains orientated in the foliation. The plagioclase is essentially an untwinned variety and in places shows extensive alteration to sericite. Grain boundaries are ragged and irregular in outline, with many strain features and sub-grain developments, consistent with at least one major cataclastic deformation.

The chlorite is colourless to pale olive green in colour. Individual flakes range up to 1.5 mm in length. The cleavage planes and margins of the chlorite are enhanced by a preferential concentration of fine-grained opaques. Muscovite commonly occurs together with the chlorite, forming micaceous bands. The muscovite flakes also range up to 1.5 mm in length, but it is usually finer-grained than the chlorite and grades down into sericite. In places there is evidence to suggest that the chlorite is derived at least in part from earlier formed coarse muscovite. The schistosity that arises from the parallel alignment of these micaceous minerals can be seen to be crenulated. There is only very minor amounts of recrystallization in the hinges of these crenulations, giving rise to one or two flakes of muscovite and lesser chlorite parallel to the axial plane.

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Sericite occurs as massive aggregates which form bands through the rock parallel to the main foliation. The sericite can be seen to be replacing an earlier feldspathic phase, and at the latest it was developed synchronously with the main schistosity-producing event.

The disruption along the axial planes of the crenulations is represented in thin section by cracks or fissures with opaque phases. In the places,parallel to these fissures there is some epidote veining. The epidote is colourless to very pale yellow-green in colour, elongate in nature, and ranges up to 0.8 mm in length. Apart from the association with chlorite, the opaques also occur as very ragged, disseminated grains, some up to 1 mm in length. Round zircon grains are present in trace amounts and there are minor secondary goethitic developments and possibly some altered sphene.

This is a chlorite and sericite-rich plagioclase gneiss that has suffered at least two main deformations.

Sample: 6231 RS 94; TSC39685

Applicant's No:
E14/45

Rock Name:
Granodioritic gneiss

Hand Specimen:
This is a medium-grained, white-coloured granitoid that is foliated.

Thin Section:
A visual estimate of the constituents gives the following:

	%
Plagioclase	80
Quartz	10
Muscovite	6
Chlorite	2
Sphene	1
Opaques	1
Apatite	Trace
Zircon	Trace

This rock has an inequigranular granoblastic texture. It dominantly consists of plagioclase which ranges up to 2.5 mm in diameter. There has been partial recrystallization of the plagioclase particularly around its grain margins, which has resulted in fine interstitial feldspar with parallel aligned,elongate plagioclase core grains. This alignment, together with the coincident alignment of some of the muscovite gives the rock a prominent foliation in thin section,as noted in hand specimen.

The plagioclase is andesine in composition and exhibits multiple lamellar twinning, antiperthitic exsolution features, and is also untwinned in places. Some of the multiple twinning resembles that seen in cordierite, however no positive identification of cordierite has been made. Grain margins are ragged in places and prominent sub-grain developments can be seen. Clouding of the plagioclase is common, together with some sericitization.

Muscovite occurs interstitial to the plagioclase. Flakes range up to 0.5 mm in length, with most being of the order of 0.1 to 0.2 mm. There is a general alignment of the muscovite, however some of the aggregates have radial arrangements. In places, chlorite can be seen to have developed from muscovite. The interstitial nature of the muscovite indicates a secondary development relative to the plagioclase and some may have been derived from earlier plagioclase.

Quartz is a relatively minor interstitial constituent, being of similar size to the plagioclase. It is distinguished by a general lack of inclusions and alteration. The quartz shows undulose extinction and is often associated with sphene.

Sphene is a prominent accessory phase. Generally ragged in outline with some relict prismatic grains present. Sphene ranges in grain size up to 0.5 mm. Other minerals present in trace amounts are apatite and zircon The apatite has a maximum grain size of 0.15 mm.

This is a medium to coarse-grained granodioritic gneiss that was probably formed through amphibolite grade metamorphism of an igneous rock.

Sample: 6231 RS 95; TSC39686

Applicant's No:
E14/51

Rock Name:
Diopside-bearing tremolite rock(or jade)

Hand Specimen:
On the weathered surfaces this is a fine-grained, massive brown-coloured rock. Variations in grain sizes are evident on the cut surface with material ranging from very fine, up to 0.5 - 1 cm in diameter. The fresh rock is a dark green colour.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	85
Diopside	10
Chlorite (and biotite)	1
Opaques	1
Secondary ferruginization	3

This rock is dominated by tremolite which exhibits a wide range in grain sizes. Relict coarse domains of tremolite, averaging 1 to 1.5 mm in diameter show partial to complete recrystallization to massive, fine-grained tremolite. These fine aggregates have an average internal grain size of 0.1 mm or less. There is a tendency for these fibrous tremolite grains to have a parallel alignment, giving the rock a micro-schistosity, although much of the tremolite is in random orientation.

The diopside occurs in coarse-grained aggregates with an internal grain size ranging up to 5 mm in diameter. The diopside is typically granular in outline and the grains are strongly cracked. Partial replacement of the diopside by tremolite can be seen. Much of the diopside is clouded by fine, dust-like inclusions, probably representing the early stages of alteration.

In places there are some fine aggregates of chlorite, interstitial to the tremolite and some biotite has also been observed with the chlorite.

Minor shearing occurs through the sample and there is rotation of the tremolite needles into the shear zones. In parts, new tremolite formation occurs adjacent to, and within these zones of intense deformation. Secondary ferruginization is also present and has resulted in an intense iron staining of some parts of the rock.

This is a diopside-bearing tremolite rock or jade that was probably formed through amphibolite-grade metamorphism of a siliceous sandy dolomite. There is evidence to suggest at least two stages of metamorphic development with early formed pro-grade diopside retrograding to tremolite.

Sample: 6231 RS 96; TSC39687

Applicant's No:
E14/52

Rock Name:
Dark green coloured massive tremolite rock (or jade)

Hand Specimen:
This is a massive rock of high density, which when fresh is very dark green in colour. The weathered surface is brown in colour and on a cut surface there is an apparent planar fabric.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
Opaques (including dust-inclusions)	5
?Apatite	Trace
Biotite	Rare

This rock consists almost entirely of tremolite. ?Relict coarse domains are emphasized by rims of fine opaque inclusions. These ?relict domains range up to 2 mm in length and have been almost completely recrystallized to aggregates of massive fine tremolite. A few scattered coarse tremolite grains are preserved, ranging up to 1.5 mm in length. Some secondary coarse tremolite is also evident, being of a similar grain size but occurring as radial clusters.

The bulk of the rock consists of fine-grained tremolite with an average grain size less than 0.1 mm. A weak alignment of these fine-grained aggregates, together with the ?relict structures give the rock an indistinct fabric as noted in hand specimen.

There are significant but minor amounts of very fine opaque material mostly concentrated along cracks through the rock which mark the boundaries to possible earlier structures. Traces of apatite and rare biotite have been observed.

This is a dense massive tremolite rock or jade which was probably formed through middle amphibolite-grade metamorphism of a siliceous dolomitic marble.

Sample: 6231 RS 97; TSC39688

Applicant's No:
E14/64

Rock Name:
Chloritized and sericitized granodioritic gneiss

Hand Specimen:
This a pale grey green-coloured rock, medium-grained, with a prominent foliation. Slightly coarser grained, pale pink-coloured feldspathic stringers are parallel to the foliation and range up to 1 cm in thickness.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	60
Quartz	10
Sericite	15
Chlorite	9
Muscovite	5
Opaques	1
Zircon	Trace
Sphene	Trace
?Apatite	Trace

This is an altered foliated granitoid with turbid and sericitized feldspar, and chloritized micas. The foliation noted in hand specimen is due to a parallel alignment of plagioclase and quartz together with muscovite and chlorite.

Both twinned and untwinned plagioclase is present and some antiperthite exsolution features can be seen. Most feldspar grains are turbid and in patches there has been extensive sericitization. The grains are elongate in outline, ranging up to 1.5 mm with an average grain size of the order of 0.5 mm. Grain margins are irregular, sutured and/or serrated with partial recrystallization and sub-grain developments peripheral to the coarser grains.

The quartz shows similar grain margin and partial recrystallization features as the plagioclase. Most grains have undulose to strongly undulose extinction.

Muscovite and chlorite commonly occur together in stringers or wispy aggregates elongated in the foliation. The flakes range up to 0.5 mm in length. Chlorite seems to have formed at the expense of muscovite or possibly an earlier ?biotite. The chlorite shows weak pale grey-green pleochroism.

Lenticular zones of fine massive aggregates of sericite are present, also orientated in the foliation. The sericite appears to have replaced earlier feldspars possibly forming augen-like structures. Muscovite usually occurs together with the sericite and there is some chlorite. The sericite and muscovite are also present as secondary interstitial phases in small aggregates around feldspars.

Opaques occur as very fine-grained inclusions along the cleavage planes and margins to the chlorite. Some secondary iron oxide developments along grain margins are present. Minerals occurring in trace amounts are zircon, sphene and ?apatite.

This is a chloritized and sericitized granodioritic gneiss that probably has an igneous precursor. There is evidence for at least one major cataclastic deformation.

Sample: 6231 RS 98; TSC39697

Applicant's No:
DJF 26

Rock Name:
Hydrothermally-altered granodiorite

Hand Specimen:
This is a massive coarse-grained granitoid with a weak foliation shown by a tendency for elongate mafic clots to be in parallel alignment.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	65-70
Biotite and chlorite	15-18
Tremolite	5-7
Quartz	?5
Opaques (goethite and rutile)	4
Apatite	1
Zircon	Trace

This rock consists principally of coarse-grained plagioclase with secondary interstitial biotite and chlorite, and late-stage acicular tremolite.

The plagioclase ranges in grain size up to 5 mm in diameter. Many of the grains show multiple lamellar twinning which in places is kinked and a deformation texture results. Some untwinned plagioclase, antiperthitic feldspar, and rare simple twins can be seen. Grain margins are cuspate to ragged and recrystallized finer interstitial aggregates are present. The plagioclase generally has a clouded appearance consistent with the early stages of alteration to ?fine clays.

In places the plagioclase has been partly replaced by acicular aggregates of tremolite. Individual tremolite needles range up to 1 mm in length and show a radial pattern, emanating from a common point usually adjacent to the junctions of several plagioclase grains. It is probable that these tremolite needles are formed from late-stage fluids moving along grain boundaries.

Biotite occurs as massive aggregates of equidimensional flakes that are interstitial to, and in part replacing an earlier feldspar phase. Relict plagioclase does occur in association with the biotite, and tremolite seems to cross-cut the biotite developments. Individual biotite flakes are 0.05 mm in diameter. It is olive green to pale green-brown in colour and there is significant alteration in places to chlorite. Coarser-grained aggregates of biotite are restricted developments, with flakes up to 0.5 mm in length. These aggregates occur in areas of intense recrystallization of the plagioclase, resulting in fine mosaics of plagioclase and ?quartz, together with biotite.

Quartz is generally of limited extent, occurring as secondary interstitial vein-like stringers with undulose extinction. Opaques are irregular to blocky in outline, ranging in size up to 1 mm. Goethite is a common opaque phase, being secondary in origin, infilling or replacing earlier phases. Some rutile is present. Apatite generally occurs as round, elongate grains up to 0.2 mm in length. It appears to be preferentially associated with, or adjacent to the biotite development. Traces of zircon are present.

This is a coarse, even-grained granodioritic rock that has suffered hydrothermal alteration resulting in replacement of plagioclase and ?other feldspar by biotite. Late-stage movement of fluids has resulted in the development of acicular aggregates of tremolite within the plagioclase.

Sample: 6231 RS 99; TSC39698

Applicant's No:
DJF 27

Rock Name:
Dark green and pale green-coloured tremolite rock (or jade)

Hand Specimen:
This is a massive fine-grained rock that has a pale green portion and a dark green portion. There is an indistinct cleavage which is subparallel to the boundary between these two colour bands.

Thin Section:
The thin section was cut mostly of the pale green material with only a small portion of the dark green material present.

A visual estimate of the constituents present gives the following:

	%
Tremolite	∿94
Opaques/ferruginous staining	∿5
Apatite	∿1

This rock consists of fibrous mats of fine-grained tremolite with scattered coarser tremolite aggregates. The fine tremolite has an average grain size of approximately 0.01 to 0.04 mm. There is an indistinct subparallel alignment of the fibrous tremolite which results in the fabric noted in hand specimen.

The coarser grained tremolite ranges up to 1 mm in length, occurring both as elongate and more needle-like grains. The coarse tremolite forms irregular interconnected zones throughout the rock which may be vein-like in origin. Within these coarse aggregates the tremolite is generally in random to radial orientation.

Apatite is a prominent accessory phase occurring as equant to round elongate grains up to 0.4 mm in length. There is conspicuous fine dust-like material occurring along cracks or fissures through the rock and there is also some secondary ferruginization of the tremolite. Fine dust-like inclusions can also be seen within some tremolite aggregates.

The colour bands noted in hand specimen do not appear to be a consequence of any textural or obvious mineralogical differences as seen in this thin section.

This is a massive tremolite rock or jade that appears to have suffered some secondary tremolite development possibly through solution veining.

3. PETROGRAPHY

Sample: 6231 RS 100; TSC40845

Applicant's No.
DJF 28

Rock Name:
Plagioclase veined actinolite rock

Hand Specimen:
This rock consists of two components, a host of coarse-grained, green coloured amphibole which is veined with thin quartzo-feldspathic material resulting in a banded appearance. One end of the hand specimen has a ca 5 cm thick vein of feldspar.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Host:	
Actinolite	85
Epidote	13
Plagioclase	2
Vein:	
Plagioclase	85
Epidote	10
Actinolite/tremolite	5
?Sphene	trace

The host portion of this sample is dominated by actinolite with lesser amounts of epidote. The actinolite is colourless to very pale green and occurs as elongate to braded crystals ranging up to 4 mm in length. Some show typical amphibole 60-120° cleavage and a few grains appear to be curved in a deformation fabric. Generally the elongate actinolite is in random orientation.

The epidote (?clinozoisite) is finer-grained and occurs as colourless aggregates with individual grains ranging up to 1 mm in length. There are some discrete prismatic epidote crystals as well as finer anhedral, granular aggregates. Plagioclase occurs as patches or discrete veinlets within the actinolite, consisting of untwinned granoblastic aggregates with subgrain developments and sutured grain margins. It is possible that there is some quartz associated with the plagioclase.

The prominent feldspathic vein noted in hand specimen can be seen to dominantly consist of coarse-grained plagioclase which has suffered considerable intergranular recrystallisation consistent with a cataclastic deformation. Coarse, relict plagioclase grains range up to 5 mm in diameter and are either twinned or untwinned. Most show antiperthic textures and have considerable subgrain developments, being surrounded by fine granular feldspar with an average grain size less than 0.1 mm. Epidote and partially fibrous actinolite/tremolite occur interstitial to the plagioclase. The epidote occurs both as massive aggregates of fine anhedral grains, and as aggregates and discrete euhedral crystals up to 0.5 mm in length. The tremolite grades from coarser more massive crystals into fibrous wispy aggregates. There is a trace of sphene.

This is a calc-silicate rock that was probably formed through middle amphibolite facies metamorphism of a siliceous dolomite. It has subsequently suffered at least one cataclastic deformation which post-dates a prominent feldspathic veining event.

Sample: 6231 RS 101; TSC40846

Applicant's No.
DJF 29

Rock Name:
Plagioclase-rich pegmatite

Hand Specimen:
This is a coarse-grained feldspathic rock which is generally massive with no obvious foliation. Quartz is evident in the hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	60-65
Quartz	10-15
Epidote	15
Actinolite	8
Apatite	1
Zircon (?xenotime)	1
Sphene	trace

This sample is similar in composition and texture to the plagioclase vein described in sample 6231 RS 100.

Coarse early-formed plagioclase grains range up to 6 mm in diameter. These show antiperthic textures and are variably twinned. A superimposed cataclastic deformation has resulted in the development of fine granular interstitial feldspar and subgrain to mosaic textures within the remnant coarse core grain. In places there is a seriate texture with grain sizes ranging from 2 to 3 mm downwards. Some of the partly recrystallised grains also show multiple lamellar twinning.

Although not positively identified in thin section it is apparent that there is a small to moderate amount of quartz in this sample. Staining of the hand specimen reveals that quartz is present in ca 10 to 15%.

The epidote and actinolite commonly occurs interstitial to the plagioclase. One coarse patch of intensely altered epidote (?clays) is 5 mm in length but mostly the epidote is found as granular aggregates with a grain size of less than 0.5 mm. In part the epidote can be seen to form at the expense of plagioclase. The actinolite is pale green to colourless in colour, weakly pleochroic and ranges up to 1 mm in length (mostly less than 0.5 mm). Some fibrous amphibole is also present and in places degradation of the amphibole to ?clays is apparent.

Apatite is a prominent accessory phase and there is some zircon and/or ?xenotime, with traces of sphene. Minor secondary ferruginisation along cracks and fissures can be seen in addition to the clay developments.

This is a coarse-grained igneous rock that is dominated by plagioclase with minor amounts of quartz. It has been subjected to a cataclastic deformation and there is some retrograde metamorphic effects in the form of epidote.

Sample: 6231 RS 102; TSC40847

Applicant's No.
DJF 30

Rock Name:
Weathered, crenulated, mica-rich gneissic schist

Hand Specimen:
This is a reddish-brown coloured foliated quartzo-feldspathic rock which appears to be deeply weathered. On the cut surface a gneissic texture is evident with discontinuous bands outlining a crenulated fabric. Some of these bands appear to be attenuated earlier fold hinges.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	25
Plagioclase	20
Muscovite	15
Biotite (chloritised)	10
Opaques	2
Zircon	trace
Secondary:	
Sericite	25
Ferruginous staining	3

This is a medium to coarse-grained gneissic schist consisting principally of quartz and plagioclase with lesser muscovite and biotite. The crenulated and attenuated banding noted in hand specimen can be seen to consist of secondary sericite.

Quartz occurs as irregularly-shaped grains of variable grain size with undulose to strongly undulose extinction. Elongate relic grains, lying in the main foliation range in length up to 5 mm. These coarser grains show considerable subgrain development. The plagioclase is more even in grain size, generally occurring as multiply twinned equant to rectangular grains averaging 0.3 mm in diameter.

Biotite appears to be the earlier formed mica with muscovite generally of a slightly younger nature. Alteration of the biotite to chlorite is common and there is also possible replacement of the biotite by muscovite. Both micas predate the main fabric in this rock and are folded together with the foliation, although there are some random orientations evident.

The sericite occurs as massive aggregates, comprising bands up to 5 mm in thickness. Some relict coarser mica developments also occur in these bands together with partly altered feldspar, and these minerals may give rise to some of the sericite. The presence of essentially unaltered plagioclase in juxtaposition with this folded sericite tends to rule out derivation of the sericite from earlier plagioclase. This implies an unknown alumino silicate source.

Irregularly-shaped opaques are present in minor amounts and there are trace amounts of ziron. Late-stage iron staining is consistent with near-surface weathering.

This is a gneissic schist with prominent muscovite and biotite. An early-formed foliation has subsequently been crenulated and the development of sericite after an unknown precursor predates this foliation.

Sample: 6231 RS 103; TSC40848

Applicant's No.
DJF 31

Rock Name:
Finely banded calc-silicate gneiss

Hand Specimen:
This is a finely banded rock consisting of alternating green, pale green, and off-white layers generally less than 1 mm in thickness.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase (including sericite and fine clay secondary developments)	45
Quartz	20
Epidote	20
Actinolite/tremolite	15
Apatite	trace
?Sphene	trace
Zircon	trace

The prominent banding seen in hand specimen is not as clearly evident in thin section. There are some semi-continuous stringers of plagioclase and quartz, and epidote, however, much of the amphibole appears to lie with the long axes at an angle to the compositional layering.

The plagioclase shows variable alteration with some completely replaced by sericite and fine clays. The average grain size is 0.2 to 0.3 mm in diameter. Quartz is of a similar grain size with undulose to strongly undulose extinction and some subgrain developments.

Epidote occurs as colourless to very pale green grains of variable size, ranging up to 5 mm in length. It appears to have been formed early and lies in the main fabric. The amphibole on the other hand seems to have formed after the main fabric, and the long axes of the pale green to colourless actinolite/tremolite are at a low angle to the early fabric. Some fibrous amphibole is present, the bladed to elongate grains range up to 8 mm in length.

Much finer-grained accessory phases are apatite and zircon, with a fine prismatic high relief mineral probably being sphene. The sericite and clays are a secondary development after plagioclase and in part possibly epidote. They would constitute 30 to 35% of the rock.

This is a finely banding calc-silicate gneiss which appears to have early-formed quartz and plagioclase and possibly epidote, with secondary actinolite developed during an amphibolite grade metamorphism postdating the main fabric development.

Sample: 6231 RS 104; TSC40849

Applicant's No.
DJF 33

Rock Name:
Weathered, crenulated gneissic schist

Hand Specimen:
This is a well foliated, weathered gneissic schist with prominent micas on the foliation surface.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	20-25
Plagioclase	20-25
Potassium feldspar	10-15
Biotite	15-20
Sillimanite	5-10
Opaques	2
Zircon	trace
Secondary:	
Kaolinite	5-10
Muscovite and sericite	5
Limonite	3

This rock consists of granoblastic aggregates of quartz and feldspar with poorly aligned stringers and zones of biotite, and lesser sillimanite. A low birefringent clay mineral is associated with the biotite and also occurs as distinct veins.

The quartz occurs as irregularly-shaped grains, with curved to mildly sutured grain boundaries. It ranges in grain size up to 1.5 mm although most are less than 1 mm. The potassium feldspar is finely perthitic with some microcline perthite. It is of a similar grain size to the quartz as is the plagioclase. Both multiply twinned and untwinned plagioclase is evident with minor alteration to sericite in places, and some secondary inclusions of biotite and sillimanite.

The biotite is red-brown to greenish-fawn in colour and individual flakes range up to 1.5 mm in length. Much of the biotite is in a subparallel orientation, except in the hinges of minor folds where somewhat random orientations are evident. Sillimanite is intimately associated with the biotite, commonly occurring as aggregates of fine granules (less than 0.02 mm in diameter) or as stringers of fibrous grains parallel with the biotite foliation. In small scale fold hinges the sillimanite grains can also be seen to have been folded.

The opaques are irregular in outline and range up to 0.8 mm in length. In one fold hinge a single opaque grain exhibits the outline of the fold together with sillimanite and biotite. Zircon and/or monazite are present in trace amounts.

Secondary alteration of the rock has resulted in the development of a very low birefringent clay mineral identified as kaolinite by X-ray diffraction. The kaolinite occurs both as veins and as ?*in situ* alteration of the sillimanite and biotite-rich bands. Limonite staining is associated with the kaolinite in places, possibly resulting from the liberation of iron due to the breakdown of biotite. Muscovite, in part after biotite, and sericite are other secondary phases.

This is a crenulated, sillimanite-bearing, quartz-feldspar-biotite schist that was probably formed through middle amphibolite facies metamorphism of a psammo-pelitic sediment. Two deformations are evident and there has been an intense weathering resulting the formation of kaolinite.

Sample: 6231 RS 106; TSC40851

Applicant's No.
DJF 35

Rock Name:
Hydrothermally-altered calc-silicate

Hand Specimen:

This is a massive, coarsely crystalline rock consisting of pale purple and white coloured segregations. There are trace amounts of a fine-grained blue mineral.

X-ray Diffraction:

Material was collected from each of the three different coloured phases seen in hand specimen. An X-ray powder photograph of the pale blue mineral indicates that this is apatite. X-ray diffraction scan of the white segregations indicates that this is mostly plagioclase, possibly of labradorite or bytownite composition.

Two X-ray diffraction scans of the purple segregations were made. The first indicated that this consists of plagioclase of approximately albite composition, and a mica close to the muscovite pattern, possibly a lithium mica due to the purple coloration. A second scan of another sampling indicates a high muscovite component with accessory albite and prehnite, and possibly some scapolite.

Thin Section:

The thin section was made so as to include both the white and purple coloured segregations. A visual estimate of the constituents present gives the following:

	%
White Segregation:	
Plagioclase	95
Sericite/muscovite	5
Purple Segregation:	
Sericite/muscovite	60
Plagioclase	15
Scapolite	15
Apatite	5
Prehnite	?5

The white coloured segregation consists dominantly of plagioclase. Coarse plagioclase crystals range up to 1 cm in length. There has been a mild to intense cataclastic deformation resulting in considerable recrystallisation of the coarse plagioclase into finer interstitial aggregates and relict coarse grains show subgrain developments and strain shadows. Alteration to fine clays, sericite, and some muscovite is evident, particularly along grain margins where interstitial sericite and muscovite can be seen.

The purple coloured segregation consists mostly of massive aggregates of sericite which appear to have replaced coarse-grained plagioclase. In places ghost multiple lamellar twinning can be seen within and marginal to the sericitic alteration of the plagioclase. The sericite grades into distinctive flakes of muscovite in some areas, the muscovite occurring as aggregates of flakes with individual flakes up to 0.2 mm in length.

Scapolite is a prominent constituent in this thin section occurring as coarse grains up to 5 mm in diameter. It is associated with plagioclase in finer granoblastic aggregates in one patch, the individual grains sizes being of the order of 0.1 mm. The coarser-grained scapolite shows marked alteration to sericite and muscovite.

Apatite is a prominent constituent, occurring as aggregates or stringers in a vein-like form, or as discrete disseminated grains. Individual grain sizes range up to 0.4 mm.

Prehnite was identified in one of the X-ray diffraction scans. This mineral is not obvious in this thin section, but may be present as fine-grained aggregates associated with the sericite, or as ?coarser, fibrous material associated with the alteration of the scapolite.

This is a plagioclase-rich rock, or calc-silicate that has suffered considerable low temperature hydrothermal alteration giving rise to the sericite, scapolite and prehnite.

Sample: 6231 RS 107; TSC40852

Applicant's No.
DJF 36

Rock Name:
Folded sericite schist

Hand Specimen:
This is a well layered gneissic schist which shows prominent folding on the cut surface.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Sericite	60
Quartz	18
Biotite (including chlorite)	10
Muscovite	5
Opaques	2
Zircon	trace

The layering in this rock is a consequence of preferential concentration of quartz, sericite, and mica into discrete bands. The bands have been folded with small parasitic folds common in the limbs. Sericite is the dominant constituent occurring as massive fine aggregates which grade into muscovite in places. The coarser sericite/fine muscovite is aligned in the early fabric and folded together with the compositional layering.

Quartz occurs as discrete elongate grains or in stringers aligned in the folded foliation. It shows undulose extinction, some subgrain developments, and ranges in grain size up to 1.5 mm in length. Much of the quartz has secondary muscovite and sericite inclusions.

Green to green-brown biotite also occurs aligned in the foliation. Individual flakes range up to 0.5 mm in length. Alteration to chlorite is common and in some of the fold hinges there are coarse ragged biotite/chlorite grains.

The muscovite for the most part appears to be of a secondary nature. Whilst some elongate flakes are aligned with the foliation much of the muscovite is rectangular to square in outline and lies with its cleavage traces at a high angle to this early fabric. This implies a secondary origin as the other constituents, for example sericite, quartz and biotite, are all aligned in the early fabric.

There are minor amounts of blocky to anhedral opaques, and elongate and round zircons can also be seen. Some late stage iron staining is preferentially concentrated along the coarse micaceous bands.

This is a strongly folded sericitic schist that appears to have suffered a main fabric forming deformation, followed by a second folding event. Late-stage development of coarse muscovite may reflect a third deformation/metamorphism.

Sample: 6231 RS 108; TSC40853

Applicant's No.
DJF 37

Rock Name:
Intensely deformed sericitic schist

Hand Specimen:
This is an intensely deformed schistose rock with a protomylonitic texture in hand specimen. Attenuated quartzo-feldspathic bands form discontinuous stringers or lenses in a fine dark coloured matrix.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Sericite	50
Muscovite	10
Quartz	20
Biotite/chlorite	15
Opaques	5
Rutile	trace
Zircon	trace
?Apatite	trace

This sample has a very similar mineralogy to sample 6231 RS 107. The protomylonitic texture is not as clearly evident in the thin section due to the presence of a high proportion of sericite. This sericite occurs as fine massive aggregates which grade into fine muscovite in places, with a subparallel alignment.

The quartz occurs as elongate grains with its long axes parallel to the foliation. Indistinct lensoid aggregates are common and the quartz shows undulose to strongly undulose extinction, with some subgrain developments. It ranges in grain size up to 1.5 mm in length.

Relict biotite also lies in the foliation plane with individual flakes up to 1.5 mm in length. The biotite is extensively replaced by muscovite or altered to chlorite. There are patches of late-stage mica development with small radial clusters of chlorite and muscovite. Some of the biotite/chlorite has abundant inclusions of ?rutile, and in many of the micas the cleavage traces are emphasised by fine opaque inclusions. The opaques also occur as minor discrete anhedral grains less than 0.02 mm in diameter. Traces of zircon, rutile, and ?apatite are also present.

This is a strongly foliated sericitic schist with prominent quartz lenses and augen.

Sample: 6231 RS 109; TSC40854

Applicant's No.
DJF 38

Rock Name:
Granitic gneiss with a prominent hematite-quartz band

Hand Specimen:
This is a coarse-grained, red coloured rock which on the cut surface shows a prominent gneissic fabric and some darker coloured compositional banding.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Granitic Component:	
Quartz	45
Potassium feldspar	40
Plagioclase	8
Opaques	5
Muscovite	2
Apatite	trace
Zircon	trace
Hematite Band:	
Hematite	45
Quartz	40
Muscovite	10
Biotite/chlorite	5

This rock is mostly composed of quartz and potassium feldspar with lesser opaques and muscovite. There is a prominent band through the host granitic gneiss which consists of quartz and opaques. Overall the sample has a granoblastic texture.

Within the granitic band the potassium feldspar is perthite and microcline perthite. It ranges up to 3 mm in diameter. Due to a superimposed cataclastic deformation there is abundant finer quartz and feldspar interstitial to and derived from the coarser grains. Some plagioclase is present, showing multiple twinning and mostly occurring in finer interstitial aggregates.

The quartz is of variable grain size, a consequence of the cataclastic deformation. Relict grains may be up to 4 mm in length, however, most have considerable subgrain developments and strongly undulose extinction. This variable grain size gives the rock a seriate texture.

Muscovite is a minor to trace constituent of the granitic component, occurring interstitial to the quartz and feldspar. It is probably of a secondary nature forming from recrystallisation of sericitised feldspar. Within the quartz-rich band muscovite is more prevalent occurring both as coarse flakes and as fine interstitial material. The coarse flakes range up to 3 mm in length and show deformation kink banding. In places there are opaque grains with cores of quartz, and interstitial to the quartz and opaques there is a fine rim of muscovite in a form of corona development.

Within the granitic component the opaques occur as anhedral elongate grains up to 4 mm in length. Within the quartz and opaque-rich band they form a semi-continuous interconnected framework with interstitial quartz and muscovite as noted above. Using oblique reflected light it can be seen that the predominant opaque phase is hematite with some limonite, and possibly leucoxene in younger cracks and joints.

There are trace amounts of zircon and apatite. One prominent zircon grain is 0.3 mm in length.

This appears to be a deformed granitic rock with some compositional bands in the form of quartz and hematite.

Sample: 6231 RS 110; TSC40855

Applicant's No.
DJF 39

Rock Name:
Granodiorite gneiss

Hand Specimen:
This is a grey coloured gneiss with a moderate mafic content and prominent megacrysts of feldspar. These feldspar megacrysts have been strung out in the foliation resulting in a partial augen texture.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	30
Quartz	25
Biotite	20
Potassium feldspar	15
Apatite	1
Zircon	1
Opaques	1
Secondary:	
Sericite	5
Muscovite	3
Limonite	1

This rock has an equigranular granoblastic texture. It has a prominent foliation arising from the parallel alignment of elongate quartz and feldspar grains, coincident with the preferential concentration and alignment of biotite.

The prominent megacrysts noted in hand specimen are mostly microcline perthite ranging up to 2 mm in length in this thin section. Some plagioclase also occurs as megacrysts. The plagioclase is both multiply twinned and untwinned and is oligoclase to andesine in composition. Alteration of the plagioclase to sericite and fine clays is variable in extent but common. The plagioclase has an average grain size of 0.3 to 0.5 mm.

Quartz is of variable grain size with undulose to strongly undulose extinction and considerable subgrain developments. Grain margins are curved to mildly serrated and the average grain size is similar to that of plagioclase.

Dark green-brown biotite occurs as flakes in parallel alignment. Individual flakes range up to 1 mm in length. There are minor but prominent amounts of zircon associated with the biotite, and some apatite. Apatite also occurs as discrete single grains in the quartzo-feldspathic material. Replacement of the biotite by muscovite can be seen in places. Blocky to anhedral opaques occur in trace amounts. There is some secondary limonite developed along grain margins in addition to the sericite and fine clays.

This is a gneissic rock of granodiorite composition with a moderate biotite content. It was probably formed through intense deformation of a clay-rich sediment or alternatively could have been formed from a biotite-rich granitoid.

Sample: 6231 RS 111; TSC40856

Applicant's No.
DJF 40

Rock Name:
Amphibolite

Hand Specimen:
This is a mafic, well-foliated, medium-grained rock which also has a prominent lineation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Hornblende	60
Plagioclase	10
Quartz	5
Epidote	2
Apatite	trace
Opaques	1
Secondary:	
Sericite (and fine clays)	18
Chlorite	4

This rock dominantly consists of aligned elongate hornblende and variably altered plagioclase giving rise to the prominent foliation seen in hand specimen. The main fabric is cut by several thin zones of intense deformation and partial recrystallisation, and there are some quartz-rich zones or veins.

The hornblende is pale green to olive-green in colour. In places it shows a well developed amphibole cleavage. Individual elongate grains range up to 2 mm in length with most being between 0.5 and 1 mm. Grain margins are irregular with inclusions of plagioclase and altered plagioclase and there appears to be some alteration to chlorite.

The plagioclase is commonly strongly altered to sericite and fine clays. Some relict plagioclase does show multiple lamellar twinning. The plagioclase has an average grain size of 0.5 mm in length. Fine granular aggregates of epidote can also be seen to have formed at the expense of plagioclase. There is some coarser epidote, up to 0.5 mm in length, associated with the hornblende.

Minor amounts of quartz occur as discrete grains of similar size to the plagioclase, with undulose extinction. The quartz is also found in thin veins, commonly less than 0.2 mm in thickness. Irregularly-shaped opaques and traces of apatite can also be seen.

This is a well-foliated/lineated amphibolite that was probably formed through middle amphibolite grade metamorphism of a mafic igneous rock or calc-silicate sediment. There has been subsequent low retrograde metamorphism with the development of epidote and sericite, and some late-stage minor shearing.

Sample: 6231 RS 112; TSC40857

Applicant's No.
DJF 41

Rock Name:
Well-foliated, magnetite-bearing, tremolite rock or jade

Hand Specimen:
This is a well-foliated, fine-grained green rock with prominent white spots, approximately 1 mm in diameter, encircling opaque cores. These opaque cores are strongly magnetic.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	90
Opaques (including magnetite)	5
Clays	5
Apatite	trace
Biotite	trace
Zircon	trace

This sample is dominated by fine-grained fibrous tremolite which for the most part has a subparallel alignment, giving rise to the well-foliated nature of the hand specimen. The fine tremolite has an average grain size of less than 0.03 mm. Coarse tremolite knots and veins are also present, with individual coarse fibrous aggregates ranging up to 0.5 mm in length. Some ghost domainal textures are evident, however, most of the fibrous tremolite appears to have crystallised in the schistosity plane thereby obliterating earlier textures. The veins are oblique to the schistosity and appear to have developed in the axial planes of small scale crenulations. These veins consist entirely of coarser tremolite and up to 0.3 mm in width. In one area the veins exhibit a type of ptygmatic folding. Clouding of the tremolite is common in places and this appears to be due to alteration to clays.

Subhedral to euhedral early-formed opaques are a prominent constituent and are probably magnetite. These opaques have remained competent during deformation and the schistosity can be seen to wrap around. Some of the opaques have an envelope of extremely fine-grained alteration products which are probably clays. These clayey envelopes are the white spots noted in hand specimen. Secondary opaque phases are very irregular in outline and some occur along cracks subparallel with the foliation.

Round to elongate grains of apatite occur in accessory amounts. Several patches of poorly formed brown to fawn coloured biotite can be seen, and there are trace amounts of zircon.

This is a foliated tremolite rock that has a moderate magnetite component. The early-formed foliation has been crenulated and in places there are veins of coarser tremolite developed in the axial planes.

Sample: 6231 RS 113; TSC40858

Applicant's No.
DJF 42

Rock Name:
Tremolite rock or jade

Hand Specimen:
This is a fine-grained, dark green coloured rock with prominent circular to ovoid patches of coarser material which range up to 5 mm in diameter. On the weathered surface there appears to be an indistinct foliation.

Thin Section:
A visual estimate of the constituents present gives the following:

		%
Tremolite	- fine	70-75
	- coarse	20-25
Opaques		2
Apatite		1
Zircon		trace

This sample is almost entirely composed of tremolite but in two distinct grain sizes. It occurs as a host of fine-grained colourless amphibole with an average grain size of less than 0.05 mm. The fine material is usually fibrous in nature with generally radiating clusters in random orientation, although in places there is a weak alignment of this fibrous material.

Coarser-grained tremolite comprises the prominent patches seen in hand specimen. Here the tremolite ranges in grain size up to 1 mm in length and the long axes of the tremolite is usually orientated in one of two directions either at approximately 60° or at 90° to adjacent tremolite. The coarse patches also contain fine tremolite aggregates which appears to have formed at the expense of the coarser tremolite, although there is evidence to suggest that the converse has also occurred. Some of the smaller patches of coarser tremolite have a core entirely composed of fine tremolite with a halo of coarse tremolite.

Apatite occurs as discrete elongate, round grains ranging up to 0.2 mm in length. Traces of zircon can also be seen. Opaques and/or fine clays occur as very fine-grained developments along cracks through the sample.

This is a tremolite rock or jade which shows two forms of tremolite development. Possible early-formed coarser tremolite aggregates appear to be degrading into finer tremolite.

Sample: 6231 RS 114; TSC40859

Applicant's No.
DJF 43

Rock Name:
Folded quartzo-feldspathic gneiss

Hand Specimen:
This is a medium- to coarse-grained, layered quartzo-feldspathic gneiss which shows open folding of the layering.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	25-30
Plagioclase	25-30
Potassium feldspar	20-25
Biotite	10-15
Muscovite/sericite	5
Opaques	3
Zircon	2
Apatite	trace

This sample has an equigranular granoblastic texture and consists of bands of biotite-rich and quartzo-feldspathic-rich material giving rise to the layering noted in hand specimen.

Both potassium feldspar and plagioclase are present with the plagioclase being slightly more abundant. Multiply twinned and untwinned plagioclase can be seen with an oligoclase composition evident. The plagioclase ranges in grain size up to 1.5 mm in length. Grain shapes are elongate with curved to irregular grain margins and some myrmekitic intergrowths. There is minor alteration to fine clays and sericite. The potassium feldspar is microcline and microcline perthite. It ranges in grain size up to 3 mm and tends to occur more as coarser elongate grains aligned in the layering.

The quartz is of variable grain size ranging up to 3 mm in length. It shows undulose to strongly undulose extinction, with the coarser grains having subgrain developments and more irregular grain shapes.

The biotite is fawn to red-brown in colour with abundant pleochroic haloes around zircon inclusions. Discrete, zoned zircon grains also occur together with the biotite-rich layers. The biotite flakes commonly lie between 0.3 and 0.6 mm in length. There does not appear to be any realignment of the biotite in the axial planes of the folds. In places fine flakes of muscovite occur interstratified with, and replacing, the biotite. Fine muscovite and sericite rims much of the biotite.

Opaques are irregular in outline and preferentially concentrated with the biotite. Zircon and possibly monazite are prominent accessory phases and there is a trace of apatite.

This is a well layered gneiss of granodioritic composition. The high zircon and biotite content suggests derivation from a sedimentary rock.

Sample: 6231 RS 115; TSC40860

Applicant's No.
DJF 44

Rock Name:
Tremolite rock or jade

Hand Specimen:
This rock has a thin brown weathering skin. On the cut surface it can be seen to be a pale to dark green coloured, very fine-grained rock which is generally massive.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
Fine clays	3
Apatite	2

This sample is composed dominantly of fine-grained tremolite with some relict coarse tremolite and a few scattered grains of apatite. The fine tremolite appears to be optically continuous in domains which range in size up to 6 or 7 mm in diameter. Some of these domains shows a ghost twinning structure. Elsewhere patches of coarse tremolite development can be seen to be partially to almost completely replaced by fine tremolite. This fine tremolite has an average grain size of less than 0.05 mm and commonly occurs as fibrous aggregates mostly in random orientation. In some areas there is a weak alignment of the fibrous tremolite. Apatite occurs as round elongate grains up to 0.3 mm in length. There is some clouding of the tremolite and fine-grained material developed along cracks probably consists of fine clays.

This is a tremolite rock or jade that shows an earlier coarse-grained texture replaced by massive aggregates of fine fibrous tremolite.

Sample: 6231 RS 116; TSC40861

Applicant's No.
DJF 45

Rock Name:
Tremolite rock or jade

Hand Specimen:
This sample has a 1 to 3 mm thick brown weathering skin. On the cut surface the fresh rock can be seen to be very fine-grained and dark green in colour.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
Clays	3
Apatite	2

This sample almost entirely consists of fine-grained tremolite with minor apatite, and dust-like inclusions near the weathering surface. The fine fibrous tremolite has an average grain size of less than 0.05 mm in length. It shows optical continuity in domainal structures which relate to earlier crystalline material. Ghost multiple lamellar twinning is apparent in some of these domains. The domains range up to 5 mm in length. Coarser-grained tremolite, up to 0.5 mm in length, occurs in a vein which has indistinct margins, and a moderate proportion of fine tremolite. Apatite occurs as ovoid-shaped, discrete grains which range up to 0.3 mm in length. The sample has late-stage fine cracks and fissures which appear to be filled with clays. These clays also occur as a clouding of the tremolite in the weathering skin.

This is a fine-grained tremolite rock or jade. Relict domainal structures indicate an early coarse-grained precursor prior to the development of the fine tremolite. Some of the fibrous tremolite shows an indistinct parallel alignment.

Sample: 6231 RS 117; TSC40862

Applicant's No.
DJF 46A

Rock Name:
Weathered diopside quartz rock

Hand Specimen:
This is a deeply weathered sample consisting of coarse-grained quartz with cream coloured ?diopside. The diopside forms coarse radial, columnar structures on one surface of the hand specimen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	40
Diopside	5
Tremolite/actinolite	2
Potassium feldspar	5
Plagioclase	5
Apatite	trace
Zircon	trace
Secondary:	
Clays	30-35
?Chlorite	5-10
Muscovite	3
Calcite	trace

This is a moderately deformed metamorphic rock consisting dominantly of quartz and the alteration products of ?diopside. The original pre-weathering texture appears to have been inequigranular granoblastic aggregates of quartz and diopside. The quartz ranges in grain size up to 3 mm in length. It shows undulose to strongly undulose extinction, considerable subgrain developments and sutured to cuspate grain margins. Most quartz grains are elongate and aligned in the foliation. More equant, generally ovoid grains of feldspar occur together with the quartz. Cross-hatch twinned microcline and multiply twinned plagioclase are both evident, ranging in grain size up to 0.3 mm.

The other main constituent of this rock has been extensively altered to a fine, very low birefringent clay ?kaolinite and in patches radiating fibrous aggregates of chlorite. There are some remnant grains of clinopyroxene ?diopside, and these suggest that the bulk of the altered material was similar in composition,and approximately similar grain size as the quartz. Associated with the diopside there are some fine tremolite/actinolite aggregates and discrete elongate grains. Other primary phases present in trace amounts are apatite and zircon, with some zoned zircon grains evident.

Apart from the more dominant clays and chlorite, other secondary phases present in minor to trace amounts are muscovite, sericite, and rare late-stage calcite.

This is a diopside quartz rock that was probably formed through middle amphibolite facies metamorphism of a siliceous dolomitic marble. A late-stage weathering/hydrothermal alteration has led to extensive breakdown of the pyroxene.

Sample: 6231 RS 118; TSC40863

Applicant's No.
DJF 46B

Rock Name:
Partly mylonitised, sericitic quartzo-feldspathic gneiss

Hand Specimen:
This is a pale pink coloured quartzo-feldspathic gneiss with medium-grained quartzo-feldspathic rich layers and finer ?micaceous bands.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	30
Sericite	25
Quartz	20
Chlorite	10
Biotite	5-7
Muscovite	5-7
Opaques	2
Zircon	trace

This sample consists of quartz and plagioclase-rich, and sericite and biotite-rich bands. Within and adjacent to the micaceous bands there is a prominent mylonitic texture with the quartz and feldspar considerably strung out in the foliation planes. In the adjacent quartzo-feldspathic bands there is a more granoblastic texture with elongated grains not as intensely deformed.

The quartz occurs both as ribbon-like aggregates and disseminated grains. The ribbons consist of several elongate grains with subgrain developments and undulose extinction, possibly representing original single grains. Elsewhere the quartz is more irregularly-shaped with ragged to curved margins. There are some finer more ovoid quartz grains associated with the plagioclase.

The plagioclase commonly occurs as elongate grains up to 1.5 mm in length. Much of the plagioclase is untwinned and clouded by fine dust-like inclusions, ?clays. There is some twinned plagioclase and also some antiperthitic segregations.

The sericite forms most of the fine micaceous bands noted in hand specimen. It grades into fine muscovite but is mostly less than 0.04 mm in diameter. Where the coarser sericite/fine muscovite is developed it is orientated at a high angle to the mylonitic fabric.

Biotite occurs in stringers together with the sericite. Individual flakes range up to 1.5 mm in length, and many have fine opaque inclusions along the cleavage traces. Alteration to chlorite is common as is replacement by muscovite. Muscovite also occurs in the quartzo-feldspathic bands interstitial and replacing the feldspar.

Zircon is a prominent accessory phase and many of the elongate grains are zoned. The opaques mostly occur as fine inclusions within the micas.

This is a sericitic quartzo-feldspathic gneiss with a mylonitic texture. It was probably derived through intense deformation of a mica-rich granitoid or psammo-pelitic sediment.

Sample: 6231 RS 119; TSC40864

Applicant's No.
DJF 47

Rock Name:
Folded, biotite-rich granodioritic gneiss

Hand Specimen:
This is a grey coloured, coarse-grained, mica-rich gneiss with openly folded quartzo-feldspathic and mica-rich layers.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	25-28
Plagioclase	20-25
Potassium feldspar	15
Biotite	15-20
Muscovite	5-10
Sericite	10
Opaques	1
Zircon	1
Apatite	trace

The layering seen in hand specimen is a consequence of the alignment and concentration of biotite and lesser muscovite, and quartz and feldspar into layers. A layer parallel schistosity is also evident and both the layering and schistosity have subsequently been folded.

The quartz show a wide range of grain sizes up to coarse elongate grains greater than or equal to 5 mm in length. The coarse-grained quartz shows considerable subgrain developments, undulose extinction, and curved to sutured grain margins. Partial to complete recrystallisation has resulted in finer-grained interstitial quartz with some mosaics.

The feldspar is generally finer-grained with microcline and microcline perthite not as prevalent as plagioclase. Grain margins to the feldspars are similarly sutured and together with the quartz they give the rock a granoblastic, inequigranular, amoeboid texture. Both twinned and untwinned plagioclase are present, there is some myrmekite, and some alteration to sericite.

The olive-brown to green-brown biotite lies mostly with its long axes in the foliation/compositional layering, although there is some scatter of orientations about this fold plane. Individual flakes range up to 1.5 mm in length, and there are prominent pleochroic haloes around the abundant zircon inclusions. Muscovite is associated with the biotite, and also occurs aligned with the foliation. Whilst the muscovite appears to have replaced some of the biotite its orientation indicates that this is an early development.

Apatite, zoned zircon, and opaques occur in accessory amounts.

There has been substantial development of sericite, in preference along the micaceous-rich bands. The sericite forms massive aggregates with individual flakes in random orientation within the sericite bands following the folded fabric. It also occurs as a secondary interstitial phase along grain margins in the quartzo-feldspathic bands.

This is a sericitised, folded, biotite-rich gneiss of granodioritic composition.

Sample: 6231 RS 120; TSC40865

Applicant's No.
DJF 48

Rock Name:
Veined tremolite rock

Hand Specimen:
This is a massive, pale green coloured rock which has a sugary texture. There is a 0.5 to 1 cm thick vein of coarser fibrous material.

X-ray Diffraction:
X-ray diffraction scans of the fibrous vein material and the host indicate that both phases are a monoclinic amphibole probably tremolite.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	95
Clays	5

This sample consists mostly of fine fibrous aggregates of a colourless amphibole which has been identified as tremolite by X-ray diffraction scans. The average grain size is of the order of 0.02 to 0.04 mm, with a gradation of the fine material into coarser amphibole. In places there is a subparallel alignment of the fibrous aggregates, giving the rock an indistinct foliation. As with other tremolite rocks from this province there is a relict domainal texture seen in the fine tremolite.

Coarser euhedral amphibole crystals are a secondary development in the fine host tremolite. These are often prismatic to needle-like in shape and range up to 1.5 mm in length. This amphibole has a marked higher relief than the host tremolite and there may be subtle chemical differences.

The coarser-grained fibrous vein noted in hand specimen also consists of tremolite. Individual grains range up to 5 mm in length, each consisting of very fibrous amphibole. Probably associated finer veins are also evident through the host tremolite. Alteration of the amphibole to pale brown, fine clay material is a late-stage development.

This is a tremolite rock that has coarse veins also consisting of tremolite.

Sample: 6231 RS 121; TSC40867

Applicant's No.
DJF 50

Rock Name:
Intensely deformed sericitic schist

Hand Specimen:
This is a grey-green coloured, strongly foliated rock with a protomylonitic texture. Coarse micas are prominent on the schistosity surface.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Sericite	60
Muscovite	15
Chlorite	15
Biotite	5
Plagioclase	5
Zircon	trace
Opaques	trace
?Epidote	trace
?Altered sphene	trace

The highly deformed nature of this rock is somewhat masked in thin section by a high proportion of sericite. The mylonitic to protomylonitic fabric is expressed by attenuated biotite and chlorite-rich bands, augen of granular ?sphene and opaques, and some very elongate plagioclase aggregates. A second fabric formed at a high angle is expressed by the development of muscovite.

Sericite forms the bulk of this rock grading into fine muscovite in places. Fine massive aggregates have an average grain size of less than 0.04 mm in diameter. The sericite/fine muscovite mimicks the mylonitic fabric in broad terms, however, on the finer scale the fine muscovite lies in a somewhat random orientation. Coarser muscovite, with individual flakes up to 1 mm in length, lie oblique and parallel to the main foliation. Those oblique appear to be subparallel indicating a second deformational phase.

Biotite appears to have been the early-formed mica. It lies in the main fabric with individual flakes up to 1.5 mm in length. Most of the biotite has now been replaced by chlorite. Chlorite also occurs interstitial to plagioclase in a prominent plagioclase-rich augen. Here the chlorite occurs as bundles of flakes in radial arrays. This chlorite appears to be secondary in nature and may be coeval with late-stage veins and coarse-grained patches which consist almost entirely of chlorite.

The plagioclase occurs as aggregates which have an overall augen-shape lying in the foliation planes. Within the augen or lenses the plagioclase ranges in grain size up to 4 mm, although most is less than 2 mm. There has been some recrystallisation of the coarser plagioclase into finer more equant grains. Antiperthitic exsolution features, multiple lamellar twinning, and minor alteration to sericite are common.

The opaques occur as elongate discontinuous aggregates in the foliation, ranging up to 2 mm in length. Some of these lenticular aggregates appear to be a titania-rich phase possibly after sphene. Zircon is a prominent accessory phase occurring as zoned elongate and round grains. There is some late-stage mylonitic staining and there may be some epidote.

This is a sericitic schist that has suffered one major deformational event with a minor younger fabric also evident.

Sample: 6231 RS 122; TSC40869

Applicant's No.
DJF 52

Rock Name:
Weakly foliated tremolite rock or jade

Hand Specimen:
This sample has a 1 to 4 mm thick red-brown weathering skin which appears to show an indistinct foliation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	97
Clays	3
?Epidote	trace

The indistinct foliation noted in hand specimen is expressed in thin section by a parallel alignment of elongate coarser tremolite and fibrous tremolite. These coarser remnant grains range up to 2 mm in length and can be seen to be replaced by massive aggregates of fine tremolite. There is a gradation in grain sizes from the coarse tremolite down to the fine massive aggregates of fibrous grains which average 0.01 mm in diameter.

In places there are fine clots of high relief material which may be epidote. The sample has some cracks which appear to be filled with fine clays.

This is a tremolite rock or jade which has remnant coarser tremolite aligned in a foliation. Subsequent recrystallisation give rise to massive aggregates of fine fibrous tremolite.

Sample: 6231 RS 123; TSC40870

Applicant's No.
EAD 134

Rock Name:
Amphibolite

Hand Specimen:
This is a black, medium-grained rock with a prominent foliation and lineation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Hornblende	55-60
Plagioclase	5-10
Quartz	10
Opaques	1
Epidote	trace
Zircon	trace
Secondary sericite and clays	25

A parallel alignment of elongate hornblende gives the rock its prominent foliation/lineation. The hornblende is bright green to olive-brown in colour and ranges in grain size up to 1.5 mm in length. Grain margins are straight to curved, and there are many triple point junctions between adjacent hornblende grains.

The plagioclase is finer-grained and interstitial to the hornblende. It has an average grain size of 0.2 to 0.3 mm. Rare multiply twinned grains can be seen, but most of the plagioclase is altered to sericite and fine clays, and in some instances epidote.

Quartz is of a similar grain size to the plagioclase occurring as elongate to round grains, with curved grain margins and straight to slightly undulose extinction.

The opaques are blocky to irregular in outline. They range up to 0.3 mm in length, with most less than or equal to 0.1 mm. Zircon is present in trace amounts, occurring as inclusions within the hornblende giving rise to pleochroic haloes.

This is a well-foliated amphibolite that was probably formed through middle amphibolite facies metamorphism of a mafic igneous rock or possibly a calcareous sediment. The prograde metamorphism seems to have reached equilibrium as evidenced by the triple point junctions. A subsequent low-grade alteration gives rise to sericite after plagioclase.

Sample: 6231 RS 124; TSC40871

Applicant's No.
EAD 152

Rock Name:
Tremolite rock or jade

Hand Specimen:
This sample has a strongly weathered surface which shows an indistinct foliation. On the cut surface it can be seen a mottled dark green and pale green coloured rock.

Thin Section:
A visual estimate of the constituents present gives the following:

		%
Tremolite	- coarse	35-40
	- fine	60-65
Clays		4
Limonite		1
Opaques		trace
Apatite		trace
?Biotite		trace

This sample dominantly consists of tremolite in two distinct grain sizes. The coarse tremolite occurs as euhedral prismatic grains which range up to 3 mm in length. These tend to have a weak alignment in thin section. More irregularly-shaped coarse-grained tremolite occurs in aggregates and veins. Within a specific aggregate or vein the orientation of the cleavage traces is consistent, but not necessarily from one aggregate to the next. The coarse tremolite in the aggregates is distinct from the euhedral prismatic grains in that it appears to be replaced at its margins by finer tremolite giving rise to ragged grain margins.

The fine tremolite consists of massive aggregates of fibrous material, with an average grain size of 0.01 mm in length. Within these aggregates there is a coarse domainal structure consistent with derivation of the fine tremolite from earlier coarser tremolite.

Some brown micaceous material is found in association with the coarse tremolite and this may be biotite. Trace amounts of opaques and apatite can also be seen. Alteration to fine clay material is evident along prominent cracks through the sample. Some limonite occurs in association with this alteration.

This is a tremolite rock or jade which appears to show three stages of tremolite development. Early coarse tremolite recrystallises to fine fibrous aggregates. Euhedral prismatic tremolite is of uncertain age.

Sample: 6231 RS 125; TS40872

Applicant's No.
EAD 155

Rock Name:
Coarse tremolite rock with secondary epidote

Hand Specimen:
This is a coarse-grained green coloured rock which has some prominent bright green epidote segregations and veins. The rock is generally massive.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	80-85
Epidote	5
Opaques	2-5
Clays	8-10
Apatite	trace
Calcite	trace

This sample consists principally of elongate coarse-grained tremolite with prominent secondary epidote. The tremolite ranges in grain size up to 3 mm in length and is generally in random orientation. Within many of the coarser tremolite grains there is a clear colourless core which does not show any obvious cleavage. This core is usually surrounded by clouded, well-cleaved amphibole which is in optical continuity with the core. The clouded material appears to be slightly altered amphibole, ?clouded by fine inclusions of clay phases. In places there may be small amounts of ?plagioclase which have been replaced by amphibole through a metasomatic process.

The pale bright green coloured epidote is clearly secondary in nature, and occurs in discrete zones or veins. Individual grains tend to be elongate and prismatic, ranging in length up to 3 mm. More equant granular aggregates of epidote can also be seen.

Trace amounts of apatite occur as a primary phase ranging in grain size up to 0.2 mm. The opaques, however, are mostly of a secondary nature occurring as very fine granular material probably formed at the same time as the clay. Some limonitic developments are of a minor extent and there are very late-stage calcite grains found interstitial to the tremolite.

This is a tremolite rock with prominent secondary epidote. Early-formed more massive tremolite appears to have partly degraded into more fibrous tremolite with minor clay developed.

Sample: 6231 RS 126; TSC40873

Applicant's No.
EAD 156

Rock Name:
Quartz and opaque-bearing actinolite schist

Hand Specimen:

This is a foliated, generally fine-grained, dark green to black coloured rock with prominent thin quartz veins or bands. On the cut surface warping of the foliation/veining can be seen.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Actinolite	55
Quartz	20
Opaques	20
Hornblende	1
Apatite	trace
Clays	3
Limonite	1

The foliated nature of this rock is expressed in thin section by a parallel alignment of elongate amphibole and quartz. A pale green coloured amphibole dominates and occurs both as coarser, relatively clear grains and as finer, clouded fibrous grains. This amphibole is probably actinolite in composition. The coarser clear actinolite ranges in grain size up to 5 mm in diameter for some relict grains which in places show prominent cleavage and rare twinning. Much of this earlier-formed actinolite has recrystallised into finer fibrous material with an average grain length of 0.3 to 0.6 mm. The fibrous amphibole is clouded by fine dust-like inclusions and opaques. The opaques rim many grains and also occur along relict cleavage traces, presumably a relict of the earlier amphibole. These opaques are very irregular in outline. Coarser discrete, blocky opaques are also present and range in grain size up to 0.6 mm in length.

Within the cores of some of the coarse actinolite trace amounts of hornblende can be seen. This hornblende is optically continuous with the surrounding actinolite and this implies a retrogradation of the hornblende to actinolite. Elsewhere trace amounts of discrete hornblende can be seen and these probably represent relict unaltered material.

The quartz occurs as irregularly-shaped elongate grains ranging up to 5 mm in length. It occurs in stringers or veins through the sample, parallel with the foliation. Grain margins are curved to cuspate and most grains show undulose to strongly undulose extinction with subgrain developments. Some of the quartz grains have a thin corona-like rim of actinolite, orientated perpendicular to the grain margins and oblique to the more general foliation shown by juxtaposed actinolite.

Trace amounts of apatite are present. There is prominent orange-brown limonite developed along late-stage cracks through the sample. Some of this also occurs interstitial to the fibrous amphibole together with fine clays.

This is a quartz and opaque-bearing actinolite schist that was probably derived through amphibolite facies metamorphism of a siliceous dolomitic limestone. Possibly early prograde hornblende has been replaced by actinolite which has subsequently recrystallised into a more fibrous amphibole.

Sample: 6231 RS 127; TSC40874

Applicant's No.
EAD 160

Rock Name:
Biotite-quartz gneiss with pegmatite vein

Hand Specimen:
This is a grey to dark grey coloured quartz-rich gneiss which has a pegmatite-like vein on one side. The pegmatite contains very coarse biotite flakes which are up to 2 to 3 cm in diameter.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Host Gneiss:	
Quartz	75-80
Biotite	10-15
Plagioclase	5
Sericite	5
Muscovite	1
Opaques	trace
Apatite	trace
Zircon	trace
Vein:	
Plagioclase	40-45
Quartz	30-35
Biotite	20-25
Sericite/muscovite	1

The host gneiss in this sample consists mostly of elongate quartz with lesser biotite in a prominent schistosity. The quartz occurs as variably recrystallised coarse grains, with relict grains exceeding 5 mm in length. Undulose to strongly undulose extinction, considerable subgrain developments, and curved to cuspate grain margins typify the quartz.

The biotite is fawn to brown in colour, with individual flakes up to 2 mm in length. Some of the biotite shows curved or kink deformational features. The muscovite is present as a primary metamorphic phase.

The plagioclase is a minor constituent, varying in grain size up to 3 mm. Most grains are clouded or show alteration to sericite and fine muscovite. The sericite also tends to rim some of the biotite. Other constituents present in trace amounts are apatite, zircon, and opaques.

The pegmatite vein consists principally of very coarse-grained plagioclase and biotite with finer interstitial quartz. The plagioclase grains are up to a centimetre or so in length, show multiple lamellar twinning, and some alteration to sericite and muscovite with minor secondary biotite. The coarse nature of the primary biotite can be seen in hand specimen. The quartz appears to represent recrystallised interstitial material.

This is a biotite-quartz gneiss that was probably derived through middle amphibolite facies metamorphism of a very siliceous sediment or quartzite. The pegmatite vein was developed post-deformation as the biotite does not appear to be preferentially aligned.

Sample: 6231 RS 128; TSC40875

Applicant's No.
EAD 163A

Rock Name:
Granodiorite gneiss

Hand Specimen:
This is a red-coloured, medium to coarse-grained granitoid with a distinct foliation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	60
Quartz	20-25
Biotite	5-10
Potassium feldspar	5
Muscovite	1
Opaques	1
Zircon	trace
Secondary clays and limonite	3

This sample has an inequigranular granoblastic texture. Coarser core grains of plagioclase are surrounded by generally finer quartz and plagioclase aggregates. The coarser plagioclase ranges in grain size up to 2 mm in length, and is aligned with its long axes in the foliation. It shows multiple lamellar twinning, some myrmekitic intergrowths, and is of an andesine composition. Plagioclase feldspar is a minor constituent with microcline evident as finer interstitial grains.

Some of the quartz is of a similar grain size as the coarse plagioclase and shows prominent subgrain developments. For the most part, however, the quartz is less than or equal to 0.5 mm in diameter. It shows undulose to strongly undulose extinction and curved to cuspate grain margins.

The biotite occurs as discontinuous stringers in the foliation planes. It is fawn to deep green-brown in colour and ranges up to 0.6 mm in length. There is alteration/replacement of the biotite by muscovite and possibly some chlorite.

The opaques are generally very irregular in outline and range up to 1 mm in length. They are of a secondary nature and can be seen encircling biotite and plagioclase. There is also some limonitic developments along grain margins together with some fine clays.

This is a granodioritic gneiss that was probably formed through amphibolite facies metamorphism of a granodiorite.

Sample: 6231 RS 129; TSC40876

Applicant's No.
EAD 163B

Rock Name:
Biotite-bearing amphibolite

Hand Specimen:
This is a well-foliated, medium-grained, dark green to black rock. On the foliation surfaces coarse flakes of mica are prominent.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Hornblende	45
Plagioclase	40
Quartz	5
Biotite (and ?muscovite)	5
Opaques	1
Secondary sericite (fine clays)	4
Limonite	trace

The well-foliated nature of this rock is a consequence of the parallel alignment of elongate hornblende and plagioclase, and biotite. The hornblende is pale green to aqua-green in colour. It has a well developed amphibole cleavage and ranges in grain size up to 1.5 mm in length.

The plagioclase is slightly finer-grained than the hornblende with an average grain size of 0.3 to 0.6 mm. Multiply twinned plagioclase is common and it is of an andesine (to labradorite) composition. Alteration of the plagioclase to sericite and some fine clays is variable but quite extensive in places.

Biotite is a distinctive constituent of this rock, it is pale brown to golden-brown in colour and the flakes are generally aligned in the foliation, with some appearing to be warped. Individual flakes are commonly between 0.5 and 1 mm in length. Some finer biotite occurs interstitial to the hornblende, and appears in part to be replacing it together with some sericite/fine muscovite.

Quartz occurs as discrete grains or grouped into short bands in the foliation. It ranges in grain size up to 1 mm, shows undulose extinction, and curved grain margins.

The opaques are blocky to anhedral in outline with an average grain size of 0.1 mm in diameter. Small amounts of limonitic staining along grain margins are evident.

This is a biotite-bearing amphibolite that was probably formed through middle amphibolite facies metamorphism of a mafic igneous rock or possibly a calcareous iron-rich sediment. The prograde metamorphic assemblage was probably hornblende, plagioclase, opaques, and/or quartz, with secondary metamorphism giving rise to the biotite.

Sample: 6231 RS 130; TSC40877

Applicant's No.
EAD 165

Rock Name:
Altered dolerite

Hand Specimen:
This is a greenish-brown coloured, medium to fine-grained rock which is generally massive with no obvious foliation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	40
Opaques	8
Hornblende	5
Clinopyroxene	5
Biotite	2
Secondary:	
Sericite (and fine clays)	15-20
Limonite	10-15
Chlorite	5-10
Epidote	trace

The primary igneous texture is still evident in thin section, however, much of the primary ferromagnesian phases have been extensively altered. The plagioclase is moderately altered and randomly oriented laths are a prominent igneous feature. Individual plagioclase laths range up to 1 mm in length with most less than or equal to 0.3 mm. Alteration to sericite is variable with unaltered plagioclase evident in some places whilst in others sericite predominates.

Relict primary igneous clinopyroxene crystals can be seen and some early-formed hornblende and ?biotite are present. These phases occur interstitial to and enclosing the plagioclase giving the rock a subophitic texture. The grain size of these ferromagnesian minerals is similar to the finer plagioclase material. Blocky opaques are the other primary phase evident. These are also interstitital to the plagioclase and have an average grain size of 0.1 to 0.15 mm in diameter.

Apart from the sericite the other dominant secondary minerals are chlorite and limonite. The chlorite is formed at the expense of the above ferromagnesian phases and the secondary limonite occurs together with the chlorite, as well as forming thin veins through the sample, and staining most grain margins. Trace amounts of epidote have been observed.

This is a dolerite that has been subjected to an intense weathering resulting in a high proportion of sericite, chlorite, and limonite. Whilst the rock is intensely weathered there is little evidence of deformation and the primary igneous texture is preserved.

Sample: 6231 RS 131; TSC40878

Applicant's No.
EAD 167

Rock Name:
Ferruginised, quartz-sericite-plagioclase schist

Hand Specimen:
This sample has a prominent red coloration in hand specimen. It is a well-foliated, coarse-grained rock.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	25
Quartz	20
Sericite	20
Secondary iron oxides	10
Muscovite	5
Biotite	5
?Kaolinite	5
Zircon	trace

The well-foliated nature of this sample can be seen in the thin section to be a consequence of parallel aligned sericite-rich bands and coarser, more massive plagioclase and quartz-rich bands.

The sericite-rich bands have in part developed at the expense of earlier-formed coarser micas in a similar orientation. Some relict biotite flakes are present, ranging up to 1 mm in length. These are replaced by muscovite and/or sericite, or have been altered to clay material ?kaolinite. Some fine muscovite also occurs together with the sericite, most probably representing a prograde development from that mineral.

The sericite-rich bands also contain abundant opaques, mostly of a secondary or remobilised origin. These appear to be principally iron oxide phases which have a very regular morphology, occurring as interstitial phases infilling any voids or cracks in the sample. The secondary iron oxides are also prominent in the plagioclase and quartz-rich bands, and occur along grain margins or cleavage traces, or in cracks.

The plagioclase ranges in grain size up to 4 mm in length. Both twinned and untwinned plagioclase are present and there is variable alteration to sericite and fine clays. The quartz is very irregular in grain size with remnant coarser grains of a similar size to the plagioclase, however, due to the deformation the quartz has been in part recrystallised into finer interstitial material. The coarser-grained quartz shows subgrain developments, strongly undulose extinction, and cuspate to curved grain margins. Secondary sericite and muscovite occur interstitial to the plagioclase and quartz in these bands.

Zircon is present in accessory amounts. The prominent red coloration noted in hand specimen is a consequence of the abundant secondary iron oxides. Some colourless low birefringent material associated with the alteration of the early-formed micas and secondary sericite is probably kaolinite.

This is a ferruginised, quartz-sericite-plagioclase schist that was possibly formed through low amphibolite facies metamorphism of a granodioritic rock or sediment of similar composition.

Sample: 6231 RS 132; TSC40879

Applicant's No.
EAD 182

Rock Name:
Folded sericite schist

Hand Specimen:
This is a greenish-grey coloured, fine-grained rock with some coarser feldspathic segregations evident on the cut surface. The rock is weakly foliated with some crenulation of this foliation also evident on the cut surface.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Sericite	60-65
Muscovite	10
Biotite	10
Plagioclase	5-10
Chlorite	2-5
Opaques	1-3

In thin section this can be seen to be a well-foliated sample which has been folded. It dominantly consists of sericite and fine muscovite with lesser relict biotite and plagioclase. The sericite and fine muscovite have an average grain size of less than or equal to 0.02 mm in length.

Plagioclase occurs as disrupted granoblastic aggregates with an average grain size of 0.3 to 0.6 mm in diameter. Interstitial remnant biotite and secondary sericite after plagioclase indicate that the disruption is a consequence of the folding, with the more competent plagioclase behaving in a brittle fashion.

Biotite appears to be the earliest formed mica, occurring as brown to fawn coloured flakes which range up to 1 mm in length. Alteration of the biotite to chlorite and replacement by muscovite is common. Muscovite also forms some coarse aggregates which predate the folding. Biotite can be seen in these aggregates and both micas have an average grain size of 0.1 to 0.2 mm in length. In places, finer chlorite can be seen together with the biotite and muscovite. It occurs in aggregates of flakes with a somewhat radial structure.

Irregularly-shaped elongate opaque grains occur strung out in the primary foliation, and folded together with that fabric. The opaques range up to 0.5 mm in length.

This is a folded sericite schist which appears to have resulted from alteration of a more plagioclase and biotite-rich schistose rock, prior to or during the early deformation. Most of the secondary minerals appear to have been subjected to the second folding episode.

Sample: 6231 RS 133; TSC40880

Applicant's No.
EAD 184

Rock Name:
Garnetiferous amphibole-rich iron formation

Hand Specimen:

This is a banded, dark brown to grey-black coloured rock which is medium to coarse-grained. The hand specimen is magnetic to weakly magnetic.

Thin Section:

A visual estimate of the constituents present gives the following:

	%
Silicates:	
Amphibole	30
Garnet	20
Apatite	3
Plagioclase	trace
Quartz	trace
Opaques:	
Magnetite	5-10
Hematite	5-10
Ilmenite	2
Secondary:	
Goethite	15
Clays	10
Sericite	5

The banding noted in hand specimen can be seen in transmitted light to be a consequence of the concentration of garnet and amphibole into diffuse compositional layers. Aggregates of garnet form semi-to discontinuous stringers through the rock. The garnets are a pale pink colour, have equant subhedral to anhedral outlines, and range in size up to 0.6 mm with most lying between 0.1 and 0.3 mm. Alteration/ replacement of the garnet by goethite is present in some areas.

The dominant primary silicate phase is a colourless amphibole. Relict coarse grains may be up to 6 mm in diameter, with some well preserved amphibole 1 mm or so in length. The relict coarser grains consist of more fibrous secondary amphibole and contain abundant inclusions of opaques and garnet. The well preserved amphibole shows rare well developed cleavage and in places multiple twinning. This amphibole is probably of a cummingtonite-grunerite composition. Some finer ?recrystallised material is evident clouded with abundant fine granular opaques as inclusions and along grain margins. Alteration of the amphibole is common, with prominent clays (?kaolinite in some instances), iron-stained clays and sericite.

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Apatite is the other notable silicate phase. It occurs as elongate to equant round grains, with an average grain size of 0.1 mm in length. Traces of plagioclase and quartz can also be seen.

In reflected light the opaques can be seen to principally iron oxides with minor iron titanium phases. Magnetite is the early-formed oxide occurring both as discrete grains and as thin rims to the silicate grains. Individual discrete grains range up to 0.6 mm in diameter, although most are less than or equal to 0.3 mm. Some primary ilmenite is also present and this occurs both as discrete grains and together with the magnetite as combined grains.

Alteration of the magnetite to hematite is common and there are several stages of alteration preserved, from magnetite with rims and thin lamellae of hematite through to hematite pseudomorphs after magnetite with ?ilmenite and magnetite lamellae, i.e. martite. There is also prominent late-stage goethite developed.

The primary mineralogy of this rock appears to have been cummingtonite-grunerite, garnet, magnetite, and apatite. Early remobilisation of the oxides leads to rims of many of the silicate phases with magnetite, and the alteration of these to hematite is evident. Late-stage weathering has resulted in alteration of the amphibole to clays and sericite, and there has been prominent goethite developed.

Sample: 6231 RS 134; TSC40881

Applicant's No.
EAD 187

Rock Name:
Banded diopside actinolite rock

Hand Specimen:
This is a well layered medium-grained metamorphic rock consisting of alternating pale green and dark green compositional layers.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Diopside	∿45
Actinolite	∿45
Sericite	8
Epidote	1
Sphene	1
Plagioclase	trace
Apatite	trace
Zircon	trace

This sample consists of diopside-rich and amphibole-rich interlayers. The amphibole is pale green to pale yellow-green in colour and occurs as elongate grains up to 1.5 mm in length, with most less than or equal to 0.6 mm. A parallel alignment of the elongate amphibole grains gives the rock a prominent foliation.

Euhedral prismatic morphologies and well developed amphibole cleavage are common, although in places fibrous amphibole is developed. The amphibole is probably of an actinolite composition and some grains have pleochroic haloes around inclusions of zircon.

The diopside occurs as anhedral grains ranging up to 2 mm in diameter. It is of a similar colour to the amphibole. Grain margins are very irregular in places and ?secondary inclusions of mainly euhedral amphibole are common.

There are several thin discontinuous bands and patches of sercite and minor epidote. The epidote mostly occurs as fine granular aggregates. These bands and patches tend to be associated more with the diopside than with the amphibole, and most probably originally consist of plagioclase. In places some partly altered multiply twinned plagioclase can still be seen.

Minerals present in accessory amounts include sphene and apatite. The sphene occurs as irregular grains up to 0.6 mm in length, and the apatite occurs as round elongate grains averaging 0.1 mm. Trace amounts of zircon occur mostly as inclusions in the amphibole.

This is a banded diopside actinolite rock or calc-silicate, with some primary plagioclase that has been altered to sericite and epidote. The rock was probably formed through middle amphibolite facies metamorphism of a siliceous dolomitic limestone.

Sample: 6231 RS 135; TSC40882

Applicant's No.
EAD 188

Rock Name:
Garnet-bearing biotite quartzo-feldspathic gneiss

Hand Specimen:
This is a grey coloured medium-grained rock which is foliated. Some coarser quartzo-feldspathic segregations lie in the foliation plane.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	30-35
Quartz	30-35
Biotite	20
Potassium feldspar	10
Sericite (and muscovite)	3
Garnet	1
Zircon	1
Chlorite	trace
Opaques	trace

This rock has an equigranular granoblastic texture consisting dominantly of elongate grains of quartz and feldspar which have a parallel alignment. Together with the alignment of the biotite the quartz and feldspar produce a prominent foliation.

Quartz occurs as irregularly-shaped grains with curved to cuspate grain margins and undulose to strongly undulose extinctions. The generally elongate quartz grains range up to 2 mm in length. The coarse grains show the effects of deformation in the form of subgranular developments and partial recrystallisation into finer material of a more regular shape.

Plagioclase is the dominant feldspar and occurs mostly as untwinned grains up to 2 mm in length. Multiply twinned plagioclase is present, there is some myrmekite, and minor alteration to sericite. The potassium feldspar is generally finer-grained than the plagioclase, with an average grain size of 0.2 to 0.5 mm. It is a cross-hatch twinned microcline with some microcline perthite. The coarser quartzo-feldspathic segregation noted in hand specimen consists of plagioclase and quartz with a range in grain sizes up to 2.5 mm in length.

The biotite is fawn to red-brown in colour and has a subparallel orientation. Individual flakes range up to 1.8 mm in length, although most lie between 0.2 and 0.6 mm. There are abundant pleochroic haloes around zircon inclusions, and inclusions and rims of fine opaques are present in some grains.

Garnet is a minor but notable constituent of this rock, generally associated with the biotite. It is found as equant round grains, often cracked, with an average grain size between 0.3 and 0.6 mm. Alteration and replacement of the garnet by chlorite and sericite is evident.

Zircon is a prominent accessory phase occurring as round, elongate, and composite grains up to 0.1 mm in length. Some monazite and/or xenotime may also be present grouped here as zircon. The opaques are mostly found as fine granular material associated with the biotite.

Apart from the chlorite and sericite after garnet, and sericite after plagioclase, there are a few fine flakes of muscovite which appear to have replaced biotite.

This is a garnet-bearing biotite-quartz-feldspar gneiss that appears to have been formed through middle to upper amphibolite facies metamorphism of a pelitic quartzo-feldspathic sediment or from a granitoid of slightly aluminous granodioritic composition.

Sample: 6231 RS 136; TSC40883

Applicant's No.
EAD 189

Rock Name:
Sericitised, garnet-bearing, biotite-plagioclase-quartz gneiss

Hand Specimen:
This is a weathered well-foliated and layered rock which has been crenulated. It is brown to orange-brown in colour.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	45
Plagioclase	15
Biotite	10-15
Opaques	3
Garnet	1
Zircon	trace
Secondary sericite and muscovite	20-25
Chlorite	1

Both the earlier-formed foliation and a secondary fabric associated with the crenulation of the first are well developed in this thin section. Parallel alignment of elongate quartz and biotite outlines both foliations.

The quartz occurs in a range of grain sizes a consequence of the variable recrystallisation. Coarser quartz ranges up to 3 mm with most lying between 1 and 2 mm in length. Abundant subgrain developments, curved to cuspate grain margins, and strongly undulose extinction typify the quartz. The plagioclase is of a similar grain size as the quartz although generally not as coarse. Untwinned and twinned plagioclase are both present and there is variable alteration to sericite.

Biotite is the primary micaceous phase, occurring as fawn to brown flakes up to 1.5 mm in length. The biotite is aligned both in the ?S_2 and ?S_3 fabric. Alteration and replacement by fine muscovite and sericite is common, with minor chlorite in places. The sericite also forms crenulated bands through the rock with some associated biotite. This sericite is secondary and may be formed after an earlier primary mica or feldspar, or could represent introduced material parallel to the foliation. Some coarser muscovite is also associated with the sericite.

Opaques occur both as discrete anhedral grains and more commonly as fine granular inclusions and rims to the biotite. Trace amounts of zircon are present and there are some conspicuous equant, strongly cracked grains of garnet in one patch.

This is an altered garnet-bearing biotite-plagioclase-quartz gneiss that has abundant secondary sericite. It was probably formed through a prograde middle to upper amphibolite facies metamorphism of a pelitic quartzo-feldspathic sediment or aluminous granitoid. An early-formed foliation designated S_2 has been crenulated and resulting in a S_3 fabric.

Sample: 6231 RS 137; TSC40884

Applicant's No.
EAD 193

Rock Name:
Diopside-tremolite rock

Hand Specimen:
On the broken surfaces this rock can be seen to be a medium to coarse-grained, dark green coloured rock with an indistinct foliation. The rock has a 1 to 3 mm thick orange-brown weathering skin.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	80
Diopside	10
Sphene	1
Apatite	1
Epidote	5
Opaques and fine clays	3

This rock consists mostly of tremolite in a variety of morphologies, and in places can be seen to have replaced primary clinopyroxene. The clinopyroxene occurs as colourless grains ranging up to 3 mm in length. The primary grain shape was rectangular, however, due to the replacement by tremolite clinopyroxene is generally ragged to granular with a strongly cracked character. It probably is of a diopside composition with the possibility of extending towards hedenbergite.

Much of the tremolite occurs as fibrous aggregates in coarse domains with optical continuity. Relict clinopyroxene can be seen in the cores of these domains and hence it is probable that the tremolite is a retrograde development after the clinopyroxene. Fibrous tremolite has an average grain size of less than 0.1 mm. Subsequent deformation of the coarse domains gives rise to a foliated texture in places with subparallel alignment of the fibrous tremolite. Partly euhedral, prismatic tremolite crystals are a late-stage development. These crystals range up to 1.5 mm in length and mostly have a random orientation. Patches of clouded darker coloured tremolite appears to be a consequence of secondary alteration with inclusion of fine-grained clay material.

Epidote occurs as irregular granular aggregates with grain sizes up to 1 mm in diameter, although mostly less than 0.5 mm. The epidote appears to have formed after the fibrous tremolite. Apatite and sphene are conspicuous accessory phases. The apatite occurs as round to elongate grains up to 0.3 mm in diameter. The sphene is mostly anhedral in shape, however, there is some prismatic grains up to 0.6 mm in length. Fine-grained opaques and/or clayey material occurs along cracks through the rock. Some grains are rimmed by a thin opaque film.

This is a diopside-tremolite rock that appears to have formed through a prograde upper amphibolite facies metamorphism of a siliceous dolomitic limestone. The prograde metamorphic assemblage appears to have been dominantly diopside. Subsequent retrograde amphibolite facies metamorphism leads to the development of tremolite and a later deformation has given rise to the variably developed foliation.

Sample: 6231 RS 138; TSC40885

Applicant's No.
EAD 201

Rock Name:
Epidote-bearing hornblende-biotite-quartz-plagioclase gneiss

Hand Specimen:
This is a dark medium-grained with fine leucocratic segregations which have a parallel alignment, giving rise to a prominent foliation. Thin, 1 to 3 mm thick veins cut across this foliation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	35
Secondary epidote	22
Quartz	15
Biotite	15
Hornblende	10
Opaques	2
Apatite	1
Sphene	trace

The foliated nature of this rock is due to subparallel alignment of elongated biotite and hornblende together with elongate quartz and plagioclase. The primary prograde metamorphic assemblage may have been plagioclase + hornblende ± quartz, however, this has been considerably modified with the development of biotite and later epidote.

The plagioclase is mostly untwinned, ragged grains with abundant secondary fine inclusions of quartz and epidote. Much of the plagioclase is clouded with fine clays. The quartz ranges in grain size up to 1.5 mm in length. The coarser elongate grains show subgrain developments, strongly undulose extinction and curved grain margins.

The hornblende is blue-green to brown-green in colour and relict grains range up to 1 mm in length. Most of the hornblende grains are ragged and have inclusions of biotite and epidote which seem to have formed at the expense of the primary amphibole. The fawn to brown coloured biotite mostly occurs together with the hornblende. Discrete biotite flakes range up to 1 mm in length, with most being less than or equal to 0.5 mm. The coarser biotite flakes have stringers of fine granular sphene which lie in the foliation plane. Elsewhere discrete single grains of sphene can also be seen.

Opaques and apatite tend to be preferentially associated with the biotite and hornblende. The opaques are anhedral in outline with an average grain size of 0.1 mm. Apatite occurs as round to elongate grains up 0.4 mm in length. Some prismatic apatite is present.

Epidote occurs both as irregularly-shaped granular aggregates throughout the host rock, and as coarse-grained veins. The epidote in the host is a late-stage development with some of it replacing hornblende and

and plagioclase. Discrete aggregates of epidote range up to 0.5 mm in length with much of the individual fine granular epidote less than 0.1 mm. The vein epidote is more uniform in grain size with an average of 0.2 to 0.3 mm in length. Clouding of the epidote with fine clay inclusions is a feature of these veins.

This is an epidote-bearing hornblende-biotite-quartz-plagioclase gneiss. It was probably formed through prograde amphibolite facies metamorphism of a basic igneous rock or impure calc-silicate sediment. The former is more likely. Subsequent retrograde metamorphism has led to the development of biotite and more recently epidote with secondary epidote veining.

Sample: 6231 RS 139; TSC40886

Applicant's No.
EAD 213

Rock Name:
Granodioritic gneiss

Hand Specimen:
This is a grey coloured, medium-grained gneissic rock with some coarser quartzo-feldspathic veining.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	45
Quartz	30
Chlorite (including biotite)	13
Sericite/fine muscovite	10
Opaques	2
Zircon	trace

This rock consists of granoblastic aggregates of elongate plagioclase and quartz, which together with the flakes of chlorite and lesser biotite have a parallel orientation, giving rise to the gneissic fabric.

Both multiply twinned and untwinned plagioclase are present with one or two relict grains ranging up to 4 mm in length. Most, however, are of the order of 1 mm or less. In places the plagioclase has been extensively altered to sericite and fine muscovite. There is a preferential concentration of this alteration into specific zones which are subparallel to the foliation. The plagioclase is of an oligoclase composition.

Quartz ranges in grain size up to 3 mm. Undulose to strongly undulose extinction, variable subgrain developments, and curved to mildly cuspate grain margins typify quartz.

The chlorite flakes have an average length of 0.2 to 0.3 mm. It is pale green to colourless, and in places relict biotite occurs with the chlorite implying that the chlorite is a secondary development.

Sericite and fine muscovite are prominent secondary phases. They form at the expense of plagioclase in specific zones. Sericite also occurs along many grain margins and at the junction of several grains.

Opaques and zircon are present in accessory amounts. The opaques range from well-formed blocky grains to irregularly-shaped material. They are generally less than 0.1 mm in diameter. The round to elongate zircon grains are present in trace amounts.

This is a gneissic rock of granodioritic composition that was probably formed through amphibolite facies metamorphism of an igneous precursor, although the derivation from a sediment of a similar composition is also possible.

E00167

Sample: 6231 RS 140; TSC40887

Applicant's No.
EAD 219

Rock Name:
Diopside rock with quartz-sericite veining mantled by actinolite-tremolite

Hand Specimen:
This is a higly veined rock consisting of a pale green, coarse-grained massive host with abundant coarse ?quartzo-feldspathic veins. The veins have a thin rim of dark green material. On the cut surface one end of rock appears to be well foliated.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Host:	
Diopside	90-95
Actinolite-tremolite	5-10
?Epidote	trace
?Clays	0-5
Vein:	
Quartz	55-60
Sericite	30-35
?Amphibole	5-10
Apatite	1
Vein Rim:	
Actinolite-tremolite	100
Zircon	trace

The host material for this rock dominantly consists of granoblastic aggregates of clinopyroxene of a diopside composition. The diopside occurs as equant grains which range up to 2 mm in diameter, with most being of the order of 0.3 to 0.6 mm. A feature of the diopside is its strongly cracked nature with secondary actinolite-tremolite and some fine clays infilling the interstices. Clouding of the grains with fine ?clayey material and intergranular thin rims of clays can also be seen. Minor amounts of epidote are a secondary development.

The main vein material consists of quartz with abundant interstitial sericite and ?amphibole. The quartz ranges in grain size up to 3 mm and the deformed nature of the quartz is evidenced by strongly undulose extinction and variable subgrain development. Grain margins are cuspate to curved with relict triple point junctions evident. Interstitial to the quartz are dominantly sericite developments which are formed at the expense of an earlier phase of a similar grain size to the quartz. In some of the sericite-rich patches relict amphibole can be seen, however, some of the original grains may have been a feldspar. Accessory phases observed in the veins are apatite, biotite, and chlorite. The apatite grains are up to 0.5 mm in length.

The veins are mantled by aggregates of subhedral actinolite/tremolite. This amphibole is pale green to colourless and rare grains are up to 7 mm in length, with most being less than or equal to 1 mm. Well developed amphibole cleavage is common and some grains have pleochroic haloes around inclusions of zircon. The boundary between the diopside and the amphibole rims is ragged with the amphibole enclosing some of the host diopside.

This is principally a diopside rock which has been veined with quartz and sericite material in turn mantled by actinolite-tremolite. The host rock was probably formed through amphibolite facies metamorphism of a siliceous dolomitic marble. Subsequent veining has resulted in the remobilisation of the calcium magnesian phases leading to the development of actinolite-tremolite rims to essentially quartzo-feldspathic veins which also contain amphibole.

Sample: 6231 RS 141; TSC40888

Applicant's No.
EAD 222

Rock Name:
Garnet-bearing serpentinised olivine calcite dolomite

Hand Specimen:
This is an off-white to grey coloured coarsely crystalline rock with a prominent dark mineral banding.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Dolomite	45
Calcite	25
Serpentine	15
Olivine	5
Opaques	5
?Chlorite	4
Garnet	1

This sample is dominated by granoblastic aggregates of dolomite and calcite, with lesser interstitial olivine and serpentine. The dolomite occurs as coarse anhedral grains up to 4 mm in diameter. Grain margins are curved to cuspate and most grains are twinned. The calcite is generally finer-grained than the dolomite, ranging up to 2 mm in diameter, with a higher proportion less than 1 mm. It is twinned and grain margins are curved. The calcite occurs preferentially together with the serpentine and olivine, and appears to be a secondary development. In places it is interstitial to the dolomite. The association of calcite with olivine and serpentine implies that magnesium is incorporated in the olivine during prograde metamorphism whereby calcite forms rather than dolomite.

Olivine occurs as anhedral round grains which originally were up to 3 or 4 mm in diameter. There has been extensive alteration of the olivine to serpentine, and now only scattered relics of strongly cracked olivine grains remain. Colourless well crystallised flakes of a micaceous mineral occur with the olivine/serpentine-rich bands. Individual flakes are commonly between 1 and 3 mm in length. This mineral has anomalously low interference colours and appears to be a chloritic phase which may have replaced an earlier mica, ?phlogopite. In some patches of serpentine there is more obvious pale green coloured chlorite.

The opaques show a variety of morphologies, with blocky to elongate grains occurring in the host dolomite and calcite. Very irregularly-shaped opaques occur in the serpentine patches, in part occurring as relict rims to the original olivine grains. Some opaques occur interstratified with the dolomite.

Garnet is a conspicuous accessory phase. It is found as granular forms up to 0.5 mm in diameter and tends to be associated with the ?chlorite and serpentine/olivine-rich bands.

This rock appears to be originally a garnet-bearing olivine-calcite-dolomite that was formed through prograde amphibolite to low granulite facies metamorphism of a mildly siliceous dolomitic limestone. The formation of the olivine which is possibly of a forsterite composition is a prograde metamorphic development, subsequent retrograde metamorphism has led to the formation of serpentine.

Sample: 6231 RS 142; TSC40889

Applicant's No.
EAD 226

Rock Name:
Altered dolerite

Hand Specimen:
This is a medium to fine-grained mafic rock with randomly orientated white lath-shaped crystals of ?plagioclase. The rock is generally massive with no obvious foliation.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	45
Biotite	20
Hornblende	10
Opaques	10
Sericite/fine clays	10
Secondary iron oxides	5
Epidote	trace

The primary igneous texture of this rock is preserved in the form of randomly orientated laths of plagioclase. The interstitial primary ferromagnesian phases, however, have been extensively altered. Individual plagioclase laths range up to 1 mm in length. They are commonly twinned and have ragged grain margins particularly along the lengths of the laths. The plagioclase is of an andesine labradorite composition. Alteration to sericite and fine clayey material is variable, but quite extensive in places.

The primary ferromagnesian phases now consist of very fine-grained green to brown coloured material which in part resembles biotite, and in part a fine admixture of sericite, clay, and iron oxides. Discrete clearly discernible fine flakes of biotite can be seen and these grade imperceptibly into the adjacent admixture. Green to blue-green coloured hornblende is also present, and appears to be formed earlier than the above admixture. Discrete partly euhedral elongate hornblendes are a rare late-stage development.

The opaques are a prominent primary phase. They range in size up to 2 mm with most being between 0.5 and 1 mm in diameter. Blocky to equant irregular outlines typify the opaques.

Epidote is a secondary phase present in trace amounts.

This is a dolerite that has been subject to an intense weathering giving rise to the high proportion of secondary ferromagnesian phases. It is similar in texture and mineralogy to sample 6231 RS 130.

Sample: 6231 RS 143; TSC40890

Applicant's No.
EAD 230

Rock Name:
Altered dolerite

Hand Specimen:
This is a medium to fine-grained, greenish-black coloured rock which is generally massive.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	45
Sericite (including fine clays)	20
Hornblende	15
Biotite	10
Opaques	10
Clinopyroxene	trace

The primary igneous texture of this rock is evident in the form of randomly orientated laths of plagioclase. Interstitial primary ferromagnesian phases have been extensively altered or replaced, as has the plagioclase. Plagioclase laths range up to 1 mm in length and have ragged margins. Most show multiple lamellar twinning. Alteration to sericite is variable with unaltered plagioclase evident in places, whilst elsewhere sericite and fine clays may dominate.

Some relict clinopyroxene can be seen, however, most of the primary igneous phase has been replaced by hornblende and to a lesser extent biotite. The hornblende is green to green-brown in colour and grain shapes are very irregular although tending to be elongate. The biotite is brown to green-brown in colour with an average grain size of less than 0.1 mm. No well-formed flakes have been seen and it appears that the biotite may be formed after the hornblende with a fine-grained admixture of the two prominent in some places.

The opaques are a primary igneous phase and occur as blocky to irregularly-shaped grains with an average grain size of 0.1 mm. Secondary iron staining is present in minor amounts.

This is a dolerite that has been considerably altered with the randomly orientated igneous plagioclase laths still present, however, the interstitial ferromagnesian has been replaced or altered. The rock is similar in texture and mineralogy to 6231 RS 130 and RS 142.

Sample: 6231 RS 144; TSC40891

Applicant's No.
EAD 232

Rock Name:
Biotite-quartz-feldspar gneiss

Hand Specimen:
This is a medium to coarse-grained, micaceous quartzo-feldspathic gneiss with much coarser quartzo-feldspathic segregations in places forming augen. The rock is pink in colour with black and grey coloured more micaceous bands.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Potassium feldspar	30
Quartz	25
Plagioclase	20
Biotite	15
Muscovite	2
Apatite	1
Zircon	trace
Sericite and fine clays	5
Secondary iron oxides	2

This rock has an equigranular granoblastic texture. The biotite is preferentially concentrated into stringers through the rock and there is a subparallel alignment of elongate quartz and feldspar grains.

Potassium feldspar is more dominant than plagioclase. Microcline, microcline perthite, and perthite are all present. The coarser augen-like grains noted in hand specimen are microcline perthite in composition, and these are simply twinned and range up to 1 cm in length in this thin section. Elsewhere the feldspars are finer-grained, generally being between 0.5 and 1.5 mm in diameter. The plagioclase is more commonly untwinned than twinned. Myrmekitic intergrowths with quartz are present and the plagioclase tends to be clouded with fine alteration products, sericite and fine clays.

Quartz occurs as irregularly-shaped grains with undulose to strongly undulose extinction and a variable subgrain development. It is of a similar grain size to the feldspar.

Biotite is dark green-brown to green-brown in colour. The flakes range up to 1.5 mm in length. Finer-grained muscovite occurs together with the biotite and is of a secondary nature. The muscovite ranges in grain size up to 0.1 mm, generally less than 0.05 mm, and lies oblique to the main foliation.

Apatite is a prominent accessory phase occurring as round to elongate grains between 0.1 and 0.2 mm in diameter. Round to elongate zircon grains are also present in accessory amounts. There is one aggregate of colourless high relief grains associated with the biotite stringers, and these may be zircon or xenotime. Apart from the secondary sericite and fine clays there is some secondary iron oxides.

This is a biotite-quartz-feldspar gneiss that was probably formed through middle amphibolite facies metamorphism of either a granitoid or an arkosic sediment.

Sample: 6231 RS 145; TSC40892

Applicant's No.
EAD 240

Rock Name:
Chlorite-plagioclase rock

Hand Specimen:
This is a grey-green coloured, medium-grained rock which has a foliation or weak compositional banding.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	60-65
Chlorite	30-35
Opaques	3
Sericite and fine clays	2
?Sphene	trace
Muscovite	trace
Zircon	trace

This rock consists of equigranular granoblastic aggregates of plagioclase with finer interstitial chlorite. The plagioclase has an average grain size of 0.4 to 0.6 mm in diameter, it is both twinned and untwinned, and shows minor alteration to sericite and fine clays. The plagioclase is probably of an oligoclase to albite composition.

Chlorite is interstitial to the plagioclase and in places appears to be slightly younger in origin. It is pale green to colourless in colour, with flakes ranging up to 0.5 mm in length. Some muscovite is associated with the chlorite.

The opaques are generally irregular in outline and fine-grained. Some coarse ?framework structures of opaques are up to 1 mm in diameter, and these now consist of an altered mush of fine granular opaques.

Zircon is a prominent accessory phase occurring mainly as round elongate grains with some euhedral lithologies also present. Small amounts of a variably altered orange-brown coloured high relief phase is probably sphene. The grains are prismatic in places and range up to 0.5 mm in length with some showing twinning.

This is a chlorite-plagioclase rock that may have been formed through metasomatic processes and subsequently deformed.

Sample: 6231 RS 146; TSC40893

Applicant's No.
EAD 250

Rock Name:
Sericitic chloritic quartzite

Hand Specimen:
This is a green coloured, medium-grained rock with a prominent foliation. On the foliation surface coarse flakes of mica can be seen.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Quartz	75
Chlorite (biotite)	15
Sericite and fine muscovite	10
Opaques	trace
Zircon	trace
?Garnet	trace

This rock is dominated by granoblastic elongate aggregates of quartz, with lesser parallel aligned chlorite and fine interstitial sericite. The quartz grains range up to 1.5 mm in length, have undulose to strongly undulose extinction, and considerable subgrain developments. Grain margins are very irregular.

Chlorite occurs as pale green to colourless flakes that have replaced biotite. Relict biotite can be seen in places, however, most has been altered to the chlorite. The flakes are up to 1 mm in length, and often have pleochroic haloes around inclusions of fine zircon.

The sericite is found in the elongate aggregates and stringers interstitial to the quartz. It appears to have formed at the expense of an earlier phase, ?plagioclase, or developed in response to secondary fluid activity.

There are some colourless, high relief grains which are isotropic and therefore probably garnet in composition. The ?garnet ranges up to 4 mm in diameter, and is altered or replaced by chlorite and sericite.

Zircon is present in accessory amounts as are subhedral opaques which are up to 6 mm in diameter.

This is a sericitic chloritic quartzite that appears to have been formed through metamorphism of an impure quartz-rich sediment. The prograde metamorphic assemblage appears to have been quartz + biotite ± garnet, and this has subsequently been retrograded to chlorite with the introduction of sericite.

Sample: 6231 RS 147; TSC40894

Applicant's No.
EAD 250 . Jade outcrop 113

Rock Name:
Tremolite rock or jade

Hand Specimen:
This is a medium to fine-grained, massive, dark green coloured rock. It has a thin orange-brown weathering skin.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Tremolite	90
Opaques	5
Epidote	3
Iron staining	2
Biotite	trace
Zircon	trace

This sample is dominated by tremolite which exhibits a wide range in grain sizes. Coarse sheaves of fibrous tremolite range up to 3 mm in length and have a partial radial structure. Finer radial aggregates of fibrous tremolite occur in domainal pattern in places with each domain ranging up to 3 mm in diameter. Some of these domains have epidote cores. Much finer-grained fibrous tremolite forms the remainder with grain sizes ranging down from 0.2 mm. The tremolite is generally colourless or iron stained, however, in places it has a pale green pleochroism which may indicate a more actinolitic composition for this sample as compared with other tremolite rocks described from the Cowell Province.

Epidote also shows a wide range in grain sizes. Coarse, pale yellow, subhedral to irregular grains are up to 1.5 mm in the cores of the tremolite domains noted above. Elsewhere the epidote occurs in granular aggregates with an average grain size of approximately 0.1 mm. There is a tendency for the tremolite to be greener in colour adjacent to the epidote possibly reflecting a more iron-rich composition. In some instances, brown to fawn coloured biotite occurs adjacent to these epidote aggregates.

The opaques show a variety of morphologies, some are euhedral with most being irregular in outline. The opaques range up to 0.5 mm. Zircon is present in trace amounts. Iron staining is prominent along cracks through the sample.

This is a tremolite rock or jade, that appears to show at least two forms of tremolite development, one of which contains cores of epidote.

Sample: 6231 RS 148; TSC40895

Applicant's No.
EAD 259

Rock Name:
Weakly deformed granite

Hand Specimen:
This is a medium-grained, grey coloured granitoid which on some surfaces appears to be weakly foliated.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Potassium feldspar	30-35
Quartz	25-30
Plagioclase	20-25
Biotite	6
Muscovite	2
Sericite	3
Opaques	2
Zircon and/or monazite	1
Chlorite	1
Apatite	trace

This sample shows the effects of a cataclastic deformation. Relict igneous phenocrysts of simply twinned potassium feldspar are evident in a rock which has a granoblastic texture and weak alignment of biotite flakes.

Potassium feldspar is more dominant than plagioclase, with perthite, microcline perthite, and microcline present. Many simply twinned potassium feldspars can be seen and these range up to 3 mm in length. Both untwinned and twinned plagioclase are present. It is generally finer-grained than the potassium feldspar and is variably altered to sericite and fine clays.

The quartz ranges in grain size up to 2.5 mm. Undulose to strongly undulose extinction and considerable subgrain developments typify the quartz. Grain margins are strongly sutured in places, and simple curved margins are also present. Some finer quartz mosaics are a consequence of the cataclastic deformation.

The biotite is brown to green brown in colour and some show small scale kinks. Individual flakes range up to 0.6 mm in length, and there is minor alteration to chlorite. Fine opaques and muscovite are commonly associated with the biotite. The muscovite ranges from fine interstitial material up to well-formed flakes of similar size to the biotite.

Zircon and/or monazite is a prominent accessory phase. Some of the zircon is euhedral, prismatic with many growth zones. Other grains are anhedral and may be monazite. The opaques are generally irregular in outline and range up to 0.3 mm in length. Traces of fine apatite are also present.

This is a granite which has suffered a mild cataclastic deformation.

Sample: 6231 RS 149; TSC40896

Applicant's No.
EAD 271

Rock Name:
Tremolite-epidote rock

Hand Specimen:
This is a coarsely crystalline, dark green coloured rock with some finer, cream coloured segregations.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Epidote	50-55
Tremolite	40-45
Clays	5
Sphene	trace
Zircon	trace
?Biotite	trace

This sample principally consists of earlier-formed coarse granular epidote and secondary mostly euhedral amphibole. The epidote is colourless, clouded to pale yellow-green in colour and ranges in grain size up to 3 mm in diameter. The coarser grains are cracked and have prominent secondary interstitial amphibole developed. The amphibole is colourless to very pale green in colour and is probably tremolite in composition, perhaps extending towards actinolite. The grains are commonly euhedral prismatic forms which range up to 2 mm in length. Typical amphibole cleavage is well developed on many grains. In places the tremolite is more fibrous and biotite can be seen to be forming.

There are one or two prominent grains of sphene, up to 1 mm in length. Zircon and opaques are accessory phases.

The clouding of the epidote appears to be a consequence of alteration and fine clays can be seen to be developed. Clayey material also occurs along grain margins.

This is a tremolite-epidote rock that was probably formed through amphibolite facies metamorphism of a siliceous dolomitic marble. The prograde mineralogy was probably epidote with secondary tremolite developed.

Sample 6231 RS 150; TSC41462; Applicant's No. DJF56

Rock Name:
Hydrothermally Altered Diorite

Hand Specimen:
This is a coarse grained grey/white coloured rock which on the cut surface has a finer grained band. The average grain size of the coarser bands either side of this finer band is 3 to 5 mm, with the finer material being between 1 to 2 mm in diameter.

Thin Section:
A visual estimate of the constituents present gives the following:

	%
Plagioclase	60
Biotite	25
Chlorite	10
Quartz	?5
Zircon	Trace
Opaques	Trace

This sample consists of coarse grained plagioclase with prominent interstitial aggregates of finer biotite, and lesser chlorite. The plagioclase ranges in grain size up to 4.5 mm in diameter. These coarser grains appear as remnants with finer grained recrystallised plagioclase at the margins, or as zones or patches within the relict coarse material. Much of the plagioclase exhibits multiple twinning and anti-perthitic exsolution features are common. Inclusions or blebs of ?quartz can also be seen. The plagioclase is probably of an oligoclase to albite composition. Alteration to sericite and fine muscovite together with replacement by biotite and chlorite can be seen.

Biotite occurs as fine aggregates interstitial to or as veins within the plagioclase. The biotite is khaki to olive green in colour and has an average grain size of 0.02 to 0.03 mm, with the range being up to 0.2 mm in length. The chlorite is colourless to very pale green. It is coarser than the biotite and tends to occur peripheral to the biotite aggregates as flakes ranging up to 1 mm in length. The chlorite also occurs within and replacing the plagioclase. Both the biotite and the chlorite are formed after plagioclase probably being introduced by hydrothermal activity.

Quartz is a minor component of the rock occurring as blebs within the plagioclase and thin veinlets around some plagioclase grains or infilling cracks. Zircon is present in trace amounts giving rise to pleochroic haloes in biotite. The opaques are mostly fine grained secondary hydrothermal iron oxide phases.

This rock appears to have primarily consisted of a dioritic composition with remnant plagioclase still evident. The early formed ferromagnesian phases appear to have been replaced by biotite and chlorite probably during a hydrothermal alteration.

6231 RS (151) DDH 17, 6.72 m Thin section C 42254

CHLORITE

Hand specimen: Massive, dark greenish block rock with about 2% disseminated yellowish grey and greyish orange aggregates but only to 1.5 mm across. Rock is soft with Hardness of 2½-3, and is very fine grained.

Thin Section:
Estimated mineral abundances (%) are:

Chlorite	98
Sphene/titanate	2
Apatite	tr

Chlorite forms only as radiating aggregates and sheaves up to 0.2mm across but averaging only 0.1mm across. Sheaves partly interlock and no preferred alingment is evident. Pleochroism is pale green.

Sphene or titanate has ragged irregular shapes but with a few relict crystal outlines, range up to 1 mm across and are the yellowish grey spots seen in hand specimen.

Comments:
Drill hole intersected 1.3 m of massive chlorite, which with chlorite + tremolite, forms hanging wall rocks to jade at outcrop #15.

ICP analyses reveals highest MgO content (24.2%) and TiO_2 (1.15%) of samples from DDH 14-17.

6231 RS 152 DDH 17, 7.86 m Thin section C 42255

TREMOLITE

Hand specimen: Massive tremolite rock exhibiting diffuse banding 2-5mm thick. Rock has speckled appearance with varying size and colour of tremolite aggregates defining banding. Aggregates and sheaves of tremolite range up to 1-2mm across. Colour bands are in shades of grey green (5G 5/2 to 10 G 4/2).

Thin section:
Estimated mineral abundances (%) are:

Tremolite	99
Epidote	trace
Opaques	trace

Tremolite is everywhere fibrous and wispy forming sheaves, rosettes and aggregates ranging up to 1mm across but averaging only 0.3mm across. Parallel alignment of fibres is present but minor, but overall, there is no alignment of aggregates or constituent tremolite. Interstital to tremolite aggregates is very fine-grained tremolite averaging 0.05 mm in length which forms about 15% of the total area. Coarsest tremolite appears to be formed first, followed by fibre sheaves, and then finest-grained matrix tremolite.

Epidote is in trace amounts only and opaques form minute dusting inclusions.

Comments:
Rock is coarse-grained tremolite marginal to jade intersected less than 1 m below in the drillcore. Texture is very similar to that of jade but much coarser grained; colour also matches that of jade.

6231 RS 153 DDH 17, 8.34 m. Thin section C 42256

TREMOLITE + CHLORITE

Hand specimen: Dark greenish black (5GY 2/1) aggregates of ?chlorite are to 30 mm across and consist of fine-grained ?chlorite with a grain size of 1 mm. These aggregates or 'pseudo-breccia' clasts are subordinate to a very fine-grained nephritic tremolite matrix, which is grey green (10 G 4/2), and contains small 0.5 - 3 mm chlorite-rich aggregates and one discontinuous band of sphene. Sphene has same characteristics as RS 151. Rock massive but with a poorly-developed schistosity in both chlorite-rich aggregates and tremolite rich matrix.

Thin section:

Estimated mineral abundances (%) are:

Tremolite matrix	
Tremolite matrix	58
Tremolite schistosity	40
Chloritised actinolite	1
Sphene	1

Greenish black aggregates	
Chloritised schistose matrix	90
Chloritised actinolite porphyroblasts	10

Greenish black aggregates consist of about 90% fine-grained chlorite and 10% extensively chloritised ?actinolite porphyroblasts. Porphyroblasts are to 0.5 mm across and are aligned across the later ?S_4 fine-grained chlorite schistosity. Porphyroblasts exhibit pale brown to light green pleochroism and low chlorite birefringence except in rim zones which show birefringence of actinolite. Chlorite schistosity folds the crystal cleavage of chloritised ?actinolite and schistosity is defined by very fine-grained aligned chlorite with an average size of only 0.02mm.

Grey green tremolite-rich zones consists of fine-grained tremolite-actinolite fibres which are aligned and indicating two schistosities. Schistosities show varying extents of development and preservation - being replaced by equant and very fine-grained tremolite-actinolite which form a matrix. Most tremolite-actinolite fibres are only 0.08 mm long.

Within this zone, chloritised actinolite exhibits pale green and green blue pleochroism, and form porphyroblasts about 0.3mm long which have a dimensional alignment in a tremolite-actinolite schistosity but a crystallographic alignment across it. Hence these porphyroblasts predate the schistosity. Rarer porphyroblasts are to 1 mm long and aligned in the schistosity. Yellowish grey specks of the hand specimen are ragged sphene grains to 0.7 mm across with minute opaque inclusions.

Comments:

Order of events is apparently:

- ?actinolite porphyroblasts
- tremolite-actinolite first schistosity
- " " second schistosity and chloritisation producing chlorite schistosity (? S_4)
- late-stage fine-grained equant tremolite-actinolite replacing the schistosites.

Sample is only 0.3 m from contact of jade lens.

6231 RS 154 DDH 17, 8.69 m. Thin section C 42257

NEPHRITE with chlorite

Hand specimen:

Banded with alternating bands 2-10 mm thick of greyish green nephrite/tremolite (5 G 5/2 to 5 G 5/3) and greenish black, speckled chlorite (about 5 GY 2/1).

Thin section:

Estimated mineral abundances (%) are:

Nephrite matrix	85
Chloritised porphyroblasts and aggregates	13
Chloritised actinolite	1-2
Apatite	trace
Pyrite?	trace

Nephrite consists of a very fine-grained mat of wispy tremolite where the mat size is no more than 0.05 mm long. Tremolite aggregates forming the mat are elongate and aligned where a cleavage/schistosity is locally developed. Schistosity slightly wraps around and enclosed chloritised amphibole porphyroblasts and chlorite-rich aggregates up to 1 mm long. Chlorite mostly forms sheaves and rosettes with no alignment with minor chlorite as larger flakes. However, chlorite-rich aggregates exhibit a poor to moderate dimensional alginment in the schistosity. Chloritised amphibole appears to have been cummingtonite with light yellow-green pleochroism but alteration is extensive.

Pyrite is subhedral, 0.9 mm across and partly oxidised producing a marginal Fe-staining in nephrite.

Comments: Sample is of jade from the hanging wall contact, is low grade because of chlorite abundance, and appears to have relicts of chloritised cummingtonite.

6231 RS155 DDH 17, 9.05 m Thin section C42258

NEPHRITE with chlorite

Hand specimen: Low-quality nephrite with abundant thin (1-3 mm) discontinuous bands of green black chlorite and speckled dark grey ?porphyroblasts. ?Porphyroblasts and chlorite bands constitute about 20-25%. Jade massive with colour about dusky green (5G 3/2) to greenish black (5G 2/2).

Thin section:

Estimated mineral abundances (%) are:

Nephrite matrix	70
Chloritised porphyroblasts and aggregates	29
Coarse-grained relicts of tremolite and ?anthophyllite	trace-1%
Titanate/sphene	trace-1%
Diopside	trace
Apatite	trace

Sample has many similarities with Rs 154 - a dominant nephrite matrix containing large chlorite aggregates and porphyroblasts, as well as a locally-developed cleavage or schistosity within nephrite. Differences to RS 154 are mainly in the extensive replacement textures still preserved:

- large chlorite aggregates exhibiting two generations of chlorite with euhedral actinolite needles.
- remnant diopside and ?anthophyllite
- relict coarse tremolite
- ghost-structures within nephrite
- large fractured actinolite needles within nephrite.

Chlorite aggregates are to 2.5 mm across but the largest individual chlorite is 1 mm. Pleochroism is pale brown to light green with some anomalous reddish brown pleochroism. This chlorite is partially replaced by a mosaic of extremely fine-grained chlorite with an average size of about 0.02 mm and of darker-green pleochroism. Prominent within the finer-grained chlorite are needles of ?actinolite to in excess of 1 mm long which also extend into zones of the earlier chlorite.

Nephrite schistosity is similar to that of RS 154 with better alignment in close proximity to the cleavage, and with goethitic /limonitic staining along the cleavage.

Remnant diopside and ?anthophyllite form as equant grains to 1mm which have been almost completely replaced by matrix nephrite.

Ghost textures are wholly within nephrite matrix; minute dustry inclusions outline former larger grains of 0.3 - 0.4 mm. Shapes vary from equant to irregularly elongate with rare ones suggesting typical amphibole cross-section.

One actinolite needle is 5 mm long, only 0.15 mm wide and is chloritised where fragmented.

Sequence of events may be:

1. Chlrotisation producing first-phase chlorite in aggregates
2. Formation of second-generation matrix chlorite, nephrite matrix and replacement of diopside, ?anthophyllite etc producing 'ghost textures'. Possibly formation of nephrite cleavage/schistosity.
3. Late-stage acicular actinolite, with minor chloritisation where fractured.

Comments: From central portion of low-quality chlorite-rich jade lens.

6231 RS 156. DDH 17, 10.52 m. Thin section C42259

NEPHRITE TREMOLITE

Hand specimen: Dusky green (5G 3/2) to greyish green (10 G 3/2) speckled tremolite rock. Grades from fine-grained and nephritic to coarser-grained aggregates 2-3 mm across of radiating tremolite. Low-grade nephrite of footwall contact. Diffuse banding from colour and grain size variations of tremolite.

Thin section:

Estimated mineral abundances (%) are:

Matrix nephrite	90
Coarse-grained tremolite and ?anthophyllite	9
Chlorite	1

Sample consists of a fine-grained nephrite matrix with relict coarser tremolite and ?anthophyllite, as we-l as aggregates up to 2.5 mm across.

Nephrite matrix consists of small sheaves and fibrous mats only 0.03 - 0.04 mm across and composed of finer tremolite fibres. Grain size grades up to 0.1 - 0.2 mm and elongate crystals interlock.

Coarser tremoliteis in aggregates to 2.5 mm across with parallel and subparallel alignments, as well as being partly replaced by matrix nephrite. Some coarse grains exhibit parallel extinction and very pale green pleochroism and may be anthophyllite.

Comments: Typical of matrix nephrite grading to coarse-grained aggregates of tremolite.

6231 RS 157 DDH 17, 10.69 m Thin section C 42260

DOLOMITIC MARBLE

Hand specimen: Banded dolomitic marble with alternating bands of:

- light greenish grey (5 G 7/1) medium-grained dolomite with less than 2% disseminated specks of green chlorite or yellow serpentine
- dark greenish grey (5 G 4/1) grading through to greenish black (5 G 2/1) dolomitic marble with more abundant aggregates and thin bands of chlorite and serpentine.

Thin section:

Estimated mineral abundances (%) are:

Dolomite	75
Tremolite poikiloblasts	15
Calcite	7
Opaques	2
Serpentine	trace-1

Banding is defined by mineralogical and grain size variations, as well as by opaque-rich bands.

Distinctive, is the very large, intensely poikiloblastic tremolite which ranges up to 5 mm across. Inclusions are dolomite, calcite and opaques. Poikiloblasts are restricted to dolomite-rich areas and in selected bands, but are randomly oriented.

Dolomite and calcite are granular, equant but with a widely variable grain size ranging from about 0.02 mm to 3 mm.

Serpentine is concentrated in one band which appears yellow in hand specimen and probably forms as replacement of large poikiloblastic olivine. Serpentine forms small diffuse aggregates of only 0.03 - 0.04 mm across but which in semicontinuous optical continuity with nearby aggregates over distances of 1-3 mm.

Opaques form en-echelon trails which cut across large poikiloblastic tremolite; these parallel very fine-grained dolomite bands and both may be related to tension gashes.

Comments: Marble is only 0.2 m from jade lens. Primary assemblage is apparently (coarse-grained) dolomite + tremolite + olivine. Olivine is later serpentinsed, with retrogressive calcite, dolomite, opaques and marked reduction in dolomite grain size.

6231 RS 158 DDH 17, 12.25 m C 42261

DIOPSIDE

Hand specimen: Massive, coarse-grained, off-white to yellowish-grey (5 Y 8/1) diopside rock with a primary grain size of 6-8 mm. Irregular cross-cutting fractures, 1-3 mm thick, apparently consist of retrogressive yellow-green epidote and greenish black chlorite.

Thin section:

Estimated mineral abundances (%) are:

Primary diopside	95
Secondary tremolite	3
" epidote	2
" opaques	trace
" serpentine	trace

Granular diopside rock with equant anhedra ranging up to 8mm across. Deformation and recrystallisation has reduced considerably the grain size so that the average size is only 0.3 mm in some areas. Deformation is evident by curved twins and cleavages, as well as numerous subgrains only in slight optical discontinuity from adjacent subgrains.

Pronounced thin deformation bands extend right across the sample, are only 0.2 - 0.4 mm wide and consist of fine-grained granular epidote, dolomite, dusty opaques and ?serpentine. Prominent brittle fracturing within and across diopside, particularly in large grains, are infilled by fine-grained calcite.

Prominent dark green black fractures in hand specimen is predominantly a vein of poorly-aligned tremolite up to 3 mm wide. Tremolite fibres are to 0.8 mm long and replace diopside. Also present are epidote and a thin, 0.2 mm wide, dolomite vein which is late-stage and central to the tremolite band.

Comments:

Primary mineralogy is 100% very coarse-grained diopside. Brittle fracture and recrystallisation is pronounced, as well as later retrogression to tremolite and epidote. A thin dolomite vein represents the final event.

6231 RS 159 DDH 17, 14.61 m Thin section C42262

DIOPSIDE

Hand specimen: Dominantly a very fine-grained greenish grey (5 G 6/1) rock, massive with disseminated darker green specks of chlorite and/or tremolite. Reflections indicate some of the greenish grey minerals are elongate and up to 3mm long. Appears to be a dolomitic marlbe except for elongate crystals.

Thin section:

Estimated mineral abundances (%) are:

Diopside	95
Chlorite	3
Dolomite	2

Rock consists predominantly of granular diopside with an average size of 0.8 mm but ranging up to 3 mm; many grains are elongate and tend to be acicular with length: breadth ratios exceeding 5:1. Chlorite and dolomite are interstitial to diopside.

Prominent cross fractures, up to 1 mm wide, are lined by dolomite but with minor chlorite and Fe-staining; epidote is absent.

Comment: Acicular diopside is unusual; coarse granular equant crystals of RS 158 are more typical.

6231 Rs 160 DDH 17, 15.89 m Thin section C42263

TREMOLITE SCHIST (mylonitised diopside)

Hand specimen: Tremolite schist with strong development of a tremolite schistosity which appears to be retrogressed diopside. Diopside relicts from small equant to elongate augen several millimetres across. Colour varies from off-white to light greenish grey (5 GY 8/1 to 5G 8/1) with darker dusky green bands (5 G 3/3) parallel to the schistosity.

Thin section:

Estimated mineral abundances (%) are:

Diopside relicts with tremolite overgrowths	5
Mylonite zone - tremolite	75
- calcite	11
- dolomite	5
- chlorite	4

Rock is a tremolite + calcite schist containing remnants of early phase, coarse-grained diopside with tremolite overgrowths. Dominant feature is the late-stage tremolite schistosity with parallel veins of dolomite.

Schistose tremolite is fine grained; fibres average 0.1 mm in length, have length: breadth ratios of about 4:1 and their alignment is good. In places, the tremolite schistosity shows repeated folding typical of mylonite zones. Calcite bands are also folded and predate at least some of the schistosity development. Dolomite bands are late stage and vary from planar to slightly sigmoidal and probably infill open fractures. Dolomite is as elongate grains perpendicular to vein margins.

Calcite of folded veins however is equant with an average size of 0.3 mm.

Diopside, as early phase relicts to 4 mm across, is equant to slightly elongate and has substantial overgrowths and rims of coarse-grained tremolite. Replacement by coarse-grained tremolite is often to the extent of 50-80%.

Chlorite is very fine grained and interstitial to tremolite forming the schistosity.

Comments: Sequence of events is apparently:

1. Coarse-grained diopside
2. Replacement of diopside by coarse-grained tremolite, ?plus calcite veining.
3. Mylonitisation with extensive development of schistose tremolite, folding of calcite veins, formation of chlorite.
4. Late-stage dolomite infilling open fractures or tension gashes.

6231 RS 161 DDH 17, 16.07 m Thin section C42264

RETROGRADED DIOPSIDE

Hand specimen: Dominantly massive off-white to light greenish grey (5 GY 8/1) diopside but with retrogression along numerous irregularly-distributed hair-line cracks. Retrogressive products are dusky green to greenish black and are probably mostly chlorite. Sample is 0.18 m from a mylonite zone through diopside producing tremolite schist (RS 160).

Thin section:

Estimated mineral abundances (%) are:

primary diopside	40
? sphene	trace
retrogressive chlorite	35
" tremolite	24
" calcite	1

Diopside has been extensively fragmented, recrystallised and retrogressed. Curved twin planes and cleavages are common, as well as subgrain development. New grains are often about 0.4 mm across and these smaller new grains are often in only slight optical discontinuity from neighbouring grains, indicating an earlier average grain size of 4 mm.

Retrogression is extensive with retrogression products of tremolite + chlorite more abundant than primary diopside. Tremolite is mostly randomly oriented except in narrow deformation bands where the alignment is good. In those zones tremolite averages 0.5 mm long and has a length:breadth ratio of 6:1. Chlorite is concentrated in the same areas as tremolite and occurs as isolated flakes as well as in sheaves and radial clusters; average size is less than 0.1 mm.

Comments: Sequence of events is:

1. Formation of coarse-grained diopside
2. Deformation, recrystallisation and retrogression during mylonitisation. Retrogressive assemblage consists of tremolite + chlorite ± calcite.

6231 RS 162 DDH 17, 17.68 m. Thin section C 42265

MASSIVE DIOPSIDE and TREMOLITE SCHIST

Hand specimen: Massive light greenish grey diopside, partially chloritised with dark greenish black chlorite lining irregular fractures, grading to tremolite schist where extensively retrogressed. Tremolite is very fine-grained and resembles nephrite - is slightly translucent and colour is dusky yellowish green (10 GY 3/2).

Thin section: Estimated mineral abundances (%) are:

Diopside zone		Tremolite schist zone	
Diopside	90	Tremolite	95
Secondary chlorite	5	Chlorite	5
" tremolite	5		

Diopside zone has the same characteristics as Rs 161 i.e. primary grain size of around 4 mm but with extensive subgrain development by deformation and recrystallisation, as well as retrogression.

Tremolite schist exhibits a diffuse banding defined by grain-size variations of tremolite. Several generations of tremolite schistosities are present as in Rs 160 and again is indicative of a mylonite zone. In addition, a crenulated schistosity is also present which probably has the same origin.

In places, large areas of elongate tremolite which extend for areas up to 4 mm across, are only in slight optical discontinuity and suggest possible early large tremolite grains of same size as diopside. Schistose tremolite averages 0.15 mm long with length:breadth ratios of 4:1 and is not fine enough to be classed as nephrite.

Dolomite is in late-stage fractures and veins which cut across the tremolite schistosity. Also forms in slightly signoidal ?tension gashes at a low angle to the schistosity.

Comments: Order of events is:

1. Coarse-grained diopside + ? tremolite or
2. Partially retrogressed to coarse-grained tremolite
3. Deformation, recrystallisation and retrogression produces tremolite schist. Retrogressive assemblage is tremolite + chlorite.
4. Late-stage veins of dolomite.

6231 RS 163 DDH 17, 18.20 m. Thin section C 42266

RETROGRADED DIOPSIDE

Hand specimen: Massive, light greenish grey diopside (as in Rs 161 & 162) grading to a pronounced speckled, which consists of irregular mottling of:

- very fine-grained greyish green (5 G 5/2) tremolite resembling nephrite and
- moderate greenish yellow (10 Y 7/3) epidote

Thin section: Estimated mineral abundances (%) are:

Diopside zone		Speckled zone	
Diopside	80	Tremolite	80
Tremolite	18	Epidote	20
Chlorite	2		

Diopside zone has some characteristics as in RS 161 and 162.

Speckled zone contains aggregates of very pale yellow epidote surrounded by tremolite; both are marked by abundant dusty inclusions. Epidote grains are to 2 mm across whereas surrounding tremolite averages 0.4 - 0.5 mm long. Tremolite has fewere inclusions than epidote. Both eipdote and surrounding tremolite are further surrounded and veined by clear tremolite which varies:

- from randomly-oriented, elongate tremolite-actinolite averaging 0.2 - 0.3 mm in length
- to veins consisting of minute tremolite of about 0.2 mm long where tremolite fibres have a sigmoidal shape at a high angle to the vein margin. The pattern is typical of S_4 tremolite schistosity/cleavage in outcrop.

Comments: Sample is of massive diopside with an unusual retrogressive style. Early phase retrogression produces epidote, tremolite overgrowths and abundant dusty inclusions. Second stage retrogression produces further tremolite of several forms; only minute tremolite in narrow cross-cutting veins approaches nephrite.

In the following sample, RS 164, this speckled retrogressive assemblage has been mylonitised.

6231 RS 164 DDH 17, 18.95 m Thin section C 42267

MYLONITISED RETROGRADED DIOPSIDE

Hand specimen: Sample is very similar to Rs 163 but has a mylonitic foliation superimposed - especially on the speckled zone.

Thin section: Coarse-grained, primary diopside on one margin of the thin section is similar to that in Rs 161 - 163 but is more extensively fragmented.

Mylonitisation has produced abundant submicroscopic flour or powder which is colourless, has high relief and is probably diopside and/or epidote. Mylonitisation also produces compositional and grain-size banding on a scale of 0.3 - 0.8 mm.

Largest remnants are of epidote aggregates 2-3 mm across strung out in the mylonitic foliation. Diopside forms smaller relicts. Tremolite, in relict aggregates and bands, tends to be acicular with lengths averaging 0.4 mm and length:breadth ratios of 5:1.

Comments: Mylonitisation is very much a comminution event with no obvious late-stage minerals. Some portions of the sample apparently contained only diopside prior to mylonitisation whereas others contained a mixture of diopside with retrogressive epidote and tremolite. Mylonitisation post-dates development of the speckled fabric in RS 163.

6231 RS 165. DDH 17, 20.05 m. Thin section C 42268

CONTAMINATED LEUCO-GRANITE

Hand specimen: Massive off-white and light grey leucogranite with white feldspar, grey quartz and a primary grian size of 2-3 mm. Abundant irregular fractures contain dusky yellow green and greyish olive epidote and greenish black chlorite. Some of the fractures are elongate and parallel, defining a retrogressive epidote-rich foliation at about 50° to the core axis.

Thin section: A microcline + quartz leucogranite with extensive deformation and recrystallisation, and with probably two periods of alteration. An early phase produced predominantly epidote, and was followed by chlorite and ?actinolite.

Estimated mineral abundances (%) are:

Primary	microcline and quartz	70
Secondary	epidote	19
	chlorite	6
	?actinolite	4
	sphene	1

Microcline and quartz apparently form the only primary minerals - any mafic phases have been completely altered. Large equant primary grains of 2-3mm have undergone extensive subgrain development producing secondary grains averaging only 0.03 mm across and with diffuse, irregular and sutured grain boundaries.

Epidote or clinozoisite appears as an early alteration phase which may be the same age as subgrain development. Largest grain is 1 mm but most forms in fine-grained epidote ± sphene aggregates to several millimetres across or in epidote-rich bands across the slide. Colourless to pale yellow pleochroism.

Chlorite, with minor quartz, infills late stage fractures as well as around and within epidote-rich zones. Chlorite mostly forms in elongate sheaves oriented at a high angle to the fracture. Prominent within these fracture zones is minute acicular ?actinolite forming felted masses with needles only 0.05 mm long and exhibiting pale green pleochroism. At times, ?actinolite needles are oriented perpendicular to the vein margin and growing into adjacent feldspar. Aligned needles within the vein also, in places, show a crenulation.

Comments: Leuco-granite often grades, when fresh and unaltered, into massive microcline-quartz without a mafic phase present. Alteration phases of epidote, chlorite, ?actinolite and tremolite are only present in the contact zone of leuco-granite and dolomitic marble.

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

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THE GENESIS OF JADE AND HOST ROCKS IN DDH14 AT OUTCROP 15, COWELL JADE PROVINCE SOUTH AUSTRALIA

ABSTRACT

Specimens examined from the Cowell Jade Province illustrate the formation of nephrite jade from metamorphosed carbonate sediments. The jade is produced by a series of episodes of recrystallisation and replacement during the retrograde metamorphism of prograde assemblages. Diopside and epidote are the parental silicates of two parallel series of alteration products. Diopside alters to tremolite which recrystallises as nephrite of progressively finer grain sizes. At the same time the epidote series passes through clinozoisite to zoisite.

The quality of the jade is controlled partly by the composition of the original sediments. Silica content is the major control. At silica contents over 50%, calcium from the carbonate reacts to form the epidote series. At levels of silica below 40%, only magnesium carbonates react, producing olivine in prograde metamorphism and serpentinites and chlorites in the retrograde episodes. The ratio of magnesium to calcium is a secondary control. Specimens of good jade occupy a very restricted field in a ternary plot of composition referred to the critical components SiO_2, CaO and MgO. Specimens from DDH14 tend to contain more calcium than is ideal for high quality jade.

The physical control of quality is the fineness of grain size in the nephrite. The best jade with the darkest colour consists of a finely felted mesh of tufted nephrite. Late stage alteration, probably hydrous, promotes regrowth of coarse grained tremolite and reduces the quality of the jade. Fine grain size is produced by recrystallisation and appears to be independent of tectonic stress. Some local stresses may be related to volume changes during alteration.

INTRODUCTION

Twenty two samples in hand specimen and thin section were received for petrographic examination from Don Flint of the Mineral Resources Branch. The specimens were cut from drill core between 5.89 m and 36.51 m in diamond drill hole 14 at outcrop 15 in the Cowell Jade Province, Eastern Eyre Peninsula. Particular interest was expressed in the textural relationships between minerals as an indication of the alteration history of the rocks.

The investigation is part of a continuing programme of geological mapping and diamond drilling of the Jade Province by Messrs. Flint and Dubowski. Chemical analyses of drill core are listed in AMDEL report AC 4545/84. Drilling logs and reports on geological mapping at outcrop 15 and in the vicinity of outcrops 32 and 36 by the above authors are in preparation.

PETROGRAPHY

Specimen 6231 RS 166, TS C42269, 5.89 m

Rock name. Amphibolitised calc silicate rock.

Hand Specimen

The specimen is banded at right angles to the length of the core. The bands consist of fine grained green minerals, a coarse grained intergrowth of green and black, vitreous minerals, very coarse grained white minerals with black veining, a fine grained black mineral and a large proportion of fine to medium grained grey mineral in close intergrowths with poorly-defined grain boundaries.

Thin section

One end of the thin section is composed of coarse crystals of epidote with interstitial amphibole. The epidote is patchy in composition with colourless and pale yellow, weakly pleochroic areas, probably depending on a low but variable iron content. The amphibole is colourless and occurs as closely intergrown, ragged prisms which are often bent and in places are acicular and fibrous. The mineral is tremolite but grades into nephrite with a decrease in grain size, probably without chemical change. This paragenesis forms the band seen in hand specimen as a coarse green and black intergrowth.

In thin section the nephritic and asbestiform amphibole is seen to have penetrated grain boundaries of the epidote, filled interstitial spaces and to have replaced the epidote itself. The replacement is seen in progressive stages between an initial corrosion of the margins and penetration of the cleavages of an epidote crystal and a final mass of fine nephrite with scattered relict inclusions of epidote. It is clear that the nephrite is a replacement phase and younger than the epidote.

In places the epidote is fine grained and as such is seen to form a band in hand specimen. While some of the fine grained epidote may be due to original metamorphic crystallisation, there are indications in places that one grain size transforms to another. The evidence is slightly unclear but on balance the coarse grained epidote appears to replace the fine grained material. In some coarse crystals faint internal outlines indicate the former presence of finer grains which are seen elsewhere as inclusions in the coarse crystals.

The fine grained epidote is also replaced by nephrite so that, where the two forms of epidote are of different ages, the time sequence is: fine epidote, coarse epidote and nephrite.

The band of fine grained epidote is distinguished by the presence of fine, irregular grains of a pale yellow brown to pinkish-brown, pleochroic sphene. The sphene does not appear to be affected by amphibolitic replacement but some recrystallisation is evident in patches where the epidote has been recrystallised into coarser grains. The sphene is probably contemporary with the fine grained epidote. Most grains show a strong preferred orientation along the band.

Adjacent to the band of fine grained epidote is a band seen in hand specimen as coarse grained white minerals veined by black and grey minerals. This is seen in thin section to consist of a pyroxene partially replaced by an amphibole. The pyroxene is often twinned and is colourless to faintly grey-brown but not detectably pleochroic. It is almost certainly diopsidic but the optical properties are not diagnostic of composition. Similarly the amphibole is almost certainly tremolitic but the composition is more effectively determined by chemical than by optical methods. The absence of a greenish tint which is often diagnostic of both diopside and tremolite is probably the result of a very low iron content.

The band of coarse grained diopside and tremolite has been invaded at several points by veins of a fine grained nephritic amphibole which extend from the mass of nephrite forming the greater part of the specimen. The nephrite is not confined to the vein system but has penetrated grain boundaries and cleavage planes in the coarser minerals. Both diopside and tremolite are replaced by the nephrite.

The remainder of the specimen consists of a closely interlocked mass of fine grained, ragged, prismatic to acicular nephrite. In a few places irregular remnants of coarser amphibole, sometimes in clusters of grains, appear to be partially replaced by the finer grained nephrite. There is no optical indication of any compositional difference in the coarse and fine phases. It is possible that the coarser crystals may represent an earlier tremolitic amphibole, possibly contemporary with the tremolite replacing diopside in the band just described. The ultimate parental material is not in evidence.

The fabric of the nephrite is generally random and interlocking. The only situation in which a preferred orientation is evident is in the walls of a branched fracture system, partly conformable to the banding but partly discordant to it. Fine and very ragged prisms of nephrite are aligned within the centre of the fracture parallel to its length. Within the walls of the fracture similar prisms extend outwards in a shallow curve from the fracture filling. The forces controlling this fabric are related to the formation of the fractures and fracture fillings and are probably of purely local origin and related to hydrostatic pressures and the movement of solutions.

Comment

The specimen consists essentially of three lithologies. The major lithology consists almost exclusively of nephrite and the two minor lithologies, one characterised by epidote and the other by diopside, are progressively altered towards nephrite. The sequence of alteration in the three lithologies is charted below.

Epidote lithology	Pyroxene lithology	Nephrite lithology
Fine epidote and sphene	Diopside	Tremolite
Coarse epidote and sphene	Tremolite	Coarse nephrite
Nephrite	Nephrite	Fine nephrite

The distinction between lithologies probably owes its origin to differences in composition of the original dolomitic sediments. Although the nephrite is clearly an alteration product, its abundance in some parts of the specimen relative to others may again reflect original differences in the chemical or physical properties of the parental sediments which facilitated the amphibolitisation process.

The petrographic evidence suggests that alteration of the original rocks occurred in more than one stage. Conversion of diopside to tremolite preceded replacement of both by nephrite in the diopsidic lithology and may have preceded it in the nephrite lithology. Recrystallisation of fine epidote to a coarser grain size may have occurred at the same time as the early stage of amphibolitisation but may have been a distinct process.

If the observed differences in lithology reflect original sedimentary compositions, the banded fabric of the specimen may be the product of original bedding. However, the presence of oriented sphene which appears to have been unaffected by the amphibolitisation indicates the probability of a deformational recrystallisation which may have produced a metamorphic differentiation, possibly with no relationship to the bedding of the original sediments.

Contrary to expectations, there is no observable consistent orientation in the products of either of the two episodes of amphibolitic alteration or the episode of recrystallisation affecting the epidote. Only the sphene mentioned above and nephrite developed within and around a late stage fracture system exhibit a preferred orientation. Both of the major episodes of alteration apparently took place in the absence of directional stress. If the development of Cowell jade is the product of regional metamorphism, it must have occurred at a later stage as a retrogressive process after regional stress had abated. The process may have been thermally driven and have involved the regional migration of hydrothermal solutions down a thermal gradient or the migration of a thermal gradient through water-impregnated country rock.

Specimen 6231 RS 167, TS C42270, 6.24 m

Rock name. Amphibolitised and mobilised calc silicate rock.

Hand specimen

The specimen consists of white, grey, pink and green minerals and shows no consistent fabric. In appearance it is patchy and fractured.

Thin section

The minerals identified in the specimen from 5.89 m are present in that from 6.24 m but in different proportions and a much more random distribution. If a banded fabric ever was present, it has been almost totally disrupted by mobilisation associated with the alteration. The pink mineral is colourless in thin section. It is a zoisite and the colour probably indicates a small manganese content (1600 ppm in the rock). With more manganese it would qualify as a thulite, with enough to constitute a major element it would become piedmontite, a manganoan epidote.

The components of the epidote lithology are present but in scattered patches. Fine grained epidote with greenish patches is rare. Most of the epidote has been recrystallised. It is very coarse grained and highly variable in composition. Even within one grain the composition often varies between a weakly ferruginous epidote and the weakly manganiferous zoisite. Compositional variation is patchy with sharply to weakly defined boundaries. Both simple and complex polysynthetic twinning is common in the zoisite. Coarse zoisite often encloses corroded and fragmentary diopside and has presumably replaced the pyroxene. The epidote and diopside lithologies overlap to a much greater extent in the patchy as compared with the banded specimen. There is a tendency for the zoisite to be concentrated in the walls of a fracture which is also a channel for the introduction of nephrite and the zoisite is clearly a replacement phase, probably developed through the agency of solutions traversing the fracture. A little finer grained sphene is present as inclusions in patches of epidote. It is not associated with the later zoisite.

The diopsidic lithology is similar to that of the banded specimen except that the initial tremolitic alteration is not as sharply distinct from the subsequent development of nephrite as it is in specimen RS166. Diopside occurs throughout the specimen in both coarse and fine grains. It is strongly altered, particularly in the coarse grains, with amphibole penetrating cleavages and along grain boundaries. The amphibole tends to be fine grained and ragged more often than it occurs as continuous, coarser grains of tremolite.

Nephrite occurs throughout the specimen in linear masses along fractures, in coherent patches and as isolated prisms along pyroxene cleavages. It forms irregular prisms, acicular grains and asbestiform fibres. Orientation of the crystals may be consistent within one mass but there is no regional preferred orientation affecting the whole specimen. In some places bands of nephrite appear to have flowed round blocks of diopside rock which have been isolated, and possibly moved, by the surrounding masses of alteration products.

Fine veins of nephrite cut the zoisite.

Comment

The major difference between the specimen from 6.24 m and that described above from 5.89 m is in the evidence of greater mobility in the former specimen. Not only the nephrite but also a mobilised form of epidote have clearly been introduced along fractures, grain boundaries and cleavage planes. It also appears possible that the structure of the host rock has been disrupted and displaced by the mobile phase. This may be the result of tectonic forces but, if so, they were locally rather than regionally applied. Local pressures are perhaps more likely to have been generated by volume changes consequent upon alteration processes producing hydrated phases.

The time relationships established from the specimen from 5.99 m are supported by the evidence in the specimen from 6.24 m. The zoisite which was not encountered in the specimen higher up the drillhole is younger than the diopside and its early tremolitic alteration product but is older than at least the latest phase of nephrite development.

Specimen 6231 RS 168, TS C42271, 6.59 m

Rock name. Cowell Jade.

Hand specimen

The specimen consists of three regular bands of dark grey, light grey and greenish-grey. The bands are perpendicular to the length of the core.

Thin section

Although three bands are distinct in hand specimen the rock is seen in thin section to be virtually monomineralic. The difference between the bands is one of grain size alone and the only mineral present of any significance is nephritic tremolite. The green, light grey and dark grey bands consist respectively of medium grained, coarse grained and very fine grained nephrite respectively. The only other minerals present are scattered remnants of partially replaced tremolite and a few very fine grains of a highly birefringent mineral which is probably sphene.

The most abundant lithology is the very fine grained nephrite which forms a closely interlocked, felted mass of fibrous and lamellar grains. Unlike the more coarsely crystalline nephrite, the very fine grained material displays a detectable tendency to a preferred orientation. The orientation is not universal but is fairly prominent when the foliation plane is at 45° to the cross hairs of the microscope. The plane is at about 65° to the length of the core.

The fine grained nephrite invades the coarser material along grain boundaries and has formed a series of embayments along the contact between the two bands.

Comment

The fine, felted nephrite probably represents the true Cowell Jade. It would be a tough, compact but fairly easily worked stone. The evidence of specimen RS168 indicates that the felted nephrite is probably the latest alteration product of the system and should be added to the sequence already established.

It is possibly contemporaneous with the oriented nephrite seen in fractures in other samples.

The petrogenetic history so far established is thus:

1. Dolomite sedimentation with quartz and minor clay.
2. ?Possible metamorphic differentiation and alteration.
3. Epidote and diopside lithologies representing respectively calcium and magnesium rich sediments.
4. Partial amphibolitisation of diopside and recrystallisation of epidote.
5. Formation of zoisite.
6. Alteration of amphibole, diopside and epidote minerals to coarse and medium grained nephrite.
7. Replacement of coarse and medium grained nephrite by fine, felted nephrite with fracturing and imposition of a moderate regional foliation.

Specimen 6231 RS 169, TS C42272, 7.69 m

Rock name. Banded epidote amphibolite.

Hand specimen

The rock is banded in shades of grey. The bands are broad, imprecisely bounded and sub-parallel to the width of the core. A few dark grains are distinct from the matrix which otherwise appears to be fine grained. A preferred orientation is evident in places along the direction of the banding.

Thin section

The rock consists mainly of fine to medium grained nephrite with relict patches of partially replaced tremolite and bands rich in iron bearing epidote and in zoisite.

The nephrite is rarely as fine grained as in specimen RS168. It consists of fibres, needles and ragged feathery flakes in the finer bands and of somewhat ragged prisms in the coarser bands. The coarser material exhibits a higher degree of preferred orientation than the finer and one band in particular consists of closely packed, almost parallel, long, thin prisms.

The relict tremolite occurs as large, ragged, patchy and discontinuous grains which are corroded and invaded by the fine nephrite amphibole.

Iron-bearing epidote occurs as the relatively coarse grained crystals that are visible in hand specimens. They are disposed in a band but are not continuous. In plane polarised light they are pleochroic in shades of pale yellow-green and they exhibit high polarisation colours between crossed polarisers. The crystals are marginally corroded by fine grained nephrite and often are surrounded by a reaction rim of iron-poor epidote.

A finer grained, iron-poor, fragmentary epidote or clinozoisite is distributed through the band of coarse, oriented nephrite.

The orthorhombic zoisite occurs as a lenticular band in one corner of the section. It consists of closely intergrown, relatively well-shaped prisms, often with lamellar twinning. There is some indication that fine grained nephrite replaces zoisite but contacts between coarser nephrite and zoisite appear to be mainly those of an equilibrium assemblage.

Fine, ragged and elongated grains of sphene are associated with the zoisite and clinozoisite.

Comment

Textural and time relationships deduced from the specimen do not differ from those suggested earlier in the investigation except that there is some indication that the early stages of nephritic amphibolitisation may overlap with the recrystallisation and alteration of epidote to zoisite.

Specimen 6231 RS 170, TS C42273, 14.87 m

Rock name. Silicified granitoid gneiss with retrograde alteration.

Hand specimen

The rock is strongly banded in grey and pink. The pink bands are coarse grained and consist partly of feldspar but largely of quartz in lenticular pods. The grey bands are indeterminate in both texture and composition except that thin layers of dark green minerals are seen in places.

Thin section

Quartz occurs in two forms. It is widely distributed as medium grained patches of mosaic grains but also occurs as extremely coarse grains and pods with a replacive relationship to other constituents. The mosaic quartz grains are separated by moderately complex intergranular sutures and appear to be the product of partial annealing in silica granulated by stress. The very coarse grains embay and surround adjacent minerals and are clearly the product of a late stage silicification.

The feldspars are sometimes polysynthetically twinned and sometimes untwinned but for the most part a sericitic alteration precludes the optical identification of feldspar composition. Much of the darker bands are made up of altered feldspar and quartz.

The green mineral which is seen in hand specimen when concentrated into substantial bands, is seen in thin section to be widely distributed. It is a chlorite with pale green to pale brown pleochroism, anomalous birefringence and a small 2V. It is probably a penninite. In places it is clearly a pseudomorph after a mica, probably biotite.

Minor sphene and opaque minerals and rare zircon and apatite are also present.

Comment

The specimen clearly demonstrates that after the major regional metamorphism had produced a moderately high grade gneiss with a strongly oriented fabric, a second episode of stress granulated the quartz. At the same or at a different time an episode of hydrous alteration sericitised the feldspar, altered the mica to chlorite and introduced additional quartz. More than one such episode may have taken place. This type of petrogenetic history is compatible with the suggested alteration of the dolomitic sediments and amphibolitised calc silicate rocks derived from them.

Specimen 6231 RS 171, TS C42274, 17.48 m

Rock name. Banded calc silicate rock.

Hand specimen

The banding is at an angle to the length of the core and is marked by colour changes in shades of grey and greenish-yellow and by changes of grain size between very fine and coarse.

Thin section

The major mineral constituents are members of the epidote-zoisite group and of the tremolite-nephrite group. An important addition, not encountered in the specimens from higher in the drillhole, appears to be wollastonite.

The epidote minerals include iron-bearing epidote, iron-free clinozoisite and orthorhombic zoisite. The two former phases tend to be closely intergrown in bands with a mosaic structure. The zoisite tends to be patchy and associated with nephrite in alteration assemblages.

Tremolite occurs in relict grains but also in what appears to be a late re-growth of coarse tremolite which post-dates at least some development of nephrite. In two bands across the section the late tremolite is associated with a mineral with most of the optical properties of wollastonite but an anomalous optical orientation. This should be checked by non-optical methods of identification.

A second mineral requiring x-ray diffraction, powder photography or electron probe microanalysis is closely associated with the apparent wollastonite. It occurs as bundles of fibres with a low refractive index and low birefringence. It is possibly antigorite.

Evidence that the apparent wollastonite, possible antigorite and re-grown tremolite are late stage developments is obtained from thin veins containing a mineral with low birefringence and multiple twinning which may be a calcium zeolite akin to scolecite but which again requires confirmation of identification. The veins are sharply defined when crossing bands of epidote and early tremolite, well defined but partly replaced by late acicular nephrite in the nephrite bands but almost completely obliterated in regrown tremolite and totally absent in the apparent wollastonite.

The wide band of nephrite at one end of the section contains several forms of the mineral which probably represent different growth stages. The most prominent structures are radial clusters of long prisms. Interstitial to these fans and rosettes are short, ragged irregular prisms. Superimposed on both these forms but most prominent in the veins where they are the only nephrite crystals, is a network of acicular crystals.

Sphene and apatite are present in the epidote bands.

Cavities in the band of apparent wollastonite are filled with an isotropic mineral of low refractive index which is almost certainly fluorite. The fluorine may have formed part of the solutions responsible for the latest stage, and undesirable, alteration processes.

Comment

The identity of three phases should be checked by x-ray diffraction, x-ray powder photography or, preferably, by electron probe microanalysis. These are: the probable wollastonite, the possible antigorite and the possible scolecite in the vein system. There is some uncertainty in the optical determination of these minerals.

Regardless of the identity of minerals not seen in other specimens of this suite, there is evidence of a type of alteration not encountered higher up the drillhole. It appears that the trend in which nephrite is formed in finer and finer grain sizes by successive episodes of recrystallisation from, among other minerals, tremolite, can be reversed at a later stage of alteration. Coarse grained, if imperfect, tremolite apparently grows at the expense of finer grained nephrite.

Some of the differences between specimen RS171 and the other specimens are probably the result of a higher calcium oontent in the original sediment. This is expressed in a high epidote abundance and also by the probable presence of wollastonite, fluorite and a calcium zeolite. Since wollastonite does not accommodate any significant amount of magnesium, the presence of antigorite is possibly explained by magnesium rejected from an original carbonate source or from a tremolitic amphibole when calcium silicates such as wollastonite formed. Both calcium and magnesium appear to be mobile at a late stage.

If the latest episode of alteration tends to produce coarsely recrystallised grains, the best Cowell Jade is not, as appeared from the specimens higher up the drillhole, the most strongly altered as well as the most magnesium rich rock. The finest jade appears at this stage to be derived from a diopsidic parent but with advanced, not terminal, alteration.

Specimen 6231 RS 172, TS C42275, 17.74 m

Rock name. Amphibolite.

Hand specimen

The specimen is grey and weakly banded by grain size variations but the bands are wide, irregular and poorly defined. A few darker grains or patches indicate rare mineralogical variations.

Thin section

The rock is almost monomineralic, consisting almost entirely of amphibole. Most of this is coarse enough to be defined as tremolite but interstitial fine grained amphibole may be classified as nephrite. The massive, very fine grained nephrite which constitutes the best Cowell Jade is absent.

In the coarser grained bands the tremolite tends to form long, prismatic crystals, often in a radiating cluster. The clusters are fan shaped rather than completely rosette shaped and many grains are randomly oriented. The finer grained bands consist of an interlocking mesh of fine prisms and felted nephrite. No preferred orientation is detectable.

The rare patches of minerals other than amphibole consist of finely fragmented zoisite and clinozoisite and a few patches of possible antigorite. Fragmentation of the epidote suggests the application of some stress, whether tectonic or related to volume changes.

Occasional cavities contain the isotropic mineral which is almost certainly fluorite.

Comment

The dependence of the process forming jade on two major factors, the right composition and the right degree of recrystallisation, is underlined by this specimen. The composition is ideal in that it is almost 100% tremolite. The absence of good quality jade, that is the paucity of fine, felted nephrite, must be entirely due to the absence of the right temperature, pressure or dynamic factors to promote the fine grained recrystallisation of the tremolite. Alternatively, the fine grained nephrite that is present may be relict material from which coarser blades of tremolite have grown by later replacement. Possibly the presence of fluorite is an indication of late recrystallisation, catalysed by fluorine. On textural evidence some tremolite is older and some younger than the nephrite.

Specimen 6231 RS 173, TS C42276, 22.20 m

Rock name. Serpentinised marble.

Hand specimen

The rock is partly massive and white in colour and partly a greenish-grey colour with a poorly defined fine banding. The bands are formed by subspherical grains of a green colour and form an angle with the length of the core.

Thin section

The matrix of the rock consists of a coarse grained mosaic of calcite and dolomite. Dolomite predominates in the white patch but the two carbonate phases are approximately equal in abundance in the banded part. Grain boundaries are often granulated and granulated patches are common.

The material which is seen as green in hand specimen is colourless to faintly brown in thin section. The grains are subspherical to irregular and of medium grain size. Most of them consist of a very weakly birefringent, fibrous mineral of low refractive index. Some grains are scaly or irregular in internal structure but in most grains the fibres are parallel and form coherent patches, sectors and concentric zones. The regularity of the fibres suggests that the mineral making up the serpentinite is chrysotile rather than the more common antigorite. Optical identification is not entirely reliable in fibrous minerals and non-optical methods are recommended.

Not all the green minerals are serpentinite. A few round grains of a pale green colour are diopside. Equally rare grains
oxidized chlorite
of penninite are also present.

Patches and trails of fine opaque grains are widespread throughout the rock. These are probably ilmenite since some grains carry a reaction rim of sphene.

Comment

The serpentinite is presumably derived from the retrograde alteration of magnesium silicates. It is possible that the original mineral may have been a forsteritic olivine but the only remaining evidence of a parental silicate is of rare diopside. Retention of carbonate minerals rather than total conversion to silicates is possibly the result of a low silica content (12%) in the original sediment.

Specimen 6231 RS 174, TS C42277, 23.15 m

Rock name. Serpentinised and recrystallised marble.

Hand specimen

The rock is more prominently greenish than specimen RS173. The colour is due to a greater abundance of green minerals which are less distinct as individual grains than in RS173. One corner of the specimen appears to be composed of massive green material. An oriented fabric at an angle to the length of the core is distinguishable but more prominent textural features are a dark ovoid patch and a few discontinuous dark bands.

Thin section

Substantial textural differences between specimens RS173 and 174 are evident in thin section and are responsible for the difference in appearance of the hand specimens. The overall texture of RS174 is much finer grained and the green silicate is interstitial rather than forming subspherical grains.

The carbonate component is fine grained, irregularly crystalline and often acicular in form. It has clearly been subjected to a similar recrystallisation as that affecting the tremolite in other specimens. The preferred orientation which is detectable in hand specimen is very weakly displayed in thin section. The fine fabric is randomly oriented with tufted and radiating clusters of acicular grains. Only a rather imperfect alignment of weakly concentrated calcite and dolomite grains forms the oriented fabric.

The dark areas are formed by concentrations of fine grained, interstitial serpentine minerals, dominantly antigorite in this specimen. The mineral is widespread throughout the specimen but is patchily concentrated.

Chlorite is relatively coarse grained and moderately abundant. It occurs as well shaped flakes, almost certainly pseudomorphous after a mica, probably phlogopite. Three varieties are present and single flakes often include more than one of the varieties. The most abundant form is the penninite encountered in specimen RS173. Another abundant form is colourless in plane polarised light but displays an anomalous green polarisation colour between crossed polarisers. A less abundant variety is weakly birefringent in shades of grey. The optical orientation of the penninite is anomalously length slow but the other two varieties are length fast. All three varieties probably represent different stages in the alteration of a phlogopite parent mineral and probably differ little in composition.

Comment

The effect of an additional episode of recrystallisation in specimen RS174 has been structural rather than compositional and reinforces the suggestion that the retention of a carbonate phase is the consequence of an initially low silica content (18%) rather than any difference in applied stress or thermal regime. No significant addition of silica is evident in the mineralogy.

Specimen 6231 RS 175, TS C42278, 24.23 m

Rock name. Amphibolitised diopside rock.

Hand specimen

The specimen is irregularly banded in shades of grey. Pale to medium grey broad bands are consistently oriented at about 40° to the length of the core but the dark grey, narrow bands are partly discordant. Fine, branching fractures are frequently filled with white or green minerals.

Thin section

The brown banding is the result of alternations between coarse grained diopside (white to pale grey) and fine grained nephritic amphibole (medium grey). A second generation of finer grained nephrite (dark grey) is responsible for the finer bands, some of which are discordant to the broad banding. The narrow, branching veins diminish in places to fractures without filling but elsewhere contain carbonate, serpentinite and fine grained diopside. The carbonate veinlets tend to cut the serpentinite (probably antigorite) but in places the two phases occur in the same fractures. Both calcite and a calcium rich dolomite occur in the veinlets, often in the same fractures. The diopside occurs partly in broader fractures which are older than both other veinlet systems and in which the diopside is altered and partly in narrow fractures which cut both carbonate and serpentinite veinlets.

The diopside tends to be coarse grained but strongly fractured and in places, particularly where substantially replaced, is granulated.

Coarse grained tremolite, encountered in other specimens from the drillhole, is absent from this specimen and the alteration product is a fine and very fine grained nephrite. The nephrite does not form large enough areas to be valuable as jade and is not of the closely felted variety. Relict fragments of diopside are frequently included in masses of nephrite.

Epidote is rare and occurs as occasional coarse, fragmented grains in the diopside bands.

Comment

Apart from minor quantities of calcium bearing carbonates and very rare epidote, there are no specifically calcic minerals in the rock. The calcium content of 18% CaO must be contained, with the 20% MgO in the diopside and nephrite. This represents approximately one calcium atom to one magnesium atom and, since this is the ratio in stoichiometric diopside, apparently indicates the ratio of magnesium to calcium which, in the presence of excess silica, promotes the formation of diopside rather than diopside plus epidote. The abundance of aluminium must also affect the formation of epidote but the 5% Al_2O_3 in the rock has not led to a significant epidote content and the major control is apparently the calcium to magnesium ratio. Conversion of a small amount of diopside to nephrite has not significantly affected the overall Mg:Ca ratio.

Specimen 6231 RS 176, TS C42279, 26.96 m

Rock name. Serpentiniferous marble (ophicalcite).

Hand specimen

Broad bands in shades of green, grey and purple cross the specimen in an orientation perpendicular to the length of the core. The prevalent colour of the matrix is a purple grey but one band consists of a slightly greenish-grey and half the specimen is tinted green by subspherical grains of a jade green and a yellow-green colour.

Thin section

The most abundant component of the rock is a medium grained carbonate which stains strongly with the alizarin red dye and is therefore a calcite low in magnesium content. This accounts for the 30% content of CaO. Dolomite occurs only in the grey band, where it is the only carbonate. Much of the carbonate is acicular.

The second most abundant component is chlorite but two chlorite minerals are present. Chlorite grains are similar to those of specimen RS174 and include normal penninite and the anomalous green-polarising chlorite, often both in one flake. The chlorite is again a probable alteration product of phlogopite and occurs as well shaped flakes. Chlorite grains are yellow-green in hand specimen, colourless in thin section.

Grains of a second green mineral, serpentinite, of darker, less yellow shade, are also present and these too consist of two phases. The serpentinite consists mainly of chrysotile in clusters of well crystallised acicular fibres. These tend to form bands and sectors within a subspherical outline. Less systematically organised antigorite also fills outlines of coarser grains, probably pseudomorphously, in random, felted masses. Some of the patterns of alteration visible in serpentinised grains indicate that the original parent mineral was an olivine, presumably forsterite, rather than diopside. Alteration of diopside tends to proceed inwards along parallel cleavage planes but olivine alters along broad, curving fractures rather than regular cleavage. Traces of such fractures in the serpentinite alteration are thus evidence supporting an olivine host. This is the only evidence since no trace of the former mineral survives and grain shapes are not on the whole reliable evidence owing to surface corrosion effects.

The grey to purple bands are composed of fine grained, often acicular carbonate with a similarly fine grained silicate of low birefringence. The silicate forms tufted flakes, often with a radial distribution and is probably antigorite.

Carbonate was apparently remobilised at a late stage. Although no discordant veinlets occur in this specimen, some serpentinised grains have been marginally corroded and penetrated along fractures, often along the same fractures through which serpentinisation was initiated.

Comment

The specimen is similar to RS174 in that a silica content of about 18% has led to the probable formation of forsterite rather than diopside, even in a calcium rich system. Subsequent alteration, and in some bands a recrystallisation of coarse grained assemblages to a finer grain size, have produced a low temperature serpentinisation without any evidence of an intermediate temperature pyroxene and amphibole assemblage. This has given rise to an ornamental marble but not to any jade.

Specimen 6231 RS 177, TS C42280, 27.36 m

Rock name. Micaceous ophicalcite.

Hand specimen

A fragmentary and irregularly developed banding in white and green forms an angle with a rather weak preferred orientation in fine grained constituents.

Thin section

The specimen contains coarse grained calcite, fine grained dolomite, much serpentinite and a little mica, probably phlogopite, altering to chlorite.

The calcite occurs as mosaic masses in discontinuous bands and patches in various orientations. It appears in many places to be a late stage product of recrystallisation and minor replacement of serpentinite.

The dolomite occurs in bands of closely interlocked and poorly defined fine grains.

Serpentinite occurs in coherent masses and as a dispersed, interstitial mineral. Rare bands consist of serpentinite in pseudomorphous outlines after earlier minerals, probably olivine but this form is not abundant in the section as a whole.

Chlorite occurs as individual flakes and with the serpentinite in large masses. It is of the colourless type with low birefringence but is visibly of micaceous parentage as stages of the transition between phlogopite and chlorite are traced in different grains and even within one grain in places. The mica is rarely present without some alteration and often forms a nucleus of a grain altered to chlorite round the margins. The very small quantity of mica remaining is reflected in a potash determination of only 600 ppm.

Comment

Despite a silica content almost twice as high as that of the marble from 0.4 m above it, specimen RS180 still contains no nephritic alteration product. The silica limit at which amphibolitic alteration (and a presumed diopside parent) appears is apparently quite sharp and close to 40% SiO_2. An increase in silica below this level simply leads to an increase in the serpentinitic and chloritic alteration products. Calcium is retained in the carbonate phase, together with magnesium in excess of requirements for the silicate phases serpentinite and chlorite.

Specimen 6231 RS 178, TS C42281, 29.29 m.

Rock name. Tremolitic marble with amphibolitised pyroxene.

Hand specimen

The specimen is weakly banded in shades of white and grey. One end is fine grained and carbonate rich but most of the other end consists of coarse white crystals of pyroxene.

Thin section

The finer grained bands of the rock consist of fine to medium grained, closely interlocked calcite and tremolite. Concentrations of both calcite and tremolite vary in patches within the bands. In some bands the tremolite is fine grained enough to make a moderately good jade but there is not enough of this material to be worked separately as jade.

The coarser grained bands consist of large but fragmented and patchy crystals of normal diopside together with a second pyroxene with positive sign, low birefringence and multiple twinning which is distinguished from the diopside by a small (25°-30°) optic axial angle. It appears on this evidence to be a pigeonite, or at least a pigeonitic diopside. The pyroxenes are peripherally replaced by fine grained tremolite which also invades the broken grains along fractures and cleavages.

No epidote was observed but neither were any serpentine phases or chlorite.

Comment

The silica content of this specimen, determined to be 41% SiO_2, just exceeds the critical 40% for the development of the pyroxene-tremolite assemblage with excess calcium remaining as calcite. Despite the excess calcium, which is in an almost 3:2 ratio with magnesium, no epidote minerals have formed. It appears that a silica content of 50% SiO_2 or better is required to form epidote where diopside is competing for the silica. It is possible that the low aluminium content of 3% Al_2O_3 may have inhibited the formation of epidote.

Specimen 6231 RS 179, TS C42282, 31.18 m.

Rock name. Weakly serpentinised marble.

Hand specimen

The specimen consists largely of carbonate, both coarse and fine grained. It is patchy rather than banded, with a tendency for fine grained patches to be greenish in colour owing to the associated serpentinite. A few thin, straight fractures carry fine grained carbonate.

Thin section

Both calcite and dolomite are distributed throughout the specimen but the distribution of the two phases is uneven and calcite rich and dolomite rich patches are common. Dolomite tends to occur in coarse grained crystals with granulated grain boundaries while calcite tends to occur in finer grained mosaics with a random orientation. However, neither carbonate occurs to the total exclusion of the other and both may crystallise in the same habit.

With a silica content of less than 8% it is not surprising that serpentinite is not abundant. It occurs as fine grains of antigorite, usually concentrated in patches and discordant veins. Some antigorite is pseudomorphous after a platy mineral. Since a few ragged relics of chlorite are present, the alteration has probably been in two stages; from phlogopite to chlorite and from chlorite to antigorite. Many of the patches of fragmentary antigorite fill a rounded pseudomorphous outline with fine grained dolomite. The flakes of altered mica, now antigorite, are corroded at the margins by poorly crystallised, fine grained dolomite.

It appears that a dolomitic phase was remobilised and partially replaced magnesian silicates at a very late stage in the alteration history of the rock. A line of fine dolomite often occurs in the middle of a veinlet of antigorite. Fine veinlets of calcite cut the antigorite-dolomite veinlets and constitute the latest mobilisation process to affect the rock.

Comment

The rock is essentially a dolomitic marble, as indicated by the very low silica and a 40% loss on ignition, and its history is one of successive recrystallisation and mobilisation, chiefly of the carbonate phases. The few silicate phases present are magnesian, despite a high CaO determination of 30%. Final alteration processes, probably at relatively low temperatures and in the presence of carbonate in solution, reversed the initial development of silicate phases and partly restored them to magnesian carbonates.

Specimen 6231 RS 180, TS C42283, 31.40 m.

Rock name. Banded diopside-tremolite rock.

Hand specimen

The specimen is divided into two parts along a line approximately perpendicular to the core. About half of the specimen is a dark greenish-grey with relatively coarse grains delineated by reflections from cleavage planes. The other half of the specimen is light grey and appears to be rich in coarse grained carbonate from the reflections from cleavage planes.

This is misleading as it is seen in thin section to be largely fine grained and composed mainly of tremolite with recrystallised calcite as a subsidiary phase.

Thin section

The dark greenish-grey part of the specimen is composed of coarse to very coarse grained diopside with a little interstitial calcite. The light grey part consists of fine to very fine grained tremolite with patches of medium grained calcite forming lenticular mosaics with an oriented disposition.

The diopside occurs as coherent bands of closely packed crystals varying only in grain size from band to band in a continuous fabric. Grains vary from euhedral to anhedral but all are well crystallised. The small amount of calcite fills a few interstitial spaces without any obvious reaction and is presumably at equilibrium with the diopside. Some grains are partially replaced by fine grained tremolite.

The tremolite of the light grey part occurs as irregular, ragged prisms and clusters of wispy acicular or feathery forms in sub-parallel to radiating arrays. Most of the tremolite is not fine grained enough to form a nephrite jade but a finer grained and closely interlocked felt occurs in patches and bands within the main mass. The fine tremolite generally, and the finer grained bands within it in particular, exhibit a preferred orientation at an angle to the compositional boundary between the diopside band and the tremolite band.

Calcite patches are composed of a medium grained mosaic of well crystallised grains in close contact along simple grain boundaries with occasional perfect 120° triple junctions. The calcite has annealed after recrystallisation to form an equilibrium assemblage. The outer margins of the calcite patches do not exhibit strong evidence of reaction with the surrounding tremolite and the two phases are probably close to equilibrium. In places where there is textural evidence of reaction the tremolite appears to have replaced the calcite. Lenses of calcite are oriented both along and perpendicular to the fabric of the tremolite.

There are no relict grains of diopside in the tremolite and the main position in which the two phases are in contact is along the boundary of the two bands. Here there is strong evidence of reaction in which fine grained tremolite has invaded diopside along cleavages and grain boundaries. Some alteration has penetrated beyond the contact and has affected diopside within the main diopside band.

Comment

The persistence of calcite may be the result of a relatively high calcium content (27% CaO) and low magnesium content (16% MgO) despite what appears to be an adequate silica content (43% SiO_2) to convert all the carbonates to silicates. (Compare, for example, with specimen RS175). The absence of an epidote phase in the presence of excess calcium may be attributed to the low aluminium content (<0.5% Al_2O_3).

Specimen 6231 RS 181, C42284, 31.66 m.

Rock name. Cowell Jade.

Hand specimen. None.

Thin section

Nephrite makes up the highest proportion of the rock and includes much of the fine, felted material typical of better quality jade. However, a substantial amount of coarse grained tremolite is also included and an irregular and fragmentary band of fibrous amphibole crosses the specimen at an angle to the length of the core.

The finest nephrite is oriented randomly but slightly coarser grains form thin, discontinuous bands in places. The main oriented fabric is imposed by a system of thin anastomosing planes accentuated by limonite layers and with a general orientation at an angle to the length of the core. The nephrite is somewhat dark in colour and dusty in appearance. The iron content of the specimen (2% Fe_2O_3) is low but may encompass fine inclusions in the amphibole as well as the limonite staining.

Coarse grained inclusions of a colourless, clear amphibole with a highly fibrous structure are scattered throughout the fine grained nephrite and form an almost continuous band at one end of the section. The amphibole is probably tremolite as there is no optical discontinuity between it and the nephrite except for the clear, dust-free transparency and in places a marginal concentration of black, opaque material which is probably a segregation of material forming the dusty inclusions. In the band of concentrated tremolite the amphibole forms tufted and radiating clusters of fibrous and feathery prisms with a substantial concentration of opaque granules between the clusters. Fan and rosette shaped clusters of the fibrous tremolite are spread from the edge of the band into the felted nephrite. In places the tremolite is altered wholely or in part to chlorite.

The wide but fragmented band of highly fibrous amphibole crossing the middle of the section of an angle to the length of the core is heavily darkened by dusty inclusions. The dense masses of fibrous material are distinguished from the surrounding nephrite by refractive index differences. However, in places the index appears to be higher and in other places lower than the nephrite. The birefringence of the fibres appears to vary from place to place. Some of the fibres are a yellow colour and in places segregations of iron have been oxidised and hydrated to limonite with a fibrous appearance. The polarisation colours displayed are nowhere high enough to identify talc and the fibrous material appears to be amphibolitic. It is probably a composite material including amphiboles such as cummingtonite and anthophyllite, the former possibly altering to the latter by rejection of iron. A check of identification by non-optical methods is recommended.

Rare grains of apatite are present.

Comment

The development of both fibrous tremolite and the fibrous masses of other amphiboles appear to be later stage processes than the formation of felted nephrite. The presence of apatite is possibly diagnositc of late stage, low temperature alteration. Fluorite was sought but not identified.

Specimen 6231 RS 182, TS C42285, 31.7 m.

Rock name. Banded calcium and magnesium silicate rock.

Hand specimen

The specimen is divided into two sections by a plane at an angle to the length of the core. One section contains white material spotted with patches of green and grey minerals, often with a radiating structure. The second section is composed of grey material tinted with green except bordering a fracture where broad zones each side of a leached zone are tinted a purple shade of grey.

Thin section

The white material consists of a combination of an amphibole, a probable member of the chondrodite series and minor fragmented epidote. The green spots consist of coarse grained, fibrous tremolite and the grey spots of fine grained, felted nephrite. The greenish grey material in the second portion of the specimen is fine grained chlorite. The chlorite is coarser in grain size each side of the fracture and has apparently acquired a purplish tint. This is not evident in thin section.

Optical identification of the minerals in the white part of the rock is not entirely definitive and a more reliable identification by electron probe microanalysis is recommended. The amphibole is highly birefringent with high refractive indices and a positive 2V of about 50°. These properties are somewhat anomalous in view of the low iron content of the rock (2.36% Fe_2O_3) but the mineral is probably in the cummingtonite-grunerite series. It is dark with dusty inclusions and may have rejected iron after initial crystallisation. A second mineral present is tabular, even higher in refractive index and birefringence and has a high positive 2V. It appears on these properties to be a member of the norbergite-chondrodite-humite-clinohumite series with a formula of:

$$Mg(OH,F)_2.nMg_2SiO_4$$

where n = 1 to 4.

A third, very minor, constituent of the white material is epidote. This occurs as rare grains which are integral and complete but which are made up of small, lenticular fragments. It appears to have been granulated by stress but there is no preferred orientation in the fabric.

The white material has been invaded by large and small patches containing medium to coarse grains of fibrous tremolite. The tremolite often forms radiating clusters which give the patches of alteration the rosette structure visible in hand specimen.

Other patches contain felted tremolite which is fine enough to justify the designation of nephrite. In some of the larger patches an outer zone of nephrite surrounds the coarser tremolite. The relationship between tremolite and nephrite indicates that at most points the nephrite is the later phase but in a few places there appears to have been a growth of fibrous tremolite which postdates the nephrite.

A few cavities contain an isotropic mineral of low refractive index which is probably fluorite. Some cavities are rimmed by relict granulated epidote and it is possible that the epidote is preferentially replaced by fluorite.

The plane separating the white and grey parts of the specimen is seen in thin section to be irregular due to veining and embayment of the tremolite-nephrite assemblage by fine grained chlorite. The mineral is fine grained close to the contact but increases in grain size substantially away from it and towards the fracture noted in the hand specimen. The immediate walls of the fracture consist of very fine grained chlorite but grain size again increases on the other side of the fracture. A second reduction of grain size occurs adjacent to another band of nephrite and tremolite. The chlorite is optically positive with a low 2V and in coarse grains exhibits a first order orange polarisation colour. Texturally it differs from the chlorite encountered in other specimens which appeared to be pseudomorphous after phlogopite. The chlorite in specimen 182 is fibrous and frequently forms radiating clusters. It is almost certainly a replacement product of tremolite and nephrite.

Comment

The paragenesis is rich in magnesian minerals and minerals in which calcium is subordinate to magnesium. This is probably to a large extent the product of an initially high magnesium content in the parental carbonate sediment, which accounts for the presence of cummingtonite and chondrodite instead of tremolite alone, and for the minimal abundance of epidote.

However, the overall calcium to magnesium atomic ratio is almost identical to that which in specimen RS181 resulted in a dominantly tremolite mineralogy. The other cause of a high magnesium content is an alteration process in which magnesian chlorite replaced both tremolite and nephrite. This imposes another constraint on the conditions promoting the formation of good quality jade. Presumably the alteration process involved substantially an aqueous solution while the recrystallisation of tremolite to nephrite occurs in essentially dry conditions. Indeed the fine grain size of the best quality jade may in itself be an indication of a high viscosity, possibly with the properties of a melt rather than a solution.

The sequence of alteration processes in this specimen appears to be:

1) Magnesium-rich carbonate sediment.
2) High temperature alteration to ?olivine+?clinoenstatite +diopside.
3) Lower temperature alteration to chondrodite+ cummingtonite+tremolite.
4) Partial alteration of tremolite and magnesian silicates to nephrite.
5) Some regrowth of tremolite. Replacement of minor epidote by fluorite.
6) Replacement of all earlier materials by chlorite in a late magnesium metasomatic alteration.

Specimen 6231 RS 183, TS C42286, 31.88 m.

Rock name. Brecciated diopside rock.

Hand specimen

The rock consists of angular fragments of white material in a grey matrix. No grain boundaries are prominent enough to permit the estimation of grain size. A very weak preferred orientation is evident in some lines of fragments at a shallow angle to the width of the core.

Thin section

The rock appears to be essentially monomineralic and as far as may be determined the mineral appears to be diopside. All grains are optically positive but in some the optic axial angle is typically large while in others the pyroxene appears to be closer to pigeonite. Very few grains exhibit high birefringence but almost all appear to have been sectioned on planes close to perpendicular to the optic axes. A non-optical check on the identification is recommended since such an exact preferred orientation is unusual.

Little or no different in refractive index is evident between the diopside fragments and the finely granulated matrix and it may be assumed that the matrix is at least dominantly fine diopside.

A few coarse grains exhibit an anomalous polarisation colour typical of clinozoisite.

The matrix is almost uniformly low in birefringence and high in refractive index but some patches are slightly lower in refractive index and may be composed of tremolitic alteration products of diopside.

Abundant fine, dusty granules of opaque material make the whole rock, but particularly the matrix, grey and with somewhat obscured detail.

Some breccia fragments are composed of earlier breccia, indicating a complex stress regime.

Comment

The specimen is highly significant in that the severe stress to which the diopside has been subjected has not led to the development of nephrite or to any substantial amphibolitic or other form of alteration. Stress by itself simply granulates the diopside. The formation of Cowell Jade requires another factor or combination of factors and appears not to be the result of regional deformation alone, however intense.

Specimen 6231 RS 184, TS C42287, 33.20 m.

Rock name. Altered calc-silicate mylonite.

Hand specimen

The specimen consists of poorly defined, lenticular areas of grey, pink and white, surrounded by irregular bands of dark grey. Individual grains are not distinguishable. There is a weak preferred orientation at a low angle to the width of the core.

Thin section

The granulation of the rock is intense but the strong alteration, which contrasts with specimen 183, is associated with veins and patches containing hydrous phases.

The coherent fragments may originally have been composed of diopside as are those in specimen RS183 but none of this mineral is recognisable. Tremolite has developed in a flaky, fragmentary mode of occurrence within the granulated material. Large areas of fragments often extinguish together in optical continuity although they are not physically continuous. Some of the tremolite is fine grained enough to be classed as nephrite but most of it is of considerably coarser grain size.

Some epidote minerals occur in patches and veinlets within the granulated masses but most of the epidote, clinozoisite and zoisite occur in the bands of highly recrystallised material between the masses and in discordant veins. Zoisite may be responsible for the pink colour seen in the hand specimen but is particularly common in late veins which cut granular masses and intervening bands alike.

Another mineral which occurs in late veinlets, often associated with zoisite, is a zeolite with polysynethtic twinning, probably scolecite.

Minor quantities of chlorite, often after mica, are formed within the interstitial bands of altered minerals.

Scattered, irregular grains of sphene are widespread but not quantitatively abundant.

Comment

The low magnesium and high aluminium determinations are hard to reconcile with the observed mineralogy but the abundant epidote is reflected in a moderate calcium content. The specimen illustrates clearly that substantial alteration occurs when volatile phases are introduced through discordant structures. In this example the alteration is not of a type which produces good jade. Trace element analyses indicate that the alteration involved the introduction of barium, strontium, rare earths, niobium, zirconium, thorium and very minor uranium.

Specimen 6231 RS 185, TS C42288, 34.04 m.

Rock name. Altered calc silicate mylonite.

Hand specimen

The specimen is predominantly grey and fine grained but lenticular patches and discontinuous bands of brown, dark grey and greenish-yellow are preferentially oriented at a small angle to the width of the core. A thin, meandering veinlet is filled with white and black minerals.

Thin section

The rock is texturally more uniform than specimen RS184. There is little clear distinction between granulated masses and bands of alteration and the grain size of the whole rock is more uniform, owing to a more evenly distributed alteration. However, mineralogical variations are distributed in bands and pods. The fine, discordant veinlets contain quartz and limonite.

Tremolite is present but not abundant. Irregular to lenticular patches and streaky bands contain ragged and feathery grains of tremolite but, despite the higher magnesium than specimen RS184, the epidote minerals are much more abundant than tremolite in specimen RS185.

Fragmented and irregular grains of epidote, clinozoisite and zoisite are scattered throughout the rock and are concentrated into almost continuous bands in some places. The epidote minerals are the most abundant group in the rock.

A mineral not yet encountered in this series of specimens, and the only one in the specimen to form coarse grained crystals, is plagioclase. With a determination of less than 1.5% Na_2O in the rock the plagioclase is probably an anorthite. Extinction angles are not helpful in this regard. The plagioclase occurs both as closely intergrown mosaics of coarse grains, often stressed, fractured and distorted, and as granulated masses, forming bands and lenticles.

A little finely granulated carbonate forms irregular patches and occasional schlieren. The refractive index remains consistently higher than the mounting medium and the carbonate may be magnesite rather than dolomite. This may be partly responsible for the magnesium level determined by analysis which is higher than can be accounted for by the small amount of tremolite present.

A few grains of highly strained quartz are associated with the plagioclase.

Comment

Both specimens RS184 and 185 are composed of bands varying in mineralogical composition. In these circumstances discrepancies in the relationship of mineral phases to the chemical analyses probably reflect the inhomogeneity of the specimen and the possibility that the thin section is not representative of the whole analysed specimen.

Mineralogically the specimen represents a facies too rich in calcium to form nephrite jade. In any case, what little tremolite is present does not form a fine, nephrite felt because the conditions of alteration are not optimum.

The same trace elements are concentrated in specimens R184 and 185.

Specimen 6231 RS 186, TS C42289, 35.30 m.

Rock name. Altered granitoid.

Hand specimen

The rock is made up of medium to coarse grains with rather poorly defined boundaries. Pink, white, grey and black minerals are distinguishable and some grains are platy in structure. A preferred orientation of grains and a weakly banded fabric is evident.

Thin section

The fabric of the rock is seen to be strongly stressed. Distorted grains, granulated and partly annealed mosaics and oriented bands of platy minerals and comminuted material are common. The mineralogy is of a granitoid which has undergone some chemical alteration as well as physical strain. Alteration products such as epidote and chlorite are similar to those of the former carbonate sediments.

The pink grains are coarse microcline crystals with a complex and often distorted twin pattern. The grains are fractured and patchy with incipient sub-grain development and are closely intergrown with plagioclase.

The plagioclase grains are similarly fractured, fragmented and patchy. They are more abundant than the potash feldspar and the granitoid is granodioritic rather than granitic in its feldspar content. It is richer in quartz than a normal granodiorite. Symmetrical extinction angles are imprecise due to strain but appear to indicate a composition of about a sodic andesine. Evidence of calcium introduction in the moderately abundant epidote suggest that the plagioclase composition may have been metosomatically modified.

Quartz is abundant and forms irregular bands and patches of equigranular mosaics with relatively simple intergranular sutures and occasional 120° triple junctions. It also occurs as scattered and less regularly shaped grains and small patches. Bands of finely comminuted material probably consist largely of quartz but may also include feldspar. The finest of these bands cut other structures and fracture large grains of feldspar. The bands often contain epidote, fine grained mica and chlorite. Sharply defined discordant pods of coarse grained quartz which occur at 14.87 m are not seen in this granitoid specimen.

Three kinds of platy minerals are associated with each other to varying extents. A fine grained, pale brown, pleochroic mica occurs in fragmentary patches and in bands marginal to zones of fine granulation. The mica is a type of biotite and appears to be a product of alteration rather than an original constituent. A pale green, pleochroic chlorite with a low birefringence and anomalous polarisation colours forms bands of well shaped platy crystals. This may be an alteration product of original mica. The third type of platy mineral is a pleochroic blue-green to yellow-brown chlorite with a higher birefringence. This forms relatively coarse grained, well-shaped flakes at discordant angles to the main fabric and is possibly the latest phase to develop in the hydrous alteration episode.

Epidote occurs as fragmented crystals associated with chlorite in the highly granulated bands. It is not highly abundant but indicates a mobility of calcium associated with magnesium in chlorite which affected the granitoid rocks as well as the carbonates and calc-silicates at a late stage in the history of the rock pile.

Comment

The movement of calcium and magnesium in hydrous solution at a late stage has been noted in several of the specimens examined. It may be said to constitute a calcium-magnesium metasomatism when related to one specific rock specimen but is probably syngenetic in terms of the formation as a whole. Since the granitoid is affected by it and since the alteration post-dates the tectonic granulation of the rock, it is improbable that any genetic association could be sustained between the granitoid and the metasomatic solutions.

Although it is probable that quartz has been introduced to the granitoid, the introduction antedates the tectonic deformation which produced an oriented structure. Since the movement of calcium and magnesium postdates the deformation it is unlikely that the movement of silica was related to the amphibolitisation of calc-silicate rocks and the formation of nephrite jade.

Specimen 6231 RS 187, TS C42290, 36.51 m.

Rock name. Epidotised feldspathic quartzite.

Hand specimen

The specimen is a coarse grained, pink, weakly banded rock with discordant patches and bands of fine grained, dark greenish-grey material.

Thin section

The rock is a plagioclase-rich quartzite with irregular bands and pods of fine-grained epidote.

The quartz includes coarse grains but is largely broken up into medium to fine grains. The visible fabric consists of bands of granulation rather than original sedimentary bedding. Much of the granulation has been annealed and a range of simple to complex grain boundaries indicate a succession of episodes of stress superimposed on the fabric.

Plagioclase exhibits the same range of grain sizes and shapes as the quartz. It probably forms about 1/3 of the original grains to the 2/3 of the quartz.

A few grains of potash feldspar are present but the trace of potassium in the assay is contained mainly in small inclusions of sericite flakes in the plagioclase.

The epidote occurs in fine but varied grain sizes in masses which are discordant to the fabric imposed by the planes of granulation. Some boundaries of the masses are sharply defined but others are diffuse with epidote grains forming interstitial offshoots from the main masses. Within the masses the original constituents of the rock remain in varied proportions with the epidote.

Small, irregular grains and patches of sphene occur in the areas of epidote.

Rare zircon crystals are found in the quartzite.

The pink colouration of the hand specimen is due to iron oxide and small interstitial clusters of often rounded spots of orange to pink oxide are scattered throughout the quartzite. Limonite stains mark many discordant fractures. The epidote appears to have incorporated, and subsequently exsolved, iron to give a patchy colour variation in plane polarised light.

Comment

The Warrow Quartzite of the contact zone has been affected by the same mobile calcium silicate phase as the overlying granitoid and the altered carbonates above that. Apart from higher silica and minimal potash, the assay of the quartzite resembles closely that of the granitoid. It appears likely that the high quartz content of the granitoid is derived from silica mobilised by reciprocal reactions with the Warrow Quartzite. It is possible that the granitoid was the source of the trace elements concentrated in the alteration of adjacent sediments, such as rare earths, zirconium, niobium, thorium and uranium. The elements may have been mobilised during the alteration of the granitoid and stabilised in epidote precipitated from calcium and silica derived from the carbonate sediments.

PETROGRAPHY OF SAMPLES FROM THE COWELL JADE PROVINCE

SAMPLE: 6231 RS200: TSC48684

Rock Name:
Gneissic Granodiorite

Hand Specimen:
A foliated, pinkish-grey coloured rock containing some larger quartz and feldspar porphyroblasts.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Plagioclase	45
Quartz	30
Potash feldspar	20
Biotite	5
Sericite	Tr
Apatite	Tr
Opaques	Tr-1

This is a well foliated rock comprised mainly of a granular quartz and feldspar mosaic intergrown with minor amounts of biotite. The foliation is defined mainly by a tendency for the biotite to be concentrated in discontinuous stringers with a parallel orientation and by a tendency for the quartz and feldspar to form lenticular bodies. The feldspar in particular tends to form larger crystals up to about 1 mm in size while the quartz tends to form granoblastic aggregates with a typical grain size of 0.1 to 0.2 mm. The quartz bodies in particular have elongate, lenticular shapes oriented parallel to the foliation direction.

Overall the rock has a deformed appearing character with much of the quartz exhibiting granulated textures with sutured grain margins. Many of the large feldspar grains exhibit marginal granulation.

The biotite forms small flakes up to 0.1 mm in length with an intensely pleochroic, dark brown colour. Minor sericite occurs as an incipient alteration product of plagioclase. Opaques form anhedral disseminated grains up to 0.2 mm wide which tend to be intergrown with the biotite or interstitial to the quartz and feldspar grains within foliation lamellae.

This appears to be a plutonic igneous rock which has been subjected to strong deformational effects producing a foliated and granulated texture.

E00232

SAMPLE: 6231 RS201: TSC48688

Rock Name:
Feldspar-Mica Gneiss

Hand Specimen:
This is a strongly banded rock with a brownish-grey colour.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Plagioclase	55
Potash feldspar	20
Muscovite	15
Chlorite	7
Biotite	1
Apatite	Tr
Opaques	2

This is a strongly banded rock comprised mainly of a granoblastic feldspar-rich mosaic intergrown with phyllosilicates which define a well-developed lepidoblastic foliation. The feldspar consists mainly of plagioclase with smaller amounts of potash feldspar and forms crystals with a typical grain size between 0.5 and 1 mm. The mica consists mainly of muscovite/sericite and chlorite, both of which tend to form moderately well-developed flakes concentrated in bands oriented parallel to the lepidoblastic foliation.

The plagioclase generally has a deformed appearing character showing a granulated texture along with deformed twin lamellae. Some of the muscovite is concentrated in bands where it exhibits a very fine, felted character which could also be a deformational feature.

Much of the chlorite forms well-developed flakes up to 0.3 mm long which have a pleochroic green colour and low birefringence. Minor chlorite also occurs as interstitial fillings between the feldspar grains. This chlorite has a slightly different green colour and birefringent character and is thought to be a much later chlorite in the well-developed chlorite flakes which define the foliation direction. The foliated chlorite most likely represents completely altered biotite flakes and locally minor amounts of remnant biotite are included with this chlorite.

Minor apatite forms small disseminated crystals up to 0.2 mm wide. Some opaques are disseminated throught the rock as euhedral to subhedral crystals up to 0.4 mm wide. Opaques also occur as narrow fracture and vein fillings particularly along foliation lamellae. Some opaques form very finely divided intergrowths with chlorite flakes after biotite.

This is a strongly foliated and deformed rock comprised mainly of feldspar and mica. The rock contains two generations of chlorite one of which forms well-developed flakes pseudomorphic after original biotite and another late chlorite which tends to occur interstitially between the feldspar crystals. This later chlorite also tends to form radiating aggregates with a random orientation and is most likely a postdeformational phase.

SAMPLE: 6231 RS202: TSC48689

Rock Name:
Sericitised Feldspar Gneiss

Hand Specimen:
A greenish-grey coloured rock with a banded and foliated character.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Plagioclase	40
Muscovite/sericite	20
Potash feldspar	20
Chlorite	12
Quartz	5
Apatite	Tr
Zircon	Tr
Biotite	Tr
Opaques	3

This sample consists mainly of feldspar (plagioclase and minor potash feldspar) and minor quartz which forms a granular mosaic intergrown with secondary phyllosilicates. The secondary phyllosilicates consist mainly of finely divided muscovite/sericite which tends to be concentrated in bands. Moderate amounts of chlorite are also present as well-developed flakes up to 0.5 mm long which exhibit a preferred orientation parallel to the mineralogical banding.

The sericite-rich bands are separated by feldspar-rich bands in which the feldspar exhibits a deformed, granulated texture. Minor quartz is also present as xenomorphic grains which commonly exhibit granulated margins.

The chlorite is generally a pleochroic green variety with low birefringence. Within localised areas traces of weakly pleochroic brown biotite intergrown with the chlorite indicating that at least some of the chlorite is an alteration product of biotite. The muscovite contains discontinuous stringers oriented parallel to the banding and foliation of a turbid mineral which tends to form a fibrous textured intergrowth. This is thought to represent a finely divided titanium mineral although the fine grain size makes positive identification difficult. Other opaque to translucent iron and titanium oxides form disseminated grains and aggregates up to 0.1 mm wide which are generally intergrown with the chlorite. Traces of apatite and zircon form small disseminated grains up to 0.2 mm wide.

This is a metamorphic rock of probable amphibolite facies grade which has been subjected to strong deformational effects and retrograde alteration with the development of abundant muscovite/sericite and chlorite.

SAMPLE: 6231 RS204: TSC48691

Rock Name:
Amphibolite

Hand Specimen:
A dark grey, strongly foliated and banded rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Amphibole	60
Sericite	20
Epidote	10
Feldspar	10
Carbonate	Tr
Apatite	Tr
Opaques	Tr-1

This is a well foliated and banded rock comprised of amphibole crystals intergrown with altered feldspar. The amphibole crystals tend to have weakly prismatic shapes and exhibit a strong preferred orientation defining a nematoblastic foliation. The altered feldspar forms xenomorphic crystals located between the amphibole crystals and it has been almost completely replaced by sericite and epidote.

Most of the amphibole forms subidiomorphic, prismatic crystals with a pleochroic brownish-green colour. A very small number of larger paler green, weakly pleochroic amphibole crystals are present and are generally surrounded by the darker brown amphibole. These paler coloured crystals have xenomorphic shapes and also tend to contain finely divided carbonate inclusions. They are thought to represent a lower grade, previously existing amphibole which has been largely replaced by the prograde more intensely pleochroic brown amphibole.

Minor remnants of feldspar are disseminated through the rock as intergrowths with the sericite and epidote. Feldspar also occurs as narrow vein fillings up to 0.1 mm wide. This feldspar consists mainly if not exclusively of untwinned potash feldspar. The feldspar shows pervasive replacement of finely divided sericite and very finely granular, turbid epidote.

Traces of apatite form small disseminated crystals up to 0.1 mm wide. Minor opaques are disseminated through the rock as small grains below 0.1 mm wide.

This is an amphibolite facies grade metamorphic rock showing strong retrograde alteration of original feldspar to sericite and epidote.

SAMPLE: 6231 RS205: TSC48692

Rock Name:
Carbonate-bearing Serpentinite

Hand Specimen:
A massive, greyish-green rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Serpentine	60
Carbonate	40
Opaques	Tr

This sample consists mainly of fibrous textured serpentine intergrown with a granular carbonate. The rock has a very uneven distribution of minerals with some areas consisting mainly of serpentine and others consisting mainly of carbonate. The carbonate forms a granoblastic mosaic with a typical grain size between 0.1 and 0.5 mm. Most of the carbonate is colourless although some carbonate has a pale brown, pleochroic appearing colour. Positive identification of the carbonate in this rock would require X-ray diffraction analysis.

The serpentine forms fibrous textured aggregates some of which range up to several millimetres in size. Most of the serpentine patches have xenomorphic shapes and are thought to represent a completely altered mafic mineral. It is possible that the serpentine at least in part could represent altered olivine.

Minor opaques are disseminated through the rock as anhedral grains and aggregates up to 0.2 mm wide.

This is thought to be a magnesian marble containing abundant carbonate (possibly dolomite or siderite) intergrown with serpentine and representing an altered mafic mineral such as olivine.

SAMPLE: 6231 RS206: TSC48693

Rock Name:
Amphibole Schist

Hand Specimen:
A banded rock with a dark brownish-grey colour.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Amphibole	60
Pyroxene	20
Garnet	3
Biotite	2
Apatite	Tr
Opaques	15

This rock consists mainly of amphibole comprised of two quite different generations of amphibole intergrown with smaller amounts of other minerals. Most of the amphibole is a very pale green, weakly pleochroic variety which often contains clinopyroxene cores and is obviously of retrograde origin. Another prograde amphibole forms xenoblastic crystals up to 1 mm in size which tends to be concentrated within bands up to a few millimetres wide. This amphibole exhibits a dark green, intensely pleochroic colour.

The pyroxene forms xenomorphic crystals up to 0.8 mm in size which show moderate to pervasive replacement with the weakly pleochroic green amphibole. Minor garnet occurs locally in the rock as xenoblastic grains and aggregates up to 3 mm wide. The garnet also tends to be concentrated in slightly elongate, lenticular bodies oriented parallel to the foliation direction.

Minor biotite was noted as well-developed flakes up to 1 mm in length which are generally intergrown with the intensely pleochroic hornblende as totally included flakes.

Opaques are disseminated through the rock as anhedral grains and aggregates up to 1 mm wide. Opaques tend to be concentrated along what appear to be remnant grain margins between pyroxene crystals and weakly pleochroic amphibole-rich areas. Opaques also are locally concentrated within discontinuous bands. Traces of apatite were noted as disseminated crystals up to 0.2 mm long.

This is an amphibolite facies grade metamorphic rock with what appears to be a primary mineralogy of clinopyroxene and hornblende in which a significant proportion of the clinopyroxene has been replaced by a secondary weakly pleochroic, pale green amphibole.

SAMPLE: 6231 RS207: TSC48694

Rock Name:
Chloritoid Schist

Hand Specimen:
A pale, brownish-grey coloured rock with a strongly foliated schistose texture.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Muscovite	60
Chloritoid	20
Sillimanite	10
Chlorite	10
Opaques	Tr

This sample consists mainly of finely divided muscovite/sericite which exhibits a foliated and banded texture due to variations in grain size. Some of the better developed muscovite flakes exhibit a lepidoblastic foliation but most of the muscovite forms very fine, felted aggregates with an essentially random orientation.

Chloritoid is disseminated through the rock as idioblastic to subidioblastic porphyroblasts up to 2 mm wide. These porphyroblasts are quite fresh although they show incipient marginal alteration to translucent, reddish-brown iron oxides. Some of the porphyroblasts also have slightly irregular, ragged outer margins.

Intergrown with the muscovite are moderate amounts of fibrous sillimanite. The sillimanite is unevenly distributed through the rock but tends to occur within localised areas as fibrous aggregates with a contorted texture.

Chlorite is disseminated through the rock as flakes and flaky aggregates up to 0.5 mm wide. Within localised areas chlorite is concentrated within discontinuous bands and lenticular bodies. Most of the chlorite has a weakly pleochroic brownish-green colour and, low anomalous birefringence. Some of the chlorite forms moderately well-developed flakes with a slightly more pleochroic character and appears to be a partially chloritised biotite.

Minor opaques are disseminated through the rock as small grains up to 0.1 mm wide.

This is a highly aluminous schist now comprised mainly of muscovite and chloritoid. It is thought that a high proportion of the muscovite/sericite represents an alteration product of original sillimanite since it locally contains remnants of fibrous sillimanite. Chlorite is also disseminated through the rock and at least in part represents a replacement product of original biotite.

SAMPLE: 6231 RS208: TSC48695

Rock Name:
Feldspathic Gneiss

Hand Specimen:
A banded, gneissic rock with a relatively coarse grain size comprised mainly of whitish-grey feldspar.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Potash feldspar	40
Plagioclase feldspar	20
Quartz	10
Amphibole	10
Chlorite	10
Epidote	10
Opaques	Tr

This sample consists mainly of a deformed feldspar-rich mosaic comprised of feldspar crystals ranging up to 5 mm in size. The feldspar consists mainly of untwinned potash feldspar along with smaller amounts of polysynthetically twinned plagioclase. Minor quartz is intergrown with the feldspar as xenoblastic crystals up to 0.5 mm in size. All of the quartz and feldspar has a deformed, granulated appearing texture and within localised areas forms finely granulated mosaics with sutured grain margins. Fracturing along with granulation along fractures is common in both the feldspar and quartz.

Amphibole is disseminated through the rock as radiating acicular aggregates up to 1 mm long. This amphibole is somewhat similar to the amphibole in sample 6230 RS418 (TSC48687) in both its colour and textural features. Epidote is also disseminated through the rock as xenomorphic to subidiomorphic crystals up to 1 mm in size. The epidote typically has a moderate to high birefringence although some epidote with low, anomalous birefringence is present.

Chlorite forms well-developed flakes up to 1.5 mm in size as well as flaky aggregates. Some of the flaky chlorite aggregates contain radiating fibrous textured chlorite with a diameter of about 0.1 mm. The chlorite typically has a very pale green, weakly pleochroic colour and low birefringence.

Minor opaque to translucent iron and titanium oxides form disseminated grains and aggregates up to 0.2 mm wide. Included in this is some turbid, birefringent granular aggregates of a titanium mineral such as leucoxene which are generally intergrown with the chlorite.

This is a strongly deformed feldspar-rich rock believed to contain retrograde epidote, chlorite and amphibole all of which appear to be essentially postdeformational.

SAMPLE: <u>6231 RS209: TSC48696</u>

Rock Name:

Tremolite (Nephritic) Schist

Hand Specimen:

A greenish-grey coloured rock with a foliated texture.

Thin Section:

An optical estimate of the constituents gives the following :

	%
Tremolite	99
Opaques and semi-opaques	1

This sample consists mainly of very finely divided tremolitic amphibole which generally forms a strongly felted mosaic. The fine tremolite fibres tend to exhibit a preferred orientation defining a foliation direction. There is a tendency for the tremolite to form patches up to 1 or 2 mm wide within which the tremolite fibres have a preferred orientation producing optically continuous zones. Within these zones despite the optical continuity much of the tremolite forms a very fine, felted intergrowth. It is considered possible that these optically distinguishable domains could represent original tremolite crystals which have been subsequently deformed.

The rock contains a small number of disseminated tremolite crystals ranging up to 0.5 mm in size which are intergrown with the felted tremolite. Some of these crystals have prismatic shapes and are oriented at a high angle to the general foliation direction.

Opaque to translucent iron oxides form discontinuous linings along foliation lamellae. These linings rarely exceed 0.05 mm in width.

This is essentially a monominerallic rock comprised of felted, nephritic tremolite. Despite the felted character of the tremolite it still tends to form large optically distinguishable domains up to 1 to 2 mm in size which could represent original tremolite crystals which have been subsequently deformed to produce the present felted texture.

SAMPLE: 6231 RS210: TSC48697

Rock Name:
Tremolite Schist

Hand Specimen:
A foliated dark grey rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	98
(?)Cordierite	1
Opaques	1

This sample consists mainly of an interlocking mosaic of tremolite crystals with a typical grain size of about 0.3 mm although some coarser grained and finer grained tremolite is present. A pneumatoblastic foliation is defined by a weakly developed preferred orientation of the tremolite which is particularly strong within some areas but quite weak in others. Many of the tremolite crystals have random orientations forming an interlocking network. The rock contains some large tremolite crystals or domains which have been broken down into much finer tremolitic intergrowths.

A small number of xenomorphic crystals up to 0.3 mm in size are disseminated through the rock. These crystals have low birefrigence and have been tentatively identified as cordierite although positive identification would require further analysis. Minor opaque to translucent iron and titanium oxides form small disseminated grains and aggregates up to 0.1 mm wide. Minor translucent, reddish-brown iron oxides also form narrow linings along foliation lamellae.

This is a tremolite-rich schistose rock showing some deformational effects of the tremolite.

SAMPLE: 6231 RS211: TSC48698

Rock Name:
Tremolite Schist

Hand Specimen:
A foliated, dark grey rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	98
(?)Cordierite	1
Carbonate	Tr-1
Opaques	1

This sample consists mainly of weakly prismatic to acicular or fibrous tremolite crystals which form an interlocking mosaic. A very vague foliation is defined by a preferred orientation of some tremolite crystals but a significant proportion of the tremolite crystals have a random orientation. Tremolite crystals up to 3 mm in length are present but most of the tremolite has a much smaller grain size and some forms a fine, felted intergrowth.

A weakly birefringent mineral (possibly cordierite) forms xenomorphic disseminated crystals up to 0.2 mm wide. Opaques are disseminated through the rock as subhedral crystals up to 0.3 mm wide. Opaque to translucent iron oxides also form narrow fillings along some foliation lamellae. Traces of carbonate were noted locally as small inclusions within tremolite crystals.

This is a tremolite schist very similar to sample 6231 RS210 although this sample has a slightly coarser grain size.

SAMPLE: 6231 RS212: TSC48701

Rock Name:
Tremolite Schist

Hand Specimen:
A massive, dark greenish-grey rock.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	98
Chlorite	1
Opaques and semi-opaques	1

This sample consists of finely intergrown fibrous tremolite which tends to exhibit a preferred orientation defining a foliation direction. Most of the tremolite forms a fine felted, nephritic intergrowth but some slightly larger crystals are present. The largest tremolite crystals range up to about 0.5 mm in size and at least some exhibit a strong preferred orientation. As with some previously described fibrous tremolitic rocks this sample also exhibits optically distinguishable domains within which fibrous intergrowths are present. Within some of these domains vague lamellar textures are also present. It is thought these domains represent original larger crystals which have been disintegrated into the finer fibrous intergrowths.

Chlorite is disseminated through the rock as flakes ranging up to 0.5 mm in size. These chlorite flakes have a very pale green colour and low birefringence.

Minor opaque to translucent iron oxides form discontinuous linings along very narrow, undulose foliation lamellae.

This is a tremolite-rich rock which generally has a fibrous, nephritic texture although some domains possibly representing original larger tremolite crystals are present.

E00243

SAMPLE: 6231 RS213: TSC48702

Rock Name:
Tremolite Schist

Hand Specimen:
A greenish-grey coloured rock with a vague foliation.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Tremolite	98
Chlorite	Tr-1
Opaques and semi-opaques	1

This sample consists mainly of a felted, nephritic intergrowth of tremolite with some disseminated larger tremolite crystals. The rock has a foliated character defined by a preferred orientation of the fine felted tremolite and by very narrow, undulose foliation lamellae which are defined mainly by linings with opaque to translucent iron oxides.

The larger tremolite crystals range up to 0.5 mm in size and have fibrous to lamellar textures believed to be of deformational origin.

Minor chlorite is disseminated through the rock as small flakes up to 0.5 mm in size.

This is an almost monomineralic rock comprised of tremolite which typically has a felted, nephritic texture.

SAMPLE: 6231 RS214: TSC48704

Rock Name:
Chlorite-Carbonate Rock

Hand Specimen:
A very fine-grained rock with a greenish-grey colour.

Thin Section:
An optical estimate of the constituents gives the following :

	%
Carbonate	50
Chlorite	50
Opaques	1

This sample consists mainly of weakly birefringent phyllosilicate flakes believed to be chlorite intergrown with granular carbonate which is most likely dolomite. The chlorite generally forms a somewhat felted interlocking mosaic comprised of flakes with a maximum size of 0.3 mm although most of the chlorite flakes form a much more finely felted intergrowth. The carbonate generally forms irregular grains and granular aggregates with a maximum size of 0.3 mm. Many of the larger carbonate crystals exhibit lamellar twinning believed to be of deformational origin.

Minor opaques are disseminated through the rock as anhedral to subhedral grains up to 0.1 mm wide.

This is a very fine-grained rock comprised mainly of weakly birefringent chlorite intergrown with granular carbonate.

APPENDIX F

COMPARISON OF COWELL JADE WITH JADE FROM XINJIANG PROVINCE, CHINA

COMPARISON WITH JADE FROM XINJIANG PROVINCE, CHINA

There are two nephrite jades in Xinjiang Province, People's Republic of China:

- Hotan jade in the region of the Kunlun Mountains to the Arjin Shan Mountains.
- Tian Shan jade (nephrite but commonly referred to as Jasper jade) in the north of Tian Shan and from some parts of the Arjin Shan Mountains. Tian Shan jade is hosted by ultramafics emplaced during the Variscan Orogeny.

However, Hotan jade exhibits many striking similarities in geological setting and controls to nephrite formation as Cowell nephrite. Host rocks to Hotan jade are late Proterozoic dolomitic marble of the Sinian series where nephrite formation is related to and controlled by both prominent faults and a series of intrusives emplaced during the Variscan (Hanchen et al., 1986).

Dolomitic marble exhibits similar mineralogical variations to the early Proterozoic dolomitic marble at Cowell with phlogopite, serpentinised olivine, dolomite the dominant carbonate, grey colour and coarse granoblastic texture. Hotan jade results from contact metasomatism of the dolomitic marble along the margins of stocks and dykes of acid-imtermediate intrusives, particularly granodiorite but including diorite, quartz diorite, syenite, quartz-syenite and syenite-aplite. Zoned skarns however are recognised for Hotan jade depending on the temperature of hydrothermal fluids (Hanchen et al., 1986), but which are not recognised as such at Cowell. Compositional banding in retrogresive assemblages (particularly chlorite, tremolite and clinozoisite/zoisite) is present at Cowell but has been interpreted to reflect original compositional banding rather than zoned skarns.

The same structure model for Cowell nephrite has also been interpreted for Hotan jade with hydrothermal fluids migrating along the faults and then percolating out along layering in dolomitic marble. The colour of jade is also partly controlled by alteration of the country rocks (Hanchen et al., 1986). Metasomatism within the middle of a band of dolomitic marble is more likely to produce whiter jade and of good quality. This is very similar to Cowell with the palest jade (pale yellowish green, Munsell 10Y 9/1) formed on the margins of quartz veins at Outcrops 52 and 53 near the centre of a dolomitic marble bed, and where iron is interpreted to be dominantly derived from chloritised gneissic anphibolite. Completely retrogressed amphibolite often forms hanging and footwall contacts with jade and hence significantly contributes to the high iron (and lower Mg) of Cowell nephrite.

Xinjiang nephrite contains from 0.12% to 8.08% Fe_2O_3 hence is a similar range to Cowell nephrite, and the tremolite grades to actinolite on the most iron-rich samples. Hotan jade exhibits a comparable deepening of colour as iron content increases. About half of the Hotan jade samples analysed contain anomolous copper i.e. 0.01 - 0.04% Cu. However, black Hotan jade is sourced from micro-flaky graphite and is associated with a markedly lower S.G. i.e. only 2.66 (Hanchen et al., 1986) and hence is not comparable to the black jade at Cowell.

Tremolite of Cowell jade forms diverse textures but the relationship of texture to colour is not well studied. However, all of the textures in both Xinjiang's Hotan jade and jasper jade (Hanchen et al., 1986; Plates 7-24 and 37-42) have been observed at Cowell - see Plates 35-40, Flint et al. (1989, Plates 19-23) and SADME slides 36656 - 36675.

OUTCROP	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	TOTAL
14											15												15
15												2	2	2	1·8	14		2	3	1·5	106		134
21-23			0·2	0·3																	14		14
24												50		50							3		103
25-30																							0·2
31-32						40	120						70						2		91		179
33-36								55	23·5					72	106			3	3		79		485
54-57																					37		37
37-38	0·02	0·1																					0·1
40-44		0·7		0·6	0·2	0·4													o/c 44 1				2·9
52															1								1
53										35	3												38
61-67		0·1	0·2	0·02																			0·3
69		0·8	0·02									50	40		105			4	6		122		328
70-72																							0·02
76										27	12	110											149
17										2													2
77-80																							
89-90 112																							
90 100											15												15
106															0·5				1	0·5			2
107																			6				6
Miltalie												1											1
TOTAL	0·02	1·7	0·4	0·9	0·2	40·4	120	55	23·5	64	45	213	112	124	214·3	14	-	9	22	2	452	-	1513

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

NEPHRITE PRODUCTION 1967-1988

COMPILED D.Flint	C.D.O.	DATE 4.7.91.
DRAWN J.W.	SCALE	
DATE June '89	PLAN NUMBER S20831	
CHECKED		

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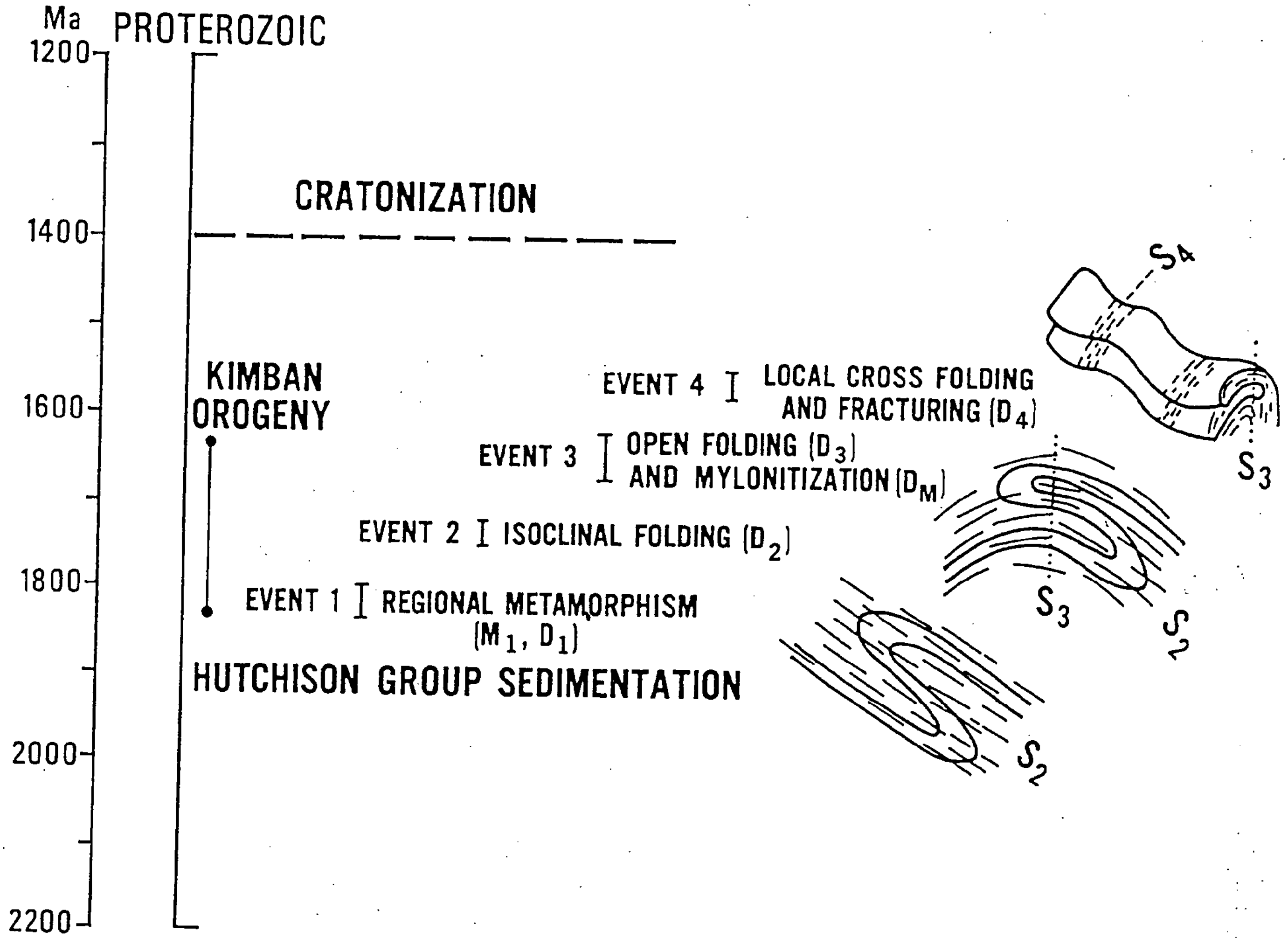

FIG. 2 COWELL JADE

KIMBAN OROGENY D_1 - D_4 SUMMARY TABLE

PLATES 1-8, CAPTIONS

1. Migmatite. Leucocratic migmatite veining in grey, banded granodiorite gneiss. ML4898, between Outcrops 105 and 75. Slide No 38087.

2. Granodiorite Gneiss. D_3 folds in banded, granodiorite gneiss (Miltalie Gneiss) in Minbinnie Creek, 150 m N-NE of ML4532. Slide No: 38088.

3. Dolomitic Marble. Typical range of colours within dolomitic marble. Yellow band from serpentine after olivine; grey band from dolomite with lesser green specks of chlorite; green band from fine-grained acicular dolomite. Bar scale in centimetres. Outcrop 15, DDH 14, 26.96m; 6230 RS 176. Slide No: 38089.

4. Jade along contact of dolomitic marble. Jade in transitional zone between light grey dolomitic marble and dark banded calc-silicate gneiss at the base. Transition zone comprises dark green marble at the top, medium green marble in the centre and dark green jade in contact with the silica-rich banded calc-silicate. Outcrop 32. Slide No: 38090.

5. Jade - Outcrop 15. Range of colours from red skin, pale green and grey-green weathering rinds through to dark green-black nephrite. Slide No: 36610.

6. Jade - Outcrop 21. Massive nephrite and semi-nephrite with thin red-brown weathering skin developed on dark green fresh jade. Slide No: 38091.

7. Jade - Outcrop 21. Relict S_1 layering within semi-nephrite at the hinge of a mesoscopic D_2 fold. Slide No: 38092.

8. D_2 folds in jade. Relict S_1 layering defined predominantly by grain size variations in tremolite folded during D_2. Outcrop 15. Slide No: 24708.

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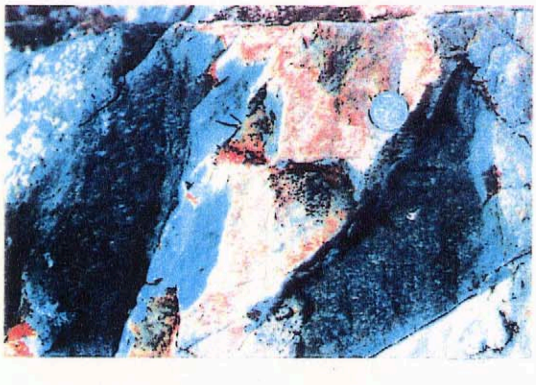

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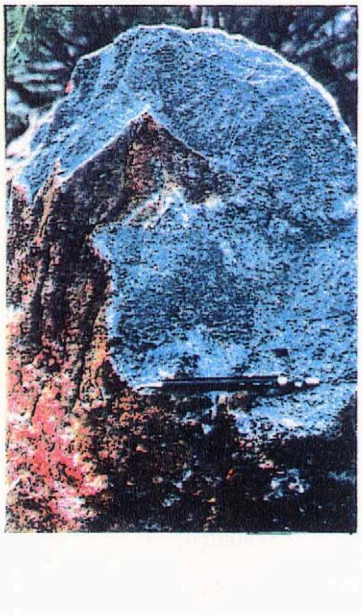

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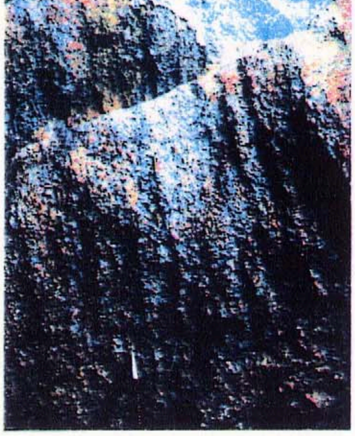

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PLATES 9-16, CAPTIONS

9. D_4 folding and fracturing in granodiorite gneiss mylonitised during D_3. D_4 gentle warping and axial planar fracturing. Minbinnie creek near ML4532. Slide No. 38093.

10. D_4 monoclinal flexure and jointing parallel with axial plane. Migmatised Miltalie Gneiss or syn-D_1 gneissic granodiorite. Slide No. 38094.

11. D_4 monoclinal flexure with thin aplite parallel with axial plane. Miltalie Gneiss. Slide No. 38095.

12. D_4 shear zone and close-spaced jointing. Gneissic amphibolite (right) retrogressed to chlorite schist with S_4 schistosity in the D_4 shear zone (left). Outcrop 76, view E-SE along S_4. Slide No. 38096.

13. S_2 v S_4 structures. Tight to isoclinal D_2 folds of S_1 gneissic layering in Warrow Quartzite crosscut by planar D_4 joints. 100m NW of Rocky Well. Slide No. 38097.

14. Pre-D_4 retrogression. Syn-D_3 retrogression produced bands of pale yellow-green clinozoisite alternating with darker grey-green bands of chlorite + tremolite. Banding gently folded and jointed during D_4. Bar scale in centimetres. Outcrop 35, DDH 15, 15.61 m, 6230 RS369. Slide No. 35049.

15. Crenulated semi-nephrite of jade Outcrop 75. Semi nephrite grades to coarser-grained tremolite schist with a probable D_3 schistosity, which is crenulated during D_4. Slide No. 24707.

16. Schematic geological plan. Nephrite formation by SiO_2 metasomatism introduced via S_4 fractures into dolomitic marble. Penetrative foliations in nephrite developed by progressive simple shear in ductile shear zones. Slide No. 36652.

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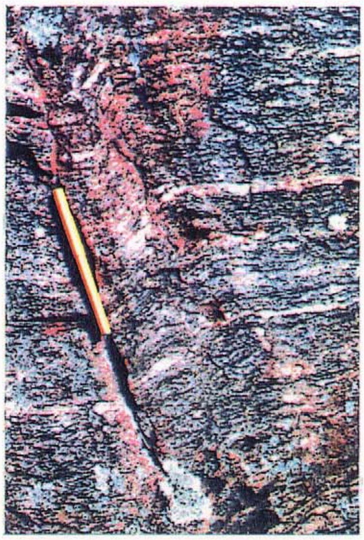

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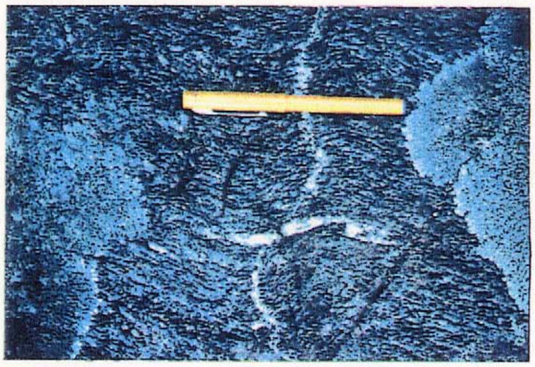

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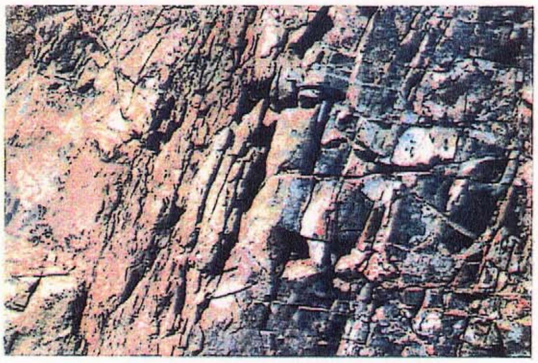

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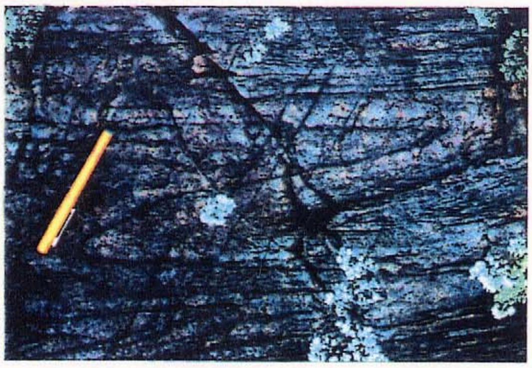

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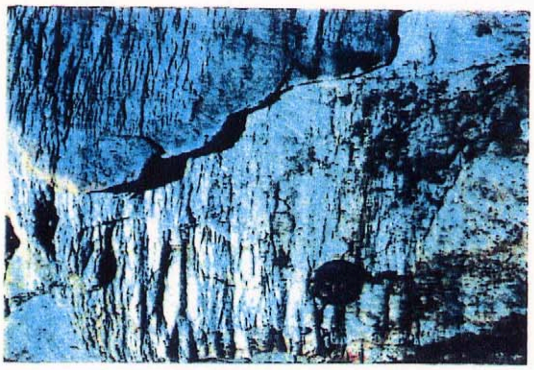

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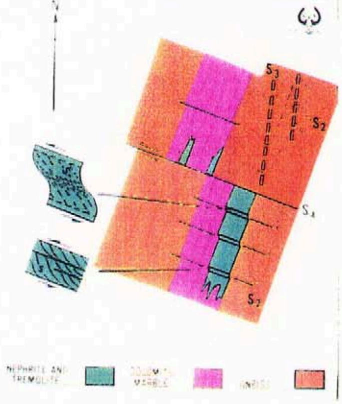

PLATES 17-24, CAPTIONS

17. <u>Nephrite in dolomitic marble</u>. Massive green nephrite wholly enclosed by white and grey dolomitic marble which grades out into yellow, serpentiferous, dolomitic marble. Bar scale in centimetres. Outcrop 35, DDH16, 3.19m. Slide No. 38098.

18. <u>Diopside and nephrite, Outcrop 55</u>. Massive, coarse-grained diopside of Outcrop 55 retrogressed to grey, grey-green nephrite. Slide No. 38099.

19. <u>Diopside and semi-nephrite, Outcrop 15</u>. Coarse-grained, off-white diopside is uralitised to green, schistose semi-nephrite with an S_4 schistosity. Thin fractures are late- to post-S_4 and infilled with calcite. Bar scale in centimetres. DDH17, 17.68m, 6231 RS162. Slide No. 35041.

20. <u>Diopside and tremolite schist, Outcrop 15</u>. Massive, coarse-grained, off-white diopside retrogressed to white, schistose semi-nephrite plus dark green chlorite. Bar scale in centimetres. DDH 17, 15.93m, 6231 RS160. Slide No. 35024.

21. <u>Diopside and chlorite, Outcrop 15</u>. Massive, coarse-grained, off-white diopside is brecciated with fractures dominantly infilled by dark green chlorite. Largest vein contains fibrous tremolite. Bar scale in centimetres. DDH17, 16.06m, 6231 RS161. Slide No. 38100.

22. <u>Diopside with clinozoisite</u>. Massive, coarse-grained, off-white diopside (lower portion) extensively retrogressed (upper portion) to green tremolite + chlorite with pale pink aggregates of clinozoisite. Bar scale in centimetres. Outcrop 15, DDH14, 6.24m, 6231 RS167. Slide No. 38101.

23. <u>Diopside and epidote, Outcrop 15</u>. Epidote ± pyrite invading and replacing brecciated off-white diopside. Bar scale in centimetres. DDH17, 18.52m. Slide No. 38102.

24. <u>Diopside and epidote, Outcrop 76</u>. Yellow, slightly-epidotised diopside is brecciated and invaded by dark green bands of tremolite and epidote. Slide No. 38103.

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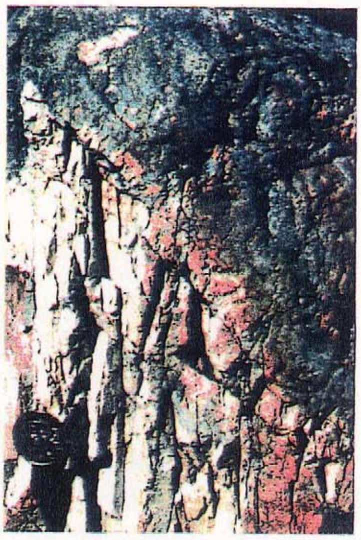

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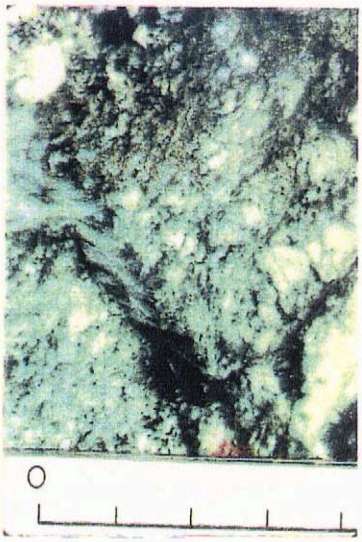

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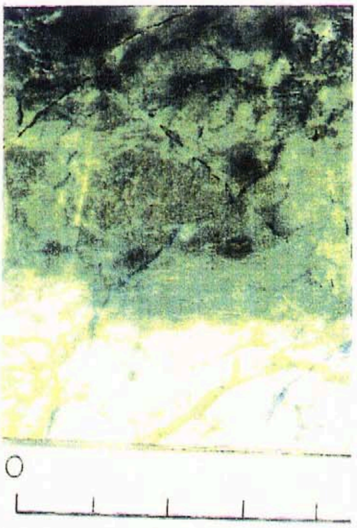

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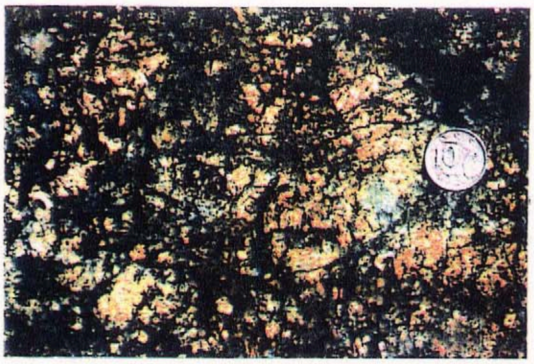

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PLATES 25-32, CAPTIONS

25. Semi-nephrite and chlorite, Outcrop 32. Hanging wall contact of jade with massive, dark green black, speckled chlorite. Semi-nephrite exhibits irregular colour mottling from pale to medium green through variable texture and grain size. Bar scale in centimetres. DDH 32, 8.69m, 6230 RS154. Slide No. 35046.

26. Chlorite, Outcrop 32. Massive, dark green chlorite is apparently brecciated with interstices infilled by pale brown phlogopite + clinozoisite. Bar scale in centimetres. DDH 16, 12.09m, 6230 RS378. Slide No. 38104.

27. Clinozoisite and phlogopite, Outcrop 32. Unusual assemblage with darker zones consisting of phlogopite and clinozoisite within pale zones of pure clinozoisite. Bar scale in centimetres. DDH 16, 11.71m, 6230RS 377. Slide No. 38105.

28. Speckled nephrite; Outcrop 15. Green nephrite at top is veined by and apparently replaced by late-stage chlorite which forms fine-grained radiating clusters. Nephrite at top grades to a speckled rock with green spots of coarser-grained tremolite and grey-green spots of fine-grained, felted nephrite. White and off-white areas consist of cummingtonite, minor epidote, a member of the norbergite-chondrodite-humite-clinohumite series as well as patches of semi-nephrite. Bar scale in centimetres. DDH 14, 31.66m, 6231 RS181 and 182. Slide No. 35039.

29. Dendrites in jade, Outcrop 106. Unidentified dendrites as diffuse staining through a broad, slightly-weathered rind of Outcrop 106. Bar scale graduation in millimetres. Slide No. 38106.

30. Hybrid pegmatite, Outcrop 69. Current assemblage is albite-oligoclase, biotite and chlorite. Original pegmatite (average grain size about 5mm) is deformed, recrystallised and metasomatised. Extensive zones of 1mm plagioclase as well as along primary grain boundaries. Biotite and chlorite from black to green black, massive aggregates which are interstitial to plagioclase and contain individual mica flakes of <0.05mm. Slide No. 36654.

31. <u>Hybrid pegmatite, Outcrop 90</u>. Pegmatite texture retained by feldspar is extensively replaced by pale pink clinozoisite (or thulite). Other zones are extensively epidotised. Slide No. 38107.

32. <u>Hybrid pegmatite, Outcrop 76</u>. Coarse graphic intergrowths are well preserved but feldspar is extensively epidotised. Silica is apparently non-reactive and immobile. Pegmatite is marginal to the jade. Slide No 38108.

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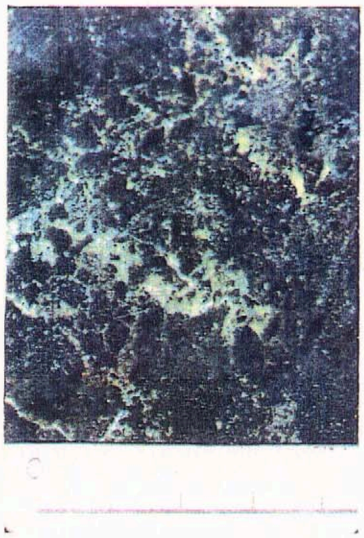

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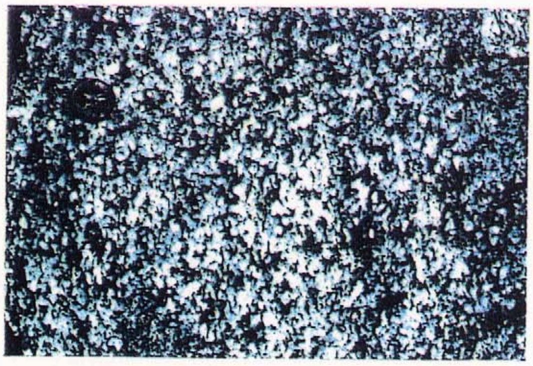

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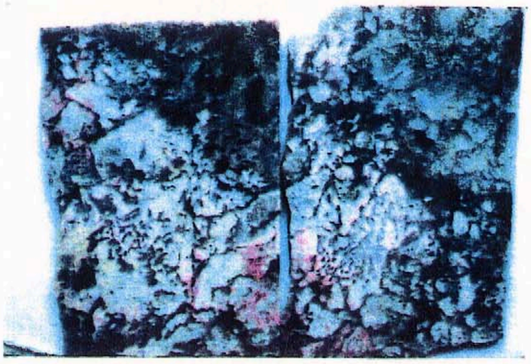

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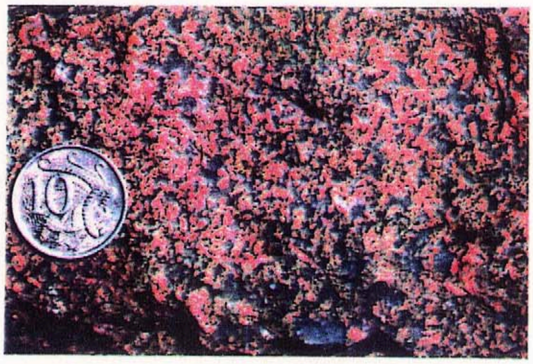

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PLATES 33-40, CAPTIONS

33. Hybrid pegmatite, Outcrop 32. Contaminated margin of pegmatite. Irregular and extensive fractures are lined by epidote (dark yellowish green) and actinolite (dark green). Bar scale in centimetres DDH 16, 14.42m, 6230 RS379. Slide No. 35023.

34. Hybrid pegmatite, Outcrop 35. Extensively metasomatised pegmatite marginal to thick chlorite, tremolite and clinozoisite zones. Pegmatite epidotised and chloritised with both phases also concentrated within D_4 fractures and joints. Bar scale in centimetres. Slide No 35025.

35. Semi-Nephrite, Outcrop 15. Typical nephritic texture - massive, fine grained, interlocking and felted tremolite fibres. Field of view 2.2 mm, x 32, crossed polars. 6231 RS168, DDH 14, 6.59 m. Slide No. 38109.

36. Jade rind, Outcrop 35. Typical pale green outer rind, especially along D_4 fracture surfaces. Munsell colours are pale green 10G 6/2 to greyish green 10GY 5/2. In addition, mottled textures and colours are evident, primarily through different microstructure. Darker green zones consist of fine-grained mats of tremolite averaging only 0.01 mm. Paler green and opaque zones consist of coarser grained tremolite aggregates and as individual grains to 0.8 mm long. Slide No. 38110.

37. Nephrite and semi-nephrite, Outcrop 15. Nephrite and semi-nephrite showing variation in grain size. Field of view 2.2 mm, x 32, crossed polars. DDH 14, 6.59m, 6231 RS168. Slide No. 38111.

38. Nephrite replacing tremolite schist, Outcrop 15. Early coarse-grained, tremolite schist (probably D_3) is invaded by and replaced by nephrite. Field of view 2.2 mm, x 32, crossed polars. 6231 RS168, DDH14, 6.59 m Slide No. 38112.

39. Nephrite rimming tremolite, Outcrop 15. Early phase (D_2 or D_3 tremolite exhibiting marginal replacement by nephrite. Field of view 2.2 mm, x 32, crossed polars. 6231 RS166, DDH14, 5.89m. Slide No. 38113.

40. Tremolite regrowth in nephrite, Outcrop 15. Aggregates of coarser-grained feathery tremolite apparently as regrowth of tremolite within nephrite matrix. Minor anastomosing D_4 fractures (top right). Field of view 2.2 mm, x 32, crossed polars. 6231 RS181, DDH14, 31.66 m. Slide No. 38114.

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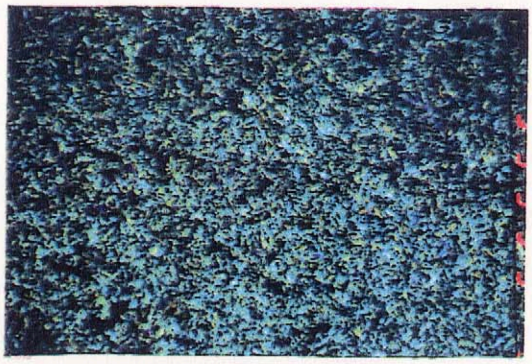

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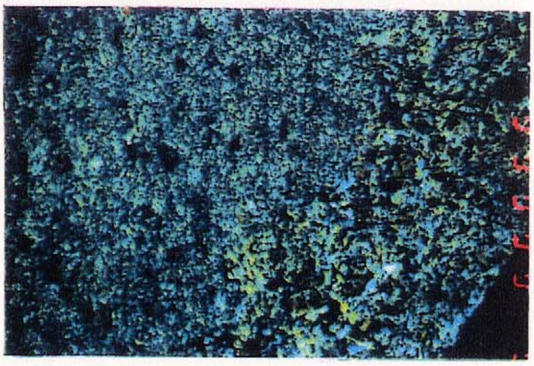

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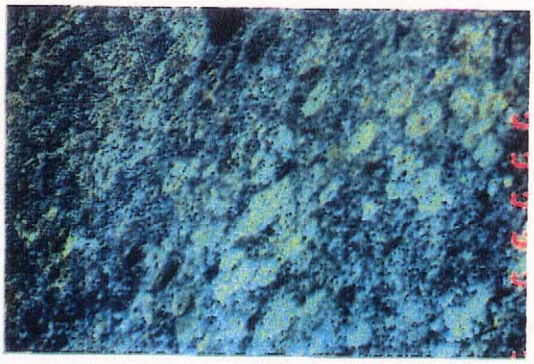

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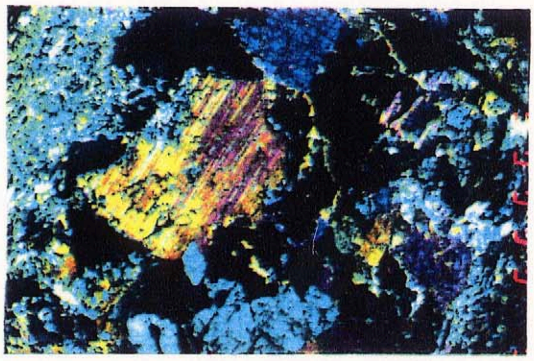

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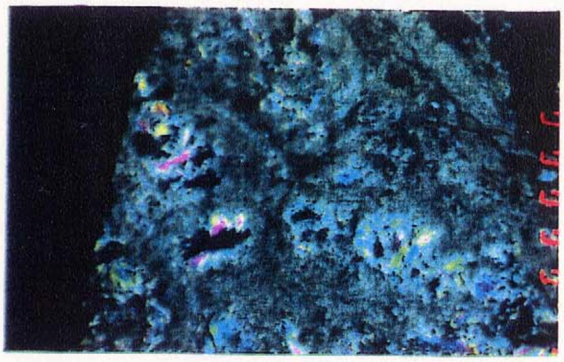

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COMPARISON WITH JADE FROM XINJIANG PROVINCE, CHINA

There are two nephrite jades in Xinjiang Province, People's Republic of China:

- Hotan jade in the region of the Kunlun Mountains to the Arjin Shan Mountains.
- Tian Shan jade (nephrite but commonly referred to as Jasper jade) in the north of Tian Shan and from some parts of the Arjin Shan Mountains. Tian Shan jade is hosted by ultramafics emplaced during the Variscan Orogeny.

However, Hotan jade exhibits many striking similarities in geological setting and controls to nephrite formation as Cowell nephrite. Host rocks to Hotan jade are late Proterozoic dolomitic marble of the Sinian series where nephrite formation is related to and controlled by both prominent faults and a series of intrusives emplaced during the Variscan (Hanchen et al., 1986).

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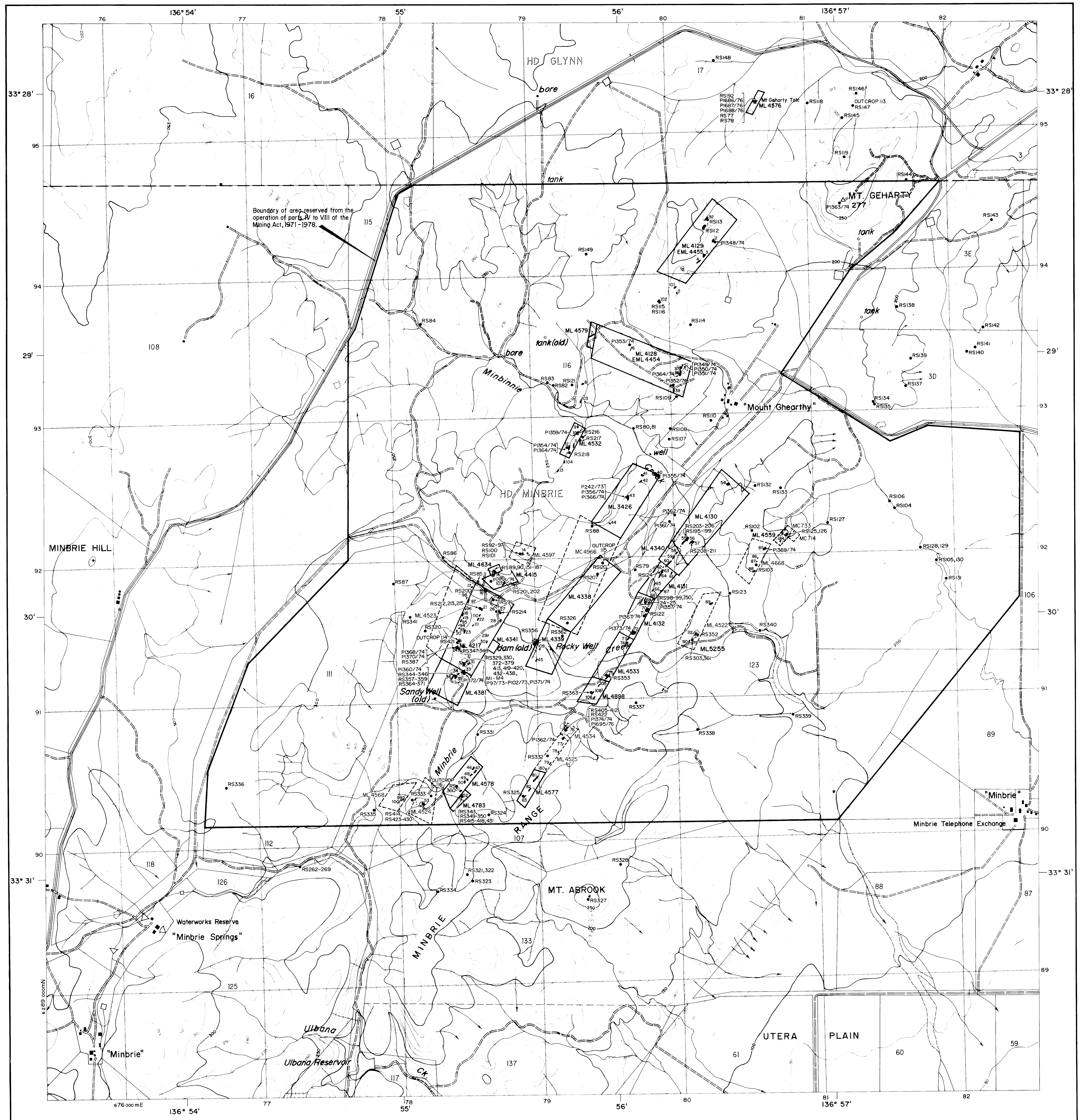

SCALE

Metres 200 0 200 400 600 800 1000 Metres

▬ 15 Nephrite jade with outcrop reference number

89 Section boundary and number

Note: The location of some jade outcrops is approximate only, having been transferred from uncontrolled base plans.

└── Current mineral lease boundary

└ - - - Former mineral lease or mineral claim boundary

Note: Tenements have been positioned from aerial photos

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE PROVINCE

JADE OUTCROPS, SAMPLES AND MINING TENEMENTS AS AT 31-12-88
LOCALITY PLAN

COMPILED	D. Flint
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COWELL JADE PROVINCE: DETAILED GEOLOGICAL MAPPING AND DIAMOND DRILLING OF JADE AND ORNAMENTAL MARBLE OUTCROPS, 1982-1987.

VOLUME 2

GEOLOGICAL SURVEY

by

D.J. FLINT

and

E.A. DUBOWSKI

SENIOR GEOLOGISTS
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OUTCROPS 9 - 12

REFER Figure 4 (Plan 88-422)

Tenement History

The first claim registered was MC 111 by Pacminex (Operations) Pty Ltd on 16 November 1972, during their base metals - uranium exploration programme over SML's 383 and 667. The claim was plainted in August 1973 by Australian (Nephrite) Jade Mines Pty Ltd, but the plaint was later withdrawn and the claim surrendered in May 1974. Jade (Australia) Pty Ltd repegged the area as MC 529 in June 1974 and ML 4532 was registered on 21 July 1976. The lease was transferred to Cowell Jade Pty Ltd in December 1976 and is now held by Gemstone Corporation.

To date there has been no mining on outcrops 9 - 12.

Geological Mapping

Nichol (1974a) described four nephrite outcrops on MC 529:

- Outcrop 9 - 5 x 1 m lens associated with calc-silicate rocks and meta-aplogranite;
- Outcrop 10 - 10 x 1 m lens associated with dolomitic marble, tremolitite and other calc-silicate rocks;
- Outcrop 11 - 45 x 7 m band associated with dolomitic marble and various calc-silicate rocks;
- Outcrop 12 - 20 x 1 m band associated with dolomitic marble and epidotite.

Three samples were petrographically described:

- P1359/74, Outcrop 10, Jade-tremolite-chlorite rock;
- P1354/74, Outcrop 12, Epidotite;
- P1365/74, Outcrop 12, Impure jade with epidote.

Scott et al. (1978) revised Nichols' (1974a) table of jade outcrops adding a further comment to Outcrop 11 i.e. 'Some pale green. Tremolite inclusions'.

A detailed stadia survey of ML 4532 was carried out by the authors and A.J. Smith (Field Assistant) together with Wilher Simandjuntak and Andi Sulaeman on 28-29 April 1987.

Site Geology

Nephrite forms predominantly as pods within basal units of ?Warrow Quartzite comprising (basal) calc-silicate, marble, and interbanded biotite-sillimanite gneiss and amphibolite (hornblende) gneiss. Minor quartzite is found within migmatised gneiss on the north-eastern side of the lease. Grey granodiorite gneiss is interpreted as migmatised Miltalie Gneiss. A structural unconformity was observed on the western Warrow Quartzite contact with Miltalie Gneiss. Both units were in part, extensively mylonitized during D_3 and intruded by syn- to late-D_3 pegmatite and reddish pink pegmatitic granite.

Miltalie Gneiss

Medium-grained (average 3-4 mm), grey, finely layered (quartz-feldspar 2 mm, biotite 1 mm) granodiorite gneiss is interpreted as Archaean Miltalie Gneiss. Mylonitic fabric is strongly developed, and feldspar porphyroblasts, to 5 cm, are stretched and rotated. Retrogressive assemblages of chlorite, epidote and clinozoisite are found along D_4 joint planes and contact margins of gneiss and intrusive pegmatite. Tight to isoclinal D_3 folds often with sheared hinges are observed in cross-section views in Minbinnie Creek approximately 100 m north-northeast of the northeastern lease peg (Plate 2). These are rarely seen on horizontal surfaces.

Banded Calc-Silicate

The calc-silicate, considered to be basal Warrow Quartzite, is characterised by banding on millimetre to metre scale.

Bands are either:-

- green - dark green, rich in tremolite and epidote;
- creamy, coarse-grained diopside; or
- very fine-grained brown, quartzite or chert.

Diopside-rich bands are extensively retrogressed to tremolite and nephrite. Contacts of diopside and marble are often marked by nephrite bands from several millimetres to centimetres thick. At one location, diopsidic breccia is in contact with buckled calc-silicate.

Marble

Typically fine to coarse grained and with pale grey to grey-green colours. A thin greenish calc-silicate layer is located on the eastern contact of marble with schist/gneiss. Thin gneissic interbands possibly represent metamorphosed pelites.

Schist and Gneiss

Outcrop of this unit is commonly subdued and rubbly, comprising thinly layered fine to medium grained quartz+biotite schist, dark grey sillimanite gneiss (6231 RS 216) and minor dark-grey to black hornblende gneiss (6231 RS 217). Warping of the unit is common compared to layering in the calc-silicate. A strongly developed schistosity, interpreted as S_3, dips predominantly eastwards.

6231 RS 216 shows that retrogression of primary mineral assemblages appears to be complete and comprises sericite, muscovite, quartz, plagioclase, chlorite and biotite. The hornblende gneiss is primarily fresh containing >60% hornblende and with hornblende defining well-developed gneissic foliation. A mylonitic fabric is well developed.

It is possible that this unit represents Lower Middleback Jaspilite as field descriptions referred to biotite+?grunnerite+magnetite schists. Schists are in part weakly magnetic and trace amounts of finely disseminated magnetite were observed. Approximately 35 m south of the southern lease boundary, a strongly magnetic ?schist was observed within pegmatite.

Quartzite

White to grey coloured, medium to coarse grained quartzite is interlayered with thin quartz-mica schist bands. Alignment of quartz may give rise to layering effect. A thin band of sillimanite gneiss crops out adjacent to the western margin. Although the quartzite may be a unit within the gneiss, it is more likely to be either a raft or mylonitized sliver of Warrow Quartzite proper, an interpretation based on the disrupted and schistose nature of the unit and association with sillimanite gneiss.

Pegmatite and Pegmatitic Granite

These rocks are typically very coarse grained, with white to pink feldspar and quartz. Outcrop is commonly subdued and rubbly. The large body on the western side of ML 4532, has a distinctly granitic texture, though weakly gneissic in places. Relict granodioritic ?xenoliths are evident especially near margins. Within gneissic portions, fine pegmatite stringers parallel the superimposed mylonitic foliation. The pegmatite is interpreted as intruded during D_3 and truncates the mylonite zone. Altered pegmatite occurs near jade outcrops 11 and 12.

Nephrite

Mapping undertaken in 1987 showed that the large outcrops depicted by Nichol (1974), actually comprise numerous smaller and discontinuous nephrite pods. The largest single nephrite lens mapped in 1987 was 12F, 6 x 1 m, in contrast to the 45 x 7 m dimensions of Outcrop 11 given in Nichol (1974a). Consequently Nichol's numbering system has been modified to allow for the observed, numerous, smaller pods hence 12A, 12B, 12C etc. In addition to the eleven nephrite pods described on Table 11, numerous small nephritic and semi-nephrite pods were observed within the calc-silicate, but are too small to map.

TABLE 11 - OUTCROPS 9-12 (ML 4532) NEPHRITE DESCRIPTIONS

OUTCROP NO.	DIMENSIONS (L x W) (metres)	DESCRIPTION
9	2 x 1	fine grained, medium green, massive, S_1/S_2 layering
10A	0.5 x 0.5	float
10B	0.25 x 0.08	boulder, fine grained, medium to dark green; trace mica
11A	1 x 0.5	pale green, nephrite to semi-nephrite
11B	1 x 0.5	fine grained, pale green to green
12A	1 x 0.5	not recorded
12B	0.5 x 0.5	not recorded
12C	0.5 x 0.3	foliated ?semi-nephrite
12D	0.5 x 0.5	boulder, semi-nephrite, medium green
12E	0.5 x 0.5	medium to deep green
12F	6 x 1	medium to dark green, S_1/S_2 layering, trace mica; thin, fibrous tremolite veins.

Nephrite formed within calc-silicate and marble, and on calc-silicate/pegmatite, calc-silicate/gneiss, and marble/gneiss contacts. Nephrite pods are commonly observed either along or adjacent to cross-cutting D_4 joints.

Nephrite is typically medium to dark green in colour, with few green to pale green pods. Texture is massive and fine grained, grading to semi-nephrite. Some pods show narrow fibrous tremolite veins, and some contain minor ?mica. The largest lens, 12F, shows S_1/S_2 layering and is interpreted as nephrite formed from variable retrogression of massive and poorly banded diopsidic calc-silicate.

Two nephrite samples were described petrographically by Nichol (1974a) - P1359/74 and P1365/74. Both show foliation, with P 1365/74 being described as schistose. The schistosity is now interpreted as a mylonitic fabric.

Sample 6231 RS 218, collected during 1987 is predominantly semi-nephrite (95%) with epidote (3-4%) and diopside (1%). Coarse, white to cream diopside in hand specimen is seen in thin section to be totally retrogressed to semi-nephrite, surrounded by a fine-grained nephritic groundmass. Uralitization of diopside, probably during D_3 mylonitization and as evidenced in P1365/74, is possibly the dominant mode of formation for nephrite on ML 4532. However, close association of nephrite and D_4 cross-fractures indicates some nephrite formed during D_4.

Structure

Lithological layering and combined S_1/S_2 gneissosity has an average strike of 025^{o}M, dips steeply to the west and is observed within the gneiss and calc-silicate/marble units. An S_3 schistosity, dipping steeply east to steeply west, is well developed in the sillimanite gneiss.

A strong D_3 mylonitic foliation, averaging 015^{o}M, is imposed on all rock units. Mylonitization has produced apparent faulted contacts:

- within the Archaean Miltalie Gneiss;
- between the Archaean and banded calc-silicate unit, although regarded as being imposed on an earlier structural unconformity;
- within and between the calc-silicate and marble units.

These contacts should be viewed as effects of mylonitization, producing augen shaped bodies of metasediment, within a broad mylonite zone.

D_4 faults are interpreted as displacing the metasediments westwards (sinistral movement) in the central part of the lease.

At least three D_4 joint sets are present:

- a dominant set striking 100-110^{o}M;
- a minor set striking 170^{o}M;
- and a third set striking southeast, but possibly associated with the 100-110^{o}M set.

Minor tight folding, with S-vergence, is observed within the gneiss near the southwestern corner of the lease. Small, disrupted isoclinal folds are rarely seen.

OUTCROP 14

REFER Figures 5 & 6 (Plans 88-82, S 20213)

Mining and Tenement History

Outcrop 14 was first pegged as MC 770 which was registered to B. Stadler on 26 July 1976, converted to ML 4597 on 9 February 1978 and transferred to Nephrite Australia Pty Ltd on 19 December 1978. The lease, along with six others of Nephrite Australia, was declared forfeited due to breach of terms and conditions of the lease and cancelled on 3 November 1980 (Olliver, 1984).

No lease is current over Outcrop 14 as the lens had been considered worked out, though minor jade is evident in the quarry face. The outcrop is now within the area reserved from Parts IV to VIII of the Mining Act, 1971-1978 as amended preventing granting of new tenements.

The only mining at Outcrop 14 was by Stadler in 1977 when 14t of jade were recovered.

Geological Mapping

Geological mapping of Outcrop 14 was by the authors in November 1982 with theodolite surveying by A.J. Smith (SFB 680).

Site Geology

The sequence at Outcrop 14 consists of alternating dolomitic marble, calc-silicate gneiss and micaceous gneiss. All are interpreted as part of the banded calc-silicate gneiss at the base of Warrow Quartzite. Units extend southwards along strike to Outcrop 107 rather than Outcrop 15, and northwards to Outcrops 9-12. By analogy with Outcrops 9-12 and regional data, the interpreted facing is eastwards. The legend on Figure 5 shows which rock types are present in the 100m of exposed banded calc-silicate gneiss, but not their stratigraphic order.

As with Outcrop 69, the main portion of the jade lens at outcrop 14 is found where a feldspathic pegmatite or leucogranite dyke crosses dolomitic marble, and is coincident with a D_4 fracture zone. Although coincident, spatially the two features are not necessarily concurrent.

Leucogranite

This unit, mineralogically a plagioclase pegmatite (6231 RS 100 and 101) is only 2-3 m wide and exhibits an outcrop trace suggesting open folding during D_3 (e.g. at sample locality 6231 RS 92; Figure 5). The unit is coarse grained, leucocratic and contains dominantly plagioclase with minor quartz. Primary grain size is to 6mm, though this is substantially decreased by granulation during ?D_4.

Typical mineralogy of the plagioclase pegmatite is given in Table 12 for two samples showing varying degrees of alteration. Free quartz is lost from the pegmatite as metasomatism proceeds. Neither sample is as extreme in its alteration as the chlorite-rich pegmatite at Outcrop 69 (Plate 30).

TABLE 12

ALTERED PLAGIOCLASE PEGMATITE

	RS 101	RS 100
Plagioclase	60-65	85
Quartz	10-15	-
Epidote	15	10
Actinolite	8	5
Apatite	1	-
Zircon	1	-
Sphene	trace	trace

Nephrite

The main lens of nephrite is located on the thickest, but poorly outcropping, dolomitic marble unit.

Massive tremolite, nephrite, semi-nephrite and tremolite ± talc ± chlorite rocks are found along the margins of the leucogranite dyke wherever it transects dolomitic marble and ?diopside units. This is best illustrated in the quarry wall at Outcrop 14 where a tremolite + chlorite + talc alteration band reaches a width of 3-4 m along the margin of the dyke. The tremolite tends to be coarse grained but forms fan-shaped and radiating aggregates.

All jade recovered from Outcrop 14 was from the marginal alteration zone where dolomitic marble was metasomatised to tremolite ± chlorite ± talc rocks. No schistosities or layering were apparently developed at the time of alteration, and most of the phases were coarse grained. Jade may have formed during dyke emplacement and metasomatism but there is no direct evidence. However, it appears that this was the main metasomatic event and the rocks recrystallised during D_4. There may have been no additional metasomatism during D_4.

Little jade remains in the quarry face, though the positions of former jade pods are clearly evident (Figure 5). The remaining jade is 40cm long, 20cm thick and elongate along a D_4 joint. The jade is dark green and tends to be coarse grained (semi-nephrite) but paler, more opaque and finer grained along joint and cleavage surfaces. Long, fibrous (asbestiform) tremolite also infills some D_4 joints striking 125^{o}M. Thus, although jade occurs within the metasomatic zone produced by emplacement of the plagioclase pegmatite dyke, its form is demonstrably related to D_4 structures. Hence the observations and interpretations are very similar to those at Outcrop 69.

The influence of D_4 structures is further evidenced by the alignment of three nephrite occurrences along one D_4 joint or fault which coincides with cross section CD, and with a 135^{o} trend parallels other observed D_4 joints.

These occurrences are:

- Outcrop 14 itself,
- jade in the small triangular pit 30m southeast of Outcrop 14, and
- a third lens less than 1 m long which is 20m northwest of Outcrop 14.

The occurrence of two smaller jade bodies away from the main quarry illustrate that D_4 metasomatism alone is certainly sufficient to produce jade.

The triangular pit 30m southeast of Outcrop 14 contains minor semi-nephrite which is mid to dark green, somewhat coarse grained and with abundant tremolite porphyroblasts up to several millimetres across. Rind on semi-nephrite is pale green to offwhite. Semi-nephrite grades to massive and schistose chlorite $\underline{+}$ talc rocks. The schistosity, striking 067^{o}M and dipping 76^{o} north, is not readily interpretable in terms of S_3 or S_4. Other smaller occurrences are found within expired ML 4597 but are either:

- from alteration of thin discontinuous dolomitic marble,
- within calc-silicate units,
- or from retrogression of thin diopside bands in banded calc-silicate.

It is suggested that nephrite at Outcrop 14 is controlled by a combination of:

- metasomatism of dolomitic marble and diopside during emplacement of plagioclase pegmatite (?D_3 or early D_4), and - additional metasomatism during faulting, fracturing and jointing (D_4).

Structure

The sequence, although interpreted as facing eastwards, dips consistently westwards (Figure 6). The only exception to this consistent orientation is apparent gneissic layering in dolomitic marble within 1m of the margin of the plagioclase pegmatite dyke in the quarry face. Outcrop suggests a possible hinge zone for a D_2 fold.

The strike averages about 30^{o}M except where disturbed by open, N-plunging, Z-vergence D_3 folds. D_3 folds in banded calc-silicate gneiss strike at 025^{o}M and dip 75^{o} west where F_3 folds in gneissic layering plunge about 30^{o} towards 020^{o}M.

As exposed in other jade quarries, D_4 jointing is common and strikes at about 125^{o}M but with pronounced variable dip (Figure 6). Several other joints are present but data are insufficient to determine their significance. One joint crossing dolomitic marble adjacent to the plagioclase pegmatite dyke and its metasomatic margin, contains fibrous (asbestiform) tremolite defining a lineation plunging 31° towards 133°M. The alignment is within a joint striking 126°M, hence the pattern is similar to many other jade outcrops where the nephritic and tremolitic D_4 foliation trends more southerly than D_4 joints.

OUTCROP 15

REFER Figures 7 & 8 (Plans 88-83, S 20214)
Logs DDHs 14 & 17, Figures 9-11 (PLANS 88-77, 88-78, 88-81)

Mining and Tenement History

Outcrop 15 was pegged as MC 5150 which was registered to L.H. Schiller on 8 September 1967 and cancelled on 27 January 1969. The outcrop was repegged by Pacminex (Operations) Pty Ltd as MC 110 registered on 16 November 1972. The claim was plainted in the Wardens Court in August 1973 by Australian (Nephrite) Jade Mines Pty Ltd, lost on plaint and cancelled on 22 September 1974. Outcrop 15 was repegged by Australian (Nephrite) Pty Ltd as MC 467 registered on 22 May 1974 and converted to ML 4415 on 4 November 1974.

Several kilograms of jade were taken from a trial mining pit in October 1976 (Scott et al., 1978) but were not carved at the O'Halloran Hill College of Further Education.

However, as ML 4415 did not cover all of Outcrop 15, that portion extending beyond the boundary was pegged by N.P. Smith as MC 887 which was registered on 20 December 1977 and subsequently converted to ML 4634 on 23 August 1978. The thickest and what has subsequently been shown to be also the finest grained and best quality portions of Outcrop 15 were within ML 4634.

On 21 November 1979, all seven leases of Australian (Nephrite) Jade Mines Pty Ltd including ML 4415, were transferred to Cowell Jade Pty Ltd. ML 4415 is currently held by Gemstone Corporation and also covers Outcrop 107.

Ownership of ML 4634 was transferred on 23 April 1981 from N.P. Smith to L.M., L.M., N.P. and C.P. Smith. Under an agreement with the Smith families, Gemstone Corporation acquired ML 4634 in January 1987.

Although it is a prominent, large outcrop measuring 40 x 4 m production from Outcrop 15 only began in 1978. Presumably this has been due to the success of quarries on Outcrops 24, 32-36 and 69, combined with a perception that Outcrop 15 was coarse grained. Surface boulders tend to be coarse grained, particularly on the southern end within ML 4415. It was only after mining by the Smith family, particularly in 1982, that the real potential of Outcrop 15 was realised, with the northern end of the lease in ML 4634 being apparently thicker and containing some very high quality, fine grained Premium Black jade.

The recorded and estimated production for Outcrop 15 is included as Table 13. Note that this does not include all production from ML 4415, as the lease also covers Outcrop 107 for which there is known production. Production figures for the Smith family are probably conservative estimates.

TABLE 13

PRODUCTION - OUTCROP 15

YEAR	ML 4634 SMITH	ML 4415 COWELL JADE & GEMSTONE CORP.	TOTAL
1978	2	-	2
1979	2	-	2
1980	2	-	2
1981	1.8	-	1.8
1982	14	-	14
1983	-	-	-
1984	2	-	2
1985	1	2	3
1986	1.5	-	1.5
1987	15	91	106
TOTAL (Tonnes)	41.3	93	134.3

The first major mining at Outcrop 15 was by the Smith family in September 1982. Drilling, blasting and bulldozing in chlorite-rich, hanging-wall rocks produced a trench 3m deep (Flint et al., 1984; Plate 20) and 14t of jade were recovered. In February 1985, a rubber-tyred Terex 72-71 bucket dozer was used to deepen the existing trench and expose more of the thicker, finer-grained, northern end of the jade lens (Flint and Dubowski, 1986; Plate 30). Some jade was recovered from both ML 4634 and ML 4415, but the most important aspect was opening up the northern end of the lens allowing recovery in 1987 of about 15t by the Smith family and promoting recovery of 91t by Gemstone Corporation. Mining in both 1985 and 1987 exposed minor jade, about 30cm thick, in a band adjacent to the western wall of the trench i.e. in hanging wall rocks.

Production by the Smith family in 1987 included an impressive 11.6 t boulder of fine-grained, Premium Black jade which may be the largest boulder of black jade mined in the world (Barnes et al., 1987; 1988). Further jade of the same quality and from the same part of the lens, forming part of a 91t parcel, was mined by Gemstone Corporation in December 1987.

Geological Mapping

Initial geological mapping of Outcrop 15 in September 1982 was by E.A. Dubowski and Mohammed Sahl with theodolite surveying by A.J. Smith (SFB 680). Additional mapping and surveying in November 1982 was undertaken by the authors and P.P. Crettenden (SFB 682). SADME drilled two diamond drill holes at Outcrop 15 during May and July 1983; DDH 14 and DDH 17. Petrographic descriptions of 22 samples from DDH 14 (6231

RS 166-187) were included in Farrand (1985). Petrographic descriptions of 14 samples from DDH 17 (6231 RS 151-164) were described by D.J. Flint and included within Appendix E.

A preliminary interpretation of the geological plan, drill hole cross sections and macro photographs of drill core were presented in Flint and Dubowski (1986; Plates 17-23). A more detailed and slightly revised interpretation is presented here (Figures 7-11). Survey data have been updated to include the results of bulldozing in 1987 but not mining by Gemstone Corporation in 1987.

Site Geology

The sequence at Outcrop 15 consisting of dolomitic marble, calc-silicate, banded gneiss, gneiss and migmatised quartzite is interpreted as part of banded calc-silicate gneiss at the base of Warrow Quartzite.

All units strike consistently north-northeast, averaging 015°M, with average dip about 75° westward (Figure 7). Stratigraphic facing is uncertain and is complicated by mylonite zones, but is interpreted to be eastward facing based on regional scale data.

A major north south mylonite zone separates migmatised quartzite with abundant pegmatite to the east from the banded calc-silicate gneiss containing interbeds of massive diopside, dolomitic marble and quartzite. D_2 folding and ?D_3 mylonitisation apparently cause repetition of some units (Fig. 7, Cross Sections AB and CD respectively).

Outcrop is relatively poor, but DDH14 intersected considerably more dolomitic marble and diopside than was expected from surface outcrops, particularly between the jade lens and the mylonite.

Although Figure 7 shows calc-silicate, banded gneiss and gneiss units the differences are slight and the units grade into each other. Distinction is predominantly on presence or absence of banding and abundance of calc-silicate minerals. Banded gneiss grades into banded calc-silicate gneiss as the abundance of impure carbonate bands increases i.e. as tremolite, actinolite, diopside and chlorite increase. Overall, the abundance of carbonate and calc-silicate phases increase from west to east. East of the main mylonite zone is migmatised feldspathic quartzite with abundant migmatite.

Diamond Drilling

Two drillholes, DDH14 of 37.15 m and DDH 17 of 26.30 m, were designed to test downdip extensions of the mapped 40 x 4 m outcrop and to obtain additional geological data on mineralisation controls. Previously, Nichol (1974a), Scott et al. (1978) and Barnes et al (1980) had estimated that only about 20-25% of the jade lenses are hosted by calc-silicates. However, the fact that both holes intersected more diopside and dolomitic marble than expected from surface outcrops, supports the contention that all jade outcrops are hosted by dolomitic marble and/or diopside.

Detailed logs of DDH14 and 17 are included as Figures 9-11 and with interpreted cross sections on Figure 7. DDH14 was planned to intersect Outcrop 15 about 15m below the surface (between 17 and 22 m downhole depth). As with all of the 13 previous drillholes, an extension of the main lens was not intersected at depth and neither were some of the typical indications of nephrite i.e. extensive alteration, abundant chlorite and coarse-grained tremolite etc. Only minor banded calc-silicate, containing some pale green, radiating tremolite was intersected at 17-18m and 19.5m.

However, nephrite and semi-nephrite were intersected in DDH14. Minor nephrite and semi-nephrite were encountered within diopside, diopsidic calc-silicate and coarse-grained tremolite between 5.8 and 8.2m (6231 RS 166-169) (Plates 35 and 37-40). Jade about 30cm thick and presumably at this stratigraphic level was found 20-25m along strike to the north during widening of the trench during mining by Gemstone Corporation in December 1987. Minor nephrite within fractures crossing partly retrograded diopside was found at 24.23 m (6231 RS 175) in DDH14.

The main jade intersected in DDH14 was at 31.7m (6231 RS 181 and 182) on the contact of dolomitic marble with massive diopside. The nephrite is unusual with a leopard-skin texture (Flint and Dubowski, 1986; Plates 19 and 28), also petrography of 6231 RS 181 and 182, and following notes.

DDH17 was sited less optimistically, aiming to intersect jade at 6-8m below the thickest part of Outcrop 15 (Fig. 7, Cross Section CD). Only 2 m of nephrite and semi-nephrite were intersected; about half of that expected. Both drill holes suggest that Outcrop 15 thins rapidly with depth. However, because of the abundance of dolomitic marble, diopside and their alteration products, the prospects are good for additional but smaller nephrite lenses between Outcrop 15 and the main mylonite zone.

Dolomitic Marble

Dolomitic marble samples are from drillcore (6231 RS 158, 173, 174, 176-179) and P1358/74, collected by Nichol (1974a) from outcrop about 30-40 m south of the southern extremity of Outcrop 15. Few trends are discernible for textures or mineralogy of dolomitic marble in close proximity to nephrite. However, 6231 RS 158 which is only 0.2 m from nephrite does exhibit two features not observed in the other seven samples, it contains en-echelon trails of opaques which are paralleled by very fine-grained dolomite bands; both may be related to tension gashes.

Typical early (M_1 and/or M_2) assemblages can be summarised as: dolomite + olivine + phlogopite ± calcite ± diopside ± tremolite. Early phases are coarse grained with a primary grain size of 3-6mm which is invariably reduced by retrogression and alteration. Coarse grained tremolite as poikiloblasts to 5 mm are present only in 6231 RS 158. Pyroxenes are minor, usually diopside, though 6231 RS 178 apparently contains diopside as well as ?pigeonite which are both partially retrogressed to tremolite. Some antigorite rich aggregates also indicate replacement of a pyroxene, but as expected, most of the antigorite and chrysotile are pseudomorphing olivine. Phlogopite is invariably chloritised and rarely, the chlorite is then altered to antigorite (e.g. 6231 RS 179).

Retrogression of early coarse grained phases is extensive and produced fine grained calcite, dolomite, serpentine and several chlorites which are commonly banded (Plate 3). The banding is a new compositional layering across the earlier S1/S2 layering and in places appears partly mylonitic. Retrogressive assemblages consists of:

Calcite + dolomite + chlorite + serpentine ± tremolite.

Light green marble sought for ornamental purposes is fine grained, calcite rich, completely recrystallised and hence entirely retrogressive. The green colour is from disseminated and interstitial serpentine with lesser chlorite.

One sample, 6231 RS 178, contains a retrogressive band containing fine grained calcite + tremolite where tremolite rich portions approach semi-nephrite in texture.

Samples 6231 RS 174 and 176 (Plate 3), contain unusual acicular carbonate with a texture similar to that of nephrite i.e. randomly oriented with tufted and radiating clusters of acicular calcite and dolomite. This texture is also observed in one diopside sample, 6231 RS 159 from DDH17. In addition to the normal retrogressive features, 6231 RS 179 also exhibits a late-stage vein of dolomite + antigorite which is cross cut by a calcite vein.

Diopside

Massive diopside is present as monominerallic zones or as thinner bands hosted by either dolomitic marble or banded calc-silicate gneiss. In all settings, diopside exhibits partial retrogression to nephrite, semi-nephrite, tremolite or tremolite schist but the alteration shows subtle variations (Plates 19-23). The following notes are extracted from descriptions of samples 6231 RS 158-163, 166, 167, 175, 180 and 183.

Early (M_1 and/or M_2) diopside is very coarse grained with a primary grain size in excess of 4 mm and often averaging 6-8 mm. Rarely is another phase present, the possible exception is 6231 RS 162 with possible tremolite relicts to 4 mm and 6231 RS180 with probable interstitial calcite.

Deformed, granulated and brecciated massive diopside is ubiquitous, exhibiting varying degrees of retrogression. In milder cases, curved twin lamellae and cleavages are evident along with a marked reduction in grain size (6231 RS 158 and 161). New diopside grains average only about 0.3mm but commonly show only slight optical discontinuity from neighbours, indicating the former, much larger, grain size. Brecciation is common and often associated with branching veins which narrow to fractures (Plates 20 and 21 in Flint and Dubowski (1986)). Minerals infilling or lining the fractures vary from assemblages of:

- tremolite
- calcite + dolomite + serpentine + tremolite
- tremolite + calcite
- tremolite + chlorite + calcite
- calcite
- dolomite + epidote + opaques + ?serpentine
- tremolite + epidote
- dolomite + chlorite

Retrogression is commonly seen in stages, with several styles present in one sample (Plates 19-23). For example 6231 RS 166 exhibits partial retrogression of diopside to tremolite but this is then invaded by veins of semi-nephrite.

Deformation bands, some only 0.2-0.4mm wide, are present and cross cut the sample. These again show various retrogressive assemblages as outlined above. 6231 RS 158 contains bands consisting of epidote, dolomite, opaques and ?serpentine. These bands are veined by later tremolite + epidote veins which contain a late-stage central vein of dolomite.

More common are broader deformation (mylonitic) zones across diopside with associated forms of tremolite including nephrite. Progressive development of such zones is illustrated in Flint and Dubowski (1986; Plates 20, 4 and 21). The retrogressive product varies from semi-nephrite to tremolite schist and consists of a tremolite + calcite or tremolite + chlorite schistosity. Semi-nephrite, e.g. 6231 RS 180, consists of irregular ragged prisms and clusters of wispy acicular or feathery forms in subparallel to radiating arrays. Calcite is then in aggregates parallel to or perpendicular to the tremolite foliation. As in surface outcrop, the foliation is commonly at an angle to the margin of the broad band. However, in 6231 RS 162 (Flint and Dubowski, 1986, Plate 21) two tremolite schistosities as well as a crenulation are present within the tremolite schist alteration band. The schistosities consist of tremolite + chlorite and are crosscut by very late-stage, thin, dolomite veins.

A more unusual style of alteration is evident in 6231 RS 163, sampled within 1 m of a mylonite zone. Initial retrogression of diopside produces the typical tremolite + chlorite alteration but grades to a speckled rock consisting of tremolite + epidote. The alteration assemblage consists of coarse-grained epidote to 2mm surrounded by tremolite prisms 0.4 - 0.5mm long. Both contain abundant dusty inclusions. This early phase of alteration gives way to clear, dust-free tremolite which surrounds the earlier phases and occurs as:

- randomly oriented tremolite, 0.2 - 0.3mm long
- veins consisting of minute tremolite fibres with a sigmoidal shape.

The latter is typical of S_4 tremolite in outcrop, whereas the original speckled epidote + tremolite alteration predates D_3 mylonitisation.

Timing of all of the phases of retrogression and alteration, with respect to D_3 and D_4, is difficult and relies heavily on interpretation of the mylonitic event(s). Nephrite and semi-nephrite are consistently late, commonly grade to tremolite schist produced during mylonitisation (D_3 or D_4) but certainly post-date an earlier phase of diopside alteration.

Nephrite

Apart from outcrop, data on jade at Outcrop 15 was obtained from a 2m intersection in DDH17, and smaller jade intersections in DDH14 at 6-8m and at 31.7m. The latter is particularly unusual with a leopard-skin texture developed involving chondrodite-humite group minerals (Plate 28). Additional petrographic data and comments are in the preceding section 'Diopside'.

Some nephrite of Outcrop 15, particularly from the extreme northern end, is very fine grained, massive, green black (5GY 2/1 to 5G 2/2) and takes a brilliant polish (Plate 5). Jade of this quality was mined by the Smith family and Gemstone Corporation in 1986 and 1987 but was not intersected 5-8m away in DDH17.

Both in outcrop and in DDH17, jade exhibits diffuse banding from colour and grain size variations of tremolite. Banding is broadly parallel to the lens margins but does include ptygmatic folds (Plate 8) with axial planar orientations suggesting D_2 or D_3 folding. Nephrite in DDH17 is impure and exhibits several unusual features. All samples (6231 RS 154 - 156) are dominated by the nephrite matrix (70-90% matrix) but with various combinations of:

- coarse-grained, relict porphyroblasts of tremolite, anthophyllite, cummingtonite and diopside
- chlorite-rich aggregates at times containing euhedral actinolite needles
- ghost textures within nephrite matrix

- large, late-stage actinolite needles in nephrite
- two schistosities in some chlorite aggregates
- tremolite schistosity in nephrite.

The anthophyllite and cummingtonite are unusual, very rarely observed in other nephrite samples, and are either chloritised or replaced by the nephrite matrix. Chlorite-rich aggregates often contain two schistosities whereas the nephrite matrix, in part, contains only one schistosity which wraps around chlorite-rich aggregates and all relict porphyroblasts. When schistose, the nephrite is coated by goethite, particularly along fractures. Actinolite is also a late-stage phase with euhedral needles to 5mm long within both chlorite-rich aggregates and the nephrite matrix.

The sequence of events is apparently:

1. Formation of assemblages of diopside, tremolite, cummingtonite, anthophyllite and ?phlogopite; presumably during ?D_2.
2. One or possibly two phases of chloritisation with extensive retrogression of earlier phases and two chlorite schistosities.
3. Nephrite matrix formation along with minor coarser tremolite, at the same time as development of a nephrite schistosity, presumably S_4. One of the chlorite schistosities may have developed at this stage. Recrystallisation of chlorite produced chlorite-aggregates containing randomly-oriented sheaves and rosettes.
4. Post-nephrite matrix development of actinolite needles to 5mm long within nephrite matrix and chloritic aggregates.

Similar very, late-stage development of coarse tremolite or actinolite needles are observed in S_4 chlorite and talc schist zones at Outcrop 53, but are otherwise rare.

Chlorite is more abundant on the hanging wall contact of the jade lens but similar features and sequences of events are still observed. One important feature is that massive to schistose chlorite rocks are very Mg-rich (i.e. 24.2% MgO in 6231 RS 151) and contain readily recognisable sphene or a titanate phase (1.15% TiO_2).

Towards the base of DDH14 at 31.7m and in footwall rocks at Outcrop 15 is 0.2m band of nephrite and unusual speckled or mottled nephrite/semi-nephrite (Plate 28). The nephrite (6231 RS 181) varies from fine grained and randomly oriented, to slightly schistose (S_4) with thin anastomosing cleavage planes lined with limonite/goethite. Nephrite is particularly dusty. A band containing ?cummingtonite and ?anthophyllite is also present where the texture is again fibrous. Farrand (1985) interpreted development of fibrous tremolite bands and fibrous ?cummingtonite and ?anthophyllite as after formation of felted nephrite.

Within 2-3cm, nephrite (6231 RS181) grades to the speckled or leopard-skin texture within semi-nephrite (6231 RS 182) (Plate 28) (Flint and Dubowski, 1986, Plate 19). White areas consist of cummingtonite, minor epidote and a member of the norbergite-chondrodite-humite-clinohumite series (Farrand, 1985). Green spots of the speckled texture consist of coarser-grained fibrous tremolite whereas the grey-green spots consist of fine-grained, felted nephrite. The white material also contains patches of medium-to-coarse tremolite in radiating clusters, which grades to nephrite. Nephrite and tremolite are veined by and apparently replaced by late-stage fibrous chlorite which forms radiating clusters.

The speckled nephrite is obviously Mg rich with an assemblage of tremolite, cummingtonite, chondrodite-humite group mineral and presumably Mg-rich chlorite. The sequence of events, which may have a dolomite-magnesite precursor, is apparently:

1. M_1-M_2 metamorphism to olivine + diopside $\underline{+}$ clinoenstatite
2. Retrogression to tremolite + cummingtonite + chondrodite
3. Partial alteration to nephrite
4. Minor regrowth of tremolite
5. Replacement of all phases by fibrous chlorite (Farrand, 1985).

Surrounding this nephrite and speckled nephrite are:

- massive diopside retrogressed to tremolite + calcite (semi-nephrite)
- and ?diopside breccia (6231 RS 183).

Diopside breccia is very fine grained and unaltered. Optical identification is uncertain and mineralogy may be Fe-free zoisite.

A third area containing jade is in DDH14 between 6 and 8m, in hanging wall rocks to Outcrop 15. Jade is minor and has mostly formed by retrogression of diopside in diopside-rich bands within banded calc-silicate gneiss (6231 RS 166-168). However, one sample (6231 RS 166) also involves epidote with nephrite. Diopside exhibits banding of retrogressive and partly mylonitic origin (?D_3) which resulted in formation of retrogressive epidote which has subsequently been replaced by ?D_4 nephrite (6231 RS 166). Naturally, adjacent diopside shows a two-stage alteration to coarse and then fine nephrite. Within epidote, tremolite forms ragged prisms grading to acicular and fibrous forms (nephrite) which have penetrated epidote grain boundaries, filled interstitial spaces and replaced epidote. This is one of the very few examples of epidote replaced by nephrite and asbestiform tremolite.

Structure

All units strike consistently N-NE averaging 015°M, with steep westerly dips averaging 75° (Fig. 7). Lithological layering S_o is not distinguished from either the S_1 or S_2 gneissosities.

D_2 and D_3 folds are interpreted in Cross Section AB through DDH14 (Fig. 7). D_3 folds are rarely observed probably because of poor, rubbly outcrop rather than their absence. Observed D_3 folds are in banded calc-silicate gneiss with axial planes essentially parallel to layering i.e. striking about 015-020°M, variable dip but with shallow N-NE fold axes plunging about 15° towards 015°M (Fig. 8). A tremolite + chlorite schistosity is observed in hanging wall tremolite + chlorite rocks exposed in the trench and corresponding to 6231 RS 151 - 153 in DDH17. Being parallel to the jade lens and observed D_3 folds in banded calc-silicate gneiss, the schistosity is interpreted as S_3. It is also interpreted as one of the earlier schistosities in jade samples 6231 RS 154-156. In outcrop, the S_3 tremolite + chlorite schistosity is overprinted by a D_4 crenulation (see following comments).

D_4 data within Outcrop 15 are scarce but are consistent with the empirical observations of a steep E to SE joint, whereas the jade foliation strikes SE to S ie. 20-40° more southerly than the joint set. A similar angular relationship between joints and foliation in jade is observed in many outcrops. A low angle joint which strikes approximately along the jade lens and dips about 40°E was observed during mining. As observed in thin sections and as exposed in the trench in hanging wall chlorite-rich rocks, the tremolite + chlorite schistosity is crenulated by a D_4 crenulation, striking 144°M and dipping 84°NE. A mineral lineation on the S_3 schistosity but at the intersection of S_3 and S_4 plunges 53° towards 319°M. Across the S_3 schistosity are abundant veins, 2-4mm thick, of coarse-grained fibrous tremolite.

The age of mylonitisation in uncertain but interpreted as synchronous with D_3. Mylonitisation is superimposed on many of the earlier retrogressive phases ie. coarse-grained epidote, tremolite, zoisite and clinozoisite but is demonstrably earlier than the late-stage, D_4 nephrite with its nephritic foliation and crenulation. However, the N-S mylonite is of the same orientation as nearby D_4 faults as interpreted by Parker (1983a and b) during 1:50 000 mapping.

OUTCROP 16

REFER Figure 12 (Plan 89-177)

Mining and Tenement History

Outcrop 16 is within ML 4217 and the full tenement details are outlined in the section OUTCROP 24. The lease is currently held by Gemstone Corporation of Australia Ltd.

There is no recorded production from Outcrop 16 (Olliver, 1984) although trial mining with a backhoe was undertaken in September-October 1976 (Scott et al, 1978 - Plates 4-7). Dark green-black nephrite from Outcrop 16 was crafted at the O'Halloran Hill College of Further Education by Val Morris into several cubes. The outcrops have not been mined previously as the jade cropping out is distinctly foliated and is apparently predominantly semi-nephrite.

Geological Mapping

The outcrop was described by Nichol (1974a, 1977) as a 8x8m pod hosted by dolomitic marble. No additional mapping or sampling of Outcrop 16 was undertaken until mapped by the authors, W. Simandjuntak, A. Sulaeman and S. Atmanwinata in April 1987.

Site Geology

Outcrop 16 is characterised by bladed outcrops to over 1m high (Nichol, 1974a, Plate 25446; Barnes et al, 1980, Plate 4; Flint et al, 1984, Plate 11), and is apparently along strike from dolomitic marble at Outcrop 15 though slightly displaced by an interpreted D_4 shear. As with many other jade outcrops, the jade lens is apparently controlled by dolomitic marble abutting a D_4 shear. D_3 mylonitic shear zones are nearby but apparently not a significant controlling factor. The backhoe pit at Outcrop 16 exposes altered pegmatite containing clinozoisite. Porphyritic adamellite grading to porphyritic granodiorite crops out 5m north of the backhoe pit. Identical porphyritic adamellite has only been observed elsewhere in the Cowell Jade Province near Outcrop 53, as 1-2m wide dykes emplaced along sheared axial planes of D_4 folds.

Stratigraphy

Lithologies at Outcrop 16 consist of Miltalie Gneiss and the basal Warrow Quartzite unit of banded calc-silicate gneiss.

All outcrop of Miltalie Gneiss lies to the west of a N-S mylonite zone, and the contact with Warrow Quartzite is faulted rather than unconformable. The unit consists dominantly of a grey to pink, granodiorite gneiss which, thought quite uniform, is thinly banded and has similarities to Miltalie Gneiss in the Plug Range area. Locally, granodiorite gneiss also includes pegmatite, migmatite and hornblende gneiss. Foliation (S_1 and/or S_2) is parallel to banding. No stratigraphic facing data are available.

By analogy with nearby outcrops (ie outcrops 15, 21, 22, 24 and 32-36), all of the rocks east of the central mylonite zone apparently represent part of the banded calc-silicate gneiss unit at the base of Warrow Quartzite.

Rock types exposed are dolomitic marble, massive diopside rock, quartzite, quartz-rich gneiss and banded calc-silicate gneiss as well as migmatite and pegmatite. Detailed descriptions of these units are presented in the section OUTCROP 15. Definitive facing data are not available but, based on regional data from Outcrops 15-36, facing is assumed to be eastwards, regionally and probably also locally.

Structure

Of all the jade outcrops mapped, Outcrop 16 provides the best opportunity to examine structural differences between Miltalie Gneiss and Warrow Quartzite. However, stereographic projections of the lithological layering, banding and parallel gneissosity ('S_1/S_2') reveal either none, or at best, barely distinguishable differences. Gneissic layering in both Miltalie Gneiss and Warrow Quartzite dominantly strikes N to NE and dips steeply westwards, though there is a tendency for layering in Miltalie Gneiss to dip about 20^o more shallowly. Both units, exhibit the same folding pattern of the gneissic layering during D_3.

The folded gneissosity indicates a fold axis plunging about 20^o towards N-NE, which is consistent with observed D_3 folds. Gneissic layering orientations suggest numerous folds as illustrated in Cross Section AB but closures are very rarely observed. Isoclinal D_2 folds are probably present but were not observed. D_3 folds are upright, close and slightly asymmetrical; fold axes plunge N to NE. D_4 structures consist of typical SE-trending late-stage planar joints subparallel to the interpreted D_4 fault at Outcrop 16. The fault is mostly interpreted from apparent discontinuity of several lithologies and fold hinges rather than direct observations. Outcrop 16 contains a pronounced D_4 foliation, with an average dip of 75^o towards 225^oM which is of similar strike (but not dip) to D_4 joints. About 25m north of and parallel to the fault through Outcrop 16 is a possible D_4 monoclinal flexure. Similar structures but only 1-2m across were observed elsewhere in the Cowell Jade Province during regional mapping at 1:10 000.

Nephrite

Outcrop 16 consists of a 6 x 3m outcrop about 1m high with the pronounced D_4 foliation which has controlled its bladed character. The quality of that part exposed is probably semi-nephrite. It also tends to be slightly coarse grained. Colour is dark green and with very low translucency.

Though the interpretive Tectonic Sketch shows Outcrop 16 located along strike of banded calc-silicate gneiss, alternative interpretations are possible including that the jade pod represents the southern limit of the dolomitic marble and diopside rocks that extend to Outcrop 15.

OUTCROPS 21, 22, 110, 111 AND GREEN MARBLE PROSPECT

REFER Figures 13-15 (Plans 88-423, S 20215, 88-424)
Logs DDHs GGM1, 2 & 3, Figures 16-18
(Plans 88-425, 88-426, 88-427)

The main features of interest for this area are:

- Outcrop 21 is located on the closure of a D_2 isoclinal fold;
- hybrid pegmatite with two alteration styles was intersected in CGM2 and 3. One style includes bright orange-pink clinozoisite or thulite;
- drilling was undertaken for ornamental, pale green and grey green, dolomitic marble;
- four small nephrite occurrences from retrogressed diopside were intersected in holes CGM2 and 3. None are directly correlated with surface outcrops of jade.

Mining and Tenement History

Outcrops 21, 22, 110 and 111 are located within ML 4217 which is currently held by Gemstone Corporation of Australia Ltd. Full details of the tenement history are described elsewhere (see section OUTCROP 24) as about 20 jade outcrops are located within ML 4217.

There has been no production of ornamental green marble from the vicinity of Outcrops 21, 22, 110 and 111.

Jade production from these four outcrops is small. Harry Schiller may have collected 0.2 - 0.3 t by hand mining in 1969-1970, but production may have been from a variety of outcrops (Olliver, 1984, Table 4). The western end of Outcrop 21 was mined with a backhoe by Gemstone Corporation in April 1987 and 14t of jade were recovered.

Geological Mapping

The first geological observations at these outcrops were by Nichol (1974a) who identified Outcrops 21 and 22 during reconnaissance geological mapping of the Cowell Jade Province.

In 1978-1979, The Corporation of the City of Adelaide was restoring Adelaide Town Hall buildings and consideration was given to carving a Coat of Arms to mount on the facade of Albert Tower facing King William

Street. Green granite from the South East and green dolomitic marble from Cowell were considered. Initial samples supplied by Graham Robertson (Cowell Jade Pty Ltd) were favourably received by the City Council.

Dolomitic marble outcrops throughout the Cowell Jade Province were inspected by D.A. Young (SADME) in May 1979 and a site between Outcrops 21 and 22 was considered to have the most potential (Fig 13). The site was tested by an air-track drill in December 1979 by D. Linke for Cowell Jade Pty Ltd during mining of Outcrops 32 and 69. Several drill holes penetrated 1.5m of strong surface outcrop, but beneath which the dolomitic marble was found to be strongly weathered to soft nodular powder for at least 6m. Drilling stopped before fresh marble was again intersected. The site was excavated and some of the surface boulders remain stockpiled (Fig. 13).

As there were (and still are) very few green dimension stones in Australia, interest was renewed in this prospect when, in 1982, Mitchell, Giurgola and Thorp, architects for the new Parliament House in Canberra intended to use a green stone (preferably marble) for panelling central parts of the main wing walls which were to be behind a glass facade. About $100m^3$ of finished panels were required, each 40mm thick and to cover a total area of $2\,000\ m^2$.

In an attempt to secure the contract for South Australia, the site was diamond drilled in 1983 at the same time as drilling DDH 14-17 on jade Outcrops 15, 32 & 35 and further testing of fine-grained, white marble (ML 4338). Depth of weathering was tested by CGM1 (24.00 m) and was followed by CGM2 (39.30m) and CGM3 (36.0m) to test for texture, colour uniformity and thickness as well as to obtain samples for compressive strength tests, water absorption etc. Detailed mapping by D.A. Young (SADME) of the site has been compiled as Figures 13-15. Drill logs of CGM1-3 are included as Figures 16-18.

During the detailed mapping, jade outcrops 110 and 111 were located. Two other occurrences remain un-numbered (Fig. 13).

Additional data were collected on Outcrop 21 by the authors and Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata immediately prior to mining by backhoe in April 1987. Petrography of pre-mining samples 6231 RS 212 and RS 213 was by Sumitra Atmanwinata (Appendix E).

Site Geology

Rock types near Outcrops 21, 22, 110 and 111, interpreted as part of basal banded calc-silicate gneiss within Warrow Quartzite, include dolomitic marble, calc-silicate, biotite/ chlorite schist and gneiss, massive diopside, and banded or layered gneiss. In addition, several lithologies are gradational into the overlying Warrow Quartzite i.e. quartzite, quartz-rich gneiss and graphite+quartz schist. The graphite+quartz schist was the only exposure mapped in the Cowell Jade Province, and nearby hybrid pegmatite also contains traces of graphite (Fig. 13).

Stratigraphic facing and sequence of units were not established, as isoclinal D_2 folds and poorly exposed D_3 mylonite zones are present but not mapped in detail.

Structure

A significant D_2 fold extends through Outcrop 21 SSW towards Outcrop 111. The fold is isoclinal and folds near Outcrop 21 suggests a plunge of 30-50^o towards O^{o}M. The axial plane hinge is probably within the areas of Cross Sections AB, CD & EF but has not been shown due to insufficient data and poor correlation across the hinge (Figure 13).

Layering and gneissosity show a systematic variation, striking about 010^{o}M near Outcrop 21 to striking 50-55^{o}M near Outcrop 111 (Figures 13 and 14). Dips are variable westerly (40-90^o) but tend to be shallower in the south. The gentle swing is due to superimposed D_3 folding or warping during D_4 buckling and fracturing.

D_3 folds and mylonite were not mapped in outcrop but both are present in drillcore (Figures 16-18), i.e.:

- open folds in banded gneiss (CGM3, 8m)
- mylonite calc-silicate and diopside (CGM2, 16m & 32m)
- D_3 crenulations and mylonitic schistosity in biotite gneiss (CGM2, 37m).

Layering is significantly different in orientation above and below the mylonite zone at 32m in CGM2 (Figure 13, Cross Section AB).

D_4 fracturing, faulting and jointing are common throughout the mapped area but only the largest are shown on Figures 13 and 15. Faults and joints generally strike 115-120^{o}M, are sub-vertical and sinistral displacement is most common. Minor gentle buckling of dolomitic marble during D_4 is also evident at the collar of CGM1 (Fig. 16), but deformation is essentially brittle fracturing.

D_4 foliation (i.e. tremolite schistosity) is evident only in Outcrop 21 and is strongly developed in the ESE tail of the outcrop. The schistosity strikes 115-125^{o}M (Fig. 14) and is essentially the same as D_4 faults and joints.

Hybrid Pegmatite and Granite

As for many other jade outcrops, hybrid pegmatite is present apparently as sills, dykes and undetermined intrusive forms. Relationships to other structures were not elucidated, hence no additional data are available on the timing of intrusion. Drill hole CGM2 spudded on hybrid pegmatite, but the relationship drawn on Cross Section AB (Figure 13) is schematic only.

Hybrid pegmatite and jade outcrops do not show a close spatial relationship as in Outcrops 14 and 69.

Hybrid pegmatite of CGM2 (2-7m) and CGM3 (28.8m) show exactly the same features as at Outcrop 76. That is, two different mutually exclusive, but related styles of alteration are present. In both styles the relict pegmatitic texture is still evident. One style of alteration is clinozoisite replacing feldspar whereas quartz remains immobile. Clinozoisite is brightly coloured in orange pink shades i.e Munsell moderate orange pink 10R 7/4, reddish orange 10R 6/4 to 10R 6/5 and even moderate reddish brown 10R 6/6. Hence the alteration style is similar to the ornamental thulite/clinozoisite prospect between Outcrops 90 and 112 (ML 4522).

The second style involves extensive replacement of feldspar by very fine grained bright green epidote. Quartz recrystallises also so, overall, hybrid pegmatite is finer grained but still with the pegmatite texture evident.

Nephrite

There are 10 pods of jade within the mapped area, some of which are grouped and referred to as Outcrops 21, 22, 110 and 111 others are left un-numbered. In addition, nephrite and semi-nephrite with no obvious relationship to surface outcrops were intersected in drill holes CGM 2 and 3. An extensive zone of massive coarse-grained tremolite, 10m NW of CGM1 and apparently related to D_4 fracturing, has potential with depth to contain nephrite (Figure 13).

Nephrite - Outcrop 21

Outcrop 21 is large (20 x 8m) and has an unusual shape apparently due to its location on the nose of a D_2 fold in dolomitic marble. In this respect it is similar to Outcrop 24 which also occurs on a fold hinge. Although located on a D_2 fold, nephrite formation is interpreted as during D_4. Prior to mining in 1987, the WNW end of the outcrop contained distinct banding with an orientation typical of D_2 axial planes and fold limbs and is interpreted as relict D_2 axial planar gneissosity/banding (Plate 7). Relict banding with D_2 folds have also been observed in Outcrop 15 (Plate 8). The ESE end of Outcrop 21 is narrow and foliated with a strongly-developed D_4 foliation.

Overall, nephrite of Outcrop 21 is medium to dark green with variable grain size but tending to be coarse grained (i.e. semi-nephrite) (Plate 6). Although dominantly massive on the WNW end, the ESE end is thoroughly foliated producing bladed outcrops. Banding in the WNW end is defined by very fine-grained bands alternating with numerous, less resistant coarser bands. The weathering rind is reddish brown and thin, rarely reaching 10mm and often only 2-3mm.

Microscopically, both massive and schistose forms of nephrite/semi-nephrite exhibit tremolitic schistosity differing only in degree of development (6231 RS 212 and RS 213). The typical fine felted texture of nephrite is present, but fibre bundles tend to be aligned defining the schistosity. Undulating or diverging fractures parallel the tremolite schistosity and are stained by opaque and transparent iron oxides. Both massive and schistose nephrite/semi-nephrite exhibit late-stage coarser tremolite, up to 0.5mm across which also tends to be aligned in the schistosity. Flakes of chlorite to 0.5mm are also present.

Apparently Outcrop 21 has been strongly sheared or sheared very late as indicated by:

- ESE end of the outcrop is narrow and highly foliated
- tremolite schistosity and fractures are parallel and not up to 40^o apart as in some other outcrops
- even very late-stage coarse tremolite is aligned in the schistosity.

In most other outcrops where late-stage tremolite is present as prisms, needles and radiating aggregates, the tremolite is not aligned in the schistosity. The strong shearing of Outcrop 21 is comparable to that observed in Outcrop 16 with its high bladed outcrops (Slide 25446 of Nichol (1974a) and Plate 11 of Flint et al. (1984)).

Vague lamellar textures and coarse domain structures in RS212 and RS213 suggest a precursor to nephrite of either dolomite or diopside.

Nephrite - Drillholes CGM 2 and 3

Four nephritic zones were intersected in drill holes CGM2 and 3, but apparently all four form retrogression of diopside (Figures 17 and 18). Based on the current interpretations (Cross Sections AB and EF, Figure 13) none of the intersections are directly correlated with the surface Outcrops 110 and 111.

Nephritic segregations in CGM2 are within dolomitic marble at 16.75 - 16.95 m. The nephritic zone is 15cm long and 2cm wide. Nephrite is dusky yellowish green, around 10GY 3/3, weakly translucent and has an unaltered core of off-white diopside. Surrounding marble is tremolitic, fine grained and pale green (5G 8/1 and 8/2). A 4mm-thick band of nephrite at 17.00m also contains relict diopside.

A massive band of diopside 1.2m thick at 23.6-24.8m in CGM2 shows minor retrogression to nephrite (dusky yellowish green 10GY 3/2) but only as one small bleb 25 x 5mm across. Similar dusky yellow green nephrite formed as a band 25mm thick in CGM3 at 4.2 m, but retrogression was incomplete and produced speckled relict white diopside and dusky green nephrite.

Green Marble

Colour variations within dolomitic marble in the vicinity of Outcrops 21, 22, 110 and 111 were mapped and are shown in Figure 15. Overall, the dolomitic marble is medium light grey (N6) but ranges from N7 to darker grey (N4-N3). Zones of grey-green dolomitic marble were defined and all are as bands parallel to lithological layering ($S_o/S_1/S_2$).

Drilling was unsuccessful in locating significant grey green dolomitic marble and core was often fractured. Detailed descriptions of dolomitic marble, including Munsell colours of all phases, are presented in the drill logs of CGM1-3 (Figures 16-18). Dolomitic marble is banded with broad non-uniform, colour zones. Irregular mottling results from disseminated aggregates of serpentine after olivine, chlorite after phlogopite and tremolite after diopside, as well as from finer-scale banding.

Yellow green aggregates of serpentinised olivine form the characteristic mottling and spotting on grey backgrounds (N8-N3). Serpentine is most commonly light olive (10Y 5/4), pale olive (10Y 6/2) to dusky yellow green (5GY 5/2) but grades into the chlorite colours.

Chlorite exhibits a variety of colours and typical colours are greyish olive (5 GY 3/2), dusky yellowish green (10GY 3/2), moderate yellow (10GY 5/3), greyish green (5G 5/2) and pale green (5G 6/2).

The yellow brown and red brown colours, typical of the ornamental marble quarry 1km NNW of 'Mount Ghearthy' in EML 4455, consist of light brown (5 YR 5/5), moderate yellow brown (10YR 5/4), greyish orange (10YR 6/4 and paler 10YR 8/4). The colours are probably also due to serpentine but its form (chrysotile versus antigorite) and/or its composition may be different.

Mineral phases of dolomite, phlogopite, diopside etc are all coarse grained (4-5mm) after D_1/M_1 and D_2/M_2. A fine-grained and uniform pale green (5G 6/2) or grey green (5G 5/2) appearance would only result after extensive retrogression and recrystallisation during which the large aggregates of olivine±phlogopite were destroyed and fine-grained disseminated serpentine or chlorite produced. Such recrystallisation probably did occur during D_3. Petrography of other fine-grained pale green and grey green dolomitic marble from elsewhere in the Cowell Jade Province (e.g. Outcrop 15), suggests the desired colour can be produced from either chlorite or serpentine. The outcrop pattern of zones of pale green and grey green dolomitic marble parallel to lithological layering and semi-continuous for tens of metres, support D_3 deformation, retrogression and recrystallisation.

However, a similar effect may have occurred during D_4, being promoted by solution activity along the numerous D_4 joints and fractures. Fine-grained, green dolomitic marble does appear to have a broad spatial relationship to nephrite, either because:

- both were produced during D_4, or
- both require D_3 retrogression before nephrite formation during D_4 (e.g. diopside retrogression to coarse-grained tremolite).

Probable D_4 recrystallisation to produce fine-grained, green dolomitic marble was interpreted, based on petrographic data at Outcrop 15. The same feature is observed in drill hole CGM2 at 16.75-16.95m, where nephrite has formed from retrogression of diopside. Surrounding dolomitic marble is tremolitic, fine grained and pale green (5 G 8/1 and 8/2 with darker variants to 10 GY 5/1). That is, the pale green, fine-grained dolomitic marble is at least in part produced during (D_4) nephrite formation.

OUTCROP 24

REFER Figures 19 and 20 (Plans 88-84, S 20216)

Mining and Tenement History

Outcrop 24 was first pegged by H.A. Schiller as MC 5332 which was registered on 12 October 1968. The claim was transferred to Jade (Australia) Pty Ltd on 25 July 1972, converted to ML 4217 on 22 October 1973 and again transferred, this time to Cowell Jade Pty Ltd on 16 December 1976. The lease is currently held by Gemstone Corporation of Australia Ltd.

Trial mining was conducted at Outcrop 24 by SADME personnel in 1976 and 12 carvings were crafted at the O'Halloran Hill College of Further Education (Scott et al., 1978). Colours ranged from mottled pale green to dark green but with paler colours dominating.

Cowell Jade Pty Ltd mined 50t of jade during 1978 and also in 1980. Remaining jade was covered by scree. Three tonnes were subsequently recovered from this pod by Gemstone Corporation in December 1987.

Geological Mapping

Nichol (1974a) recorded Outcrop 24 as a 7 x 2 m lens hosted by dolomitic marble. Two samples of nephrite and semi-nephrite were petrographically examined (P1368/74 and P1370/74). Both contained dendrite patterns.

Samples collected during phase III of the 1976 trial mining program were studied in a scanning electron microscope by D. Hos (SADME) (Scott et al., 1978, Plates 16 and 17).

Theodolite surveying by A.J. Smith (SFB 681) and geological mapping by the authors was undertaken in November 1982 and again in March 1985. At the time of mapping the jade pod was obscured by scree (H. Carmody, 1987, pers. comm.).

Site Geology

The sequence at Outcrop 24 has an outcrop width of only 40m and consists of alternating dolomitic marble, calc-silicate, quartzite, biotite schist and banded gneiss representing banded calc-silicate gneiss at the base of Warrow Quartzite. Stratigraphic facing (?eastwards) is uncertain and relies on interpretation of regional data, particularly D_2 isoclinal folds.

The dump at Outcrop 24 obscures much of the controls to jade mineralisation and outcrop is poor. Unlike most other outcrops and quarries, prominent D_4 fractures and/or altered feldspathic pegmatite dykes were not observed. However, massive and schistose tremolite and chlorite rocks are present along strike of dolomitic marble so that D_4 fractures or altered pegmatites are assumed to be present to produce the metasomatic tremolite + chlorite rocks. Jade would have formed within this metasomatic zone.

This outcrop also permits distinction between effects of D_3 folding and the superimposed S_4 schistosity which is at a low angle to S_3. The structural relationship of D_2 and D_3 is the key to interpreting Outcrop 24.

Structure

Folded layering in dolomitic marble and gneissosity define a poorly-developed, great-circle distribution, about a D_3 fold axis plunging about 55^o towards 020^oM (Figure 20). Within that trend, layering and gneissosity form groups clustering at striking N-S (minor), 35^oM and 65^oM (equally dominant). Regional data indicate that the long limb is expected to be N-S, but the 35^o-65^o limb dominates at Outcrop 24. Hence Outcrop 24 appears to be on the short limb of a D_3 fold. Folding effects attributable to D_2 folding were not observed.

D_3 folds are abundant, both surrounding Outcrop 24 and as a synformal fold in quartzite and dolomitic marble in the quarry face (Figure 19). Folds are open to closed, and without axial plane structures except one example of axial planar crenulation in mica gneiss. F_3 folds plunge about 30^o towards 35^oM i.e. close to the interpreted fold axis from the distribution of S_1/S_2 layering and gneissosity (Figure 20). The average D_3 axial plane strikes at 030^oM and dips 70^oSE.

Chlorite, tremolite + chlorite and tremolite rocks exposed in the quarry face are typical, being generally massive but grading to schistose equivalents. Chlorite-rich rocks tend to be fine grained and dark green whereas tremolite is pale green, milky opaque and predominantly fine grained. Rare compositional banding suggests relict original layering (S_1/S_2). Contacts of chlorite-rich and tremolite-rich rocks parallel lithological layering. Apart from minor relict S_1/S_2 banding, chlorite and tremolite rocks show only an S_4 schistosity. The S_4 schistosity was observed only in these rocks exposed in the quarry face and not in adjacent dolomitic marble or gneiss.

The S_4 schistosity exhibits considerable variation, but on average strikes 020^{o}M and dips 75^{o}W. The orientation of the S_4 schistosity is in part dependent on the orientation of lithological layering. Where layering strikes 030-065^{o}M the S_4 also strikes more northeasterly. As lithology strikes more N-S, then so does the S_4 schistosity. Importantly, the S_4 schistosity is distinguishable in both style and orientation from D_3 axial planar structures. D_3 foliations are apparently absent from the chlorite + tremolite metasomatic zones.

The jade which has already been mined from Outcrop 24 looks as if it formed a lens or lenses which were located in a metasomatic zone at the closure and hinge of a D_3 fold. However, as no D_3 structures are evident in tremolite and chlorite, metasomatism is interpreted as post-D_3 folding. Similar geology controls jade at Outcrop 21. Metasomatism is presumed to have occurred during D_4 fracturing and/or emplacement of altered plagioclase pegmatite - neither of which are exposed.

Three joint sets presumed to be D_4 are present (Figure 20). The typical steep joint striking 100^{o}M is present as well as one of very similar strike but dipping only 10^{o}N. The steep E-W joint intersects the S_4 schistosity to produce an apparent slickenside lineation plunging 63^o towards 290^{o}M.

Nephrite

Minor jade is exposed in dolomitic marble and tremolite rocks in the quarry as well as 25m to the NE (Figure 19).

Within the quarry, jade is either:

- within dolomitic marble as bands up to 20 x 6 cm parallel to lithological layering. Nephrite is massive, pale green to grey green, massive and moderately translucent.
- within dolomitic marble but terminated against a D_4 joint striking at 168^{o}M. Nephrite is pale green and translucent to semi-translucent.
- within green dolomitic marble but within an unusual low-angle D_4 joint i.e. striking 086^{o}M and dipping only 10^{o}N.

- within tremolitic, metasomatic zones which locally grade to small patches, only a few centimetres across, of semi-nephrite. Semi-nephrite is pale green, milky opaque and tends to be foliated (S_4), hence grades to tremolite schist.

Two pre-mining samples collected by Nichol (1974a) were of nephrite and mottled semi-nephrite (P1368/74 and P1370/74). Both were dendritic with goethite/limonite staining along branching, irregular to anastomosing fractures. Mottled semi-nephrite (P1370/74), containing serpentine and epidote/clinozoisite, has tremolite in two grain sizes and has a microstructure very similar to the mottled semi-nephrite from Outcrop 52. Many of the carvings from the trial mining program, crafted at O'Halloran Hill College of Further Education, show this typical mottled texture (Scott et al., 1978, Plates 9-11).

Jade of Outcrop 24 is schistose in part with a N-S S_4 schistosity. Foliated jade samples include P1368/70 of Nichol (1974a) and scanning electron microscope sample of Scott et al (1978) as well as 6230 RS 347 and 348 of this report from an outcrop 25m NE of the quarry. Samples consist of minor relict coarse tremolite prisms, relict augen of coarser fibrous tremolite to about 1-1.5mm, and a finer felted to schistose matrix. Both rotated tremolite prisms and fibre patterns within the coarser aggregates indicate repeated and prolonged rotational and shearing stresses (see Scott et al., 1978, Plates 16 & 17).

OUTCROP 30 AND ML 4341

REFER Figure 21 (Plan S 19838)

Mining and Tenement History

Outcrop 30 is located within ML 4217 and has not been mined. No jade outcrops are known within ML 4341. Tenement history for ML 4217 is detailed in the section for OUTCROP 24.

Jade (Australia) Pty Ltd had pegged Outcrop 30 and others within ML 4217 in 1968, but the adjacent tenement (MC195/ML4341) was not pegged until 1973. Australian (Nephrite) Jade Mines Pty Ltd sought an extension of Outcrop 30 and pegged MC 195 which was registered on 26 June 1973. However, they were unsuccessful as no jade was known at the time nor has subsequently been found on that tenement. MC 195 was converted to ML4341 on 10 December 1973 and was eventually acquired by Cowell Jade Pty Ltd on 21 November 1979. ML 4341 is currently held by Gemstone Corporation of Australia Ltd.

Geological Mapping

Centamin No Liability mapped MC 195 (ML 4341) during September 1973 after acquiring the rights to explore, mine, extract and market jade on all tenements held by Australian (Nephrite) Jade Mines Pty Ltd. Their geological sketch (Australian Nephrite, 1973) is included as Figure 21 with additional data from SADME geological mapping of the Cowell Jade Province.

Nichol (1974a) described Outcrop 30 as 12 x 2 m in calc-silicate host rocks, whereas Scott et al. (1978) described the dominant jade colour as dark green.

Site Geology

Little attention has been given to ML 4341 as it mostly covers migmatised Warrow Quartzite. Outcrop 30 is hosted by banded calc-silicate gneiss which forms a basal unit of Warrow Quartzite. Hence the sequence is interpreted to face east, though the sequence dips west; this is consistent with regional data. Banded calc-silicate gneiss apparently extend onto ML 4341 but outcrop is poor. Vegetation suggests dolomitic marble is present in the poorly outcropping area of ML 4341.

Mesoscopic, D_2 isoclinal folds are abundant. Lithological layering, gneissosity and D_2 axial planes strike at about 020°M and dip 70-80°W.

OUTCROPS 31-36

REFER Figures 22-24 (Plans 88-85, 88-86, S 20217)
Logs DDHs 16 & 15 Figures 25 & 26
(Plans 88-80, 88-79)

Mining and Tenement History

The tenement history for Outcrops 31-33 have been discussed previously (OUTCROP 24) as all are located within ML 4217.

Outcrops 34-36 were first pegged by Pacminex (Operations) Pty Ltd and registered as MC 108 on 16 November 1972, but was lost on plaint to Australian (Nephrite) Jade Mines Pty Ltd and forfeited on 30 July 1973. Outcrops 34-36 were then repegged by Australian (Nephrite) Jade Mines Pty Ltd as MC 291 registered on 31 August 1973. This was converted to ML 4381 on 7 August 1974. In June 1973, Centamin No Liability acquired the rights to explore, mine, extract and market jade on all tenements held by Australian (Nephrite) Pty Ltd, including

MC 291/ML 4381, but the indenture was cancelled on 4 July 1979. ML 4381 was transferred to Cowell Jade Pty Ltd on 21 November 1979 and is now held by Gemstone Corporation of Australia Ltd.

H.A. Schiller recovered 0.2 and 0.3t of jade in 1969 and 1970 respectively from ML 4217. The lease covers about 23 jade outcrops but production was probably from Outcrop 32. Bulldozing of Outcrops 31-36 in late 1972 and early 1973 on and south of MC 5332 by McDonald Earthmovers led to recovery of 160t (Olliver, 1984). This was the first use of bulldozers in the jade province; previously production was restricted to collecting floaters or hand mining.

Under their indenture with Australian (Nephrite) Jade Mines Pty Ltd on MC 291/ML 4381, Centamin No Liability mined 55t and 23.5t of jade in 1974 and 1975 respectively from Outcrops 35-36.

A backhoe trench 1.5 m deep was dug at Outcrop 32 during Stage III of a trial mining program in 1976 (Scott et al., 1978), but apparently no samples recovered were carved at the O'Halloran Hill College of Further Education.

Whilst ML 4217 and ML 4381 were held by Cowell Jade Pty Ltd, the two quarries on Outcrops 31-32 and 35-36 were extended with production of 70t from Outcrops 31-32 in 1979 as well as 72t and 106t from Outcrops 35-36 in 1980 and 1981 respectively. By this stage, a 2-bench quarry had been established on Outcrops 35-36. It is still the only 2-bench quarry in the Cowell Jade Province.

The next major mining was in 1987 when David Linke Contractor Pty Ltd for Gemstone Corporation recovered 91t from Outcrop 32 and 79t from Outcrops 35-36.

Total production from Outcrops 31-36 is estimated at 664.5t; about 179.5t from Outcrops 31-32 and 485t from Outcrops 35-36 (Figure 2). Most production has been green, low translucency jade, but some bright green, deeply translucent nephrite has also been produced. The occurrence of bright green, translucent jade and reliable yields from these outcrops have resulted in 44% of the recorded and estimated production from the Cowell Jade Province being from the two quarries on Outcrops 31-36.

Geological Mapping

Under an option arrangement with H.A. Schiller, Murumba Minerals No Liability mapped MC 5332 (Outcrops 31-33) as well as the adjacent Outcrops 34-36, which at that time, were within SML 383/SML 667 held by Pacminex (Operations) Pty Ltd (Hopwood and Coles, 1971). Their geological mapping is reinterpreted in terms of current rock classifications and represented as Figure 22. At that time, high-quality, translucent green nephrite was exposed (Hopwood and Coles, 1971).

During 1973, Centamin No Liability had an indenture agreement with Australian (Nephrite) Jade Mines Pty Ltd over Outcrops 33-36 within MC 291. Centamin prepared a geological sketch of MC 291 (now ML 4381) (Centamin N.L., 1973).

At the same time, 4 nephrite samples from Outcrop 32 (M1-M4) were analysed and petrographically described for Jade (Australia) Pty Ltd - included in Appendix B.

During geological mapping of the Cowell Jade Province (Nichol, 1974a; 1975; 1977), a suite of nephrite, banded calc-silicate and dolomitic marble rocks were analysed and petrographically described, including a nephrite sample, (P100/73) from Outcrop 32. Of the five outcrop 32 samples, M1 of very dark greyish green colour had the highest iron content, 7.91% Fe_2O_3 (total iron expressed as Fe_2O_3). As Outcrop 32 apparently does not contain green black or Premium Black jade, higher iron contents are expected from black jade at outcrops such as Outcrop 15, 44 and 69 but analyses have not been done to confirm this.

Geological mapping by the authors in September and November 1982 was assisted by Abdulazziz Ziab and Mohammed Rehaili (Figure 23). Theodolite surveying was by A.J. Smith (S.F.B. 681). SADME drilled two diamond holes in May - June 1983; DDH 15 of 28.15m at Outcrop 35 and DDH16 of 25.66m at Outcrop 32 (Figures 26 & 25). Subsequent mining by Gemstone Corporation at Outcrops 32 and 35-36 has significantly changed quarry details as shown on Figure 23.

Site Geology

Major bulldozing of outcrops from late-1972 to 1987 has obscured much of the geology by extensive dumps (Figure 23) but the pre-mining geological map and observations of Hopwood and Coles (1971), included here as Figure 22 can be interpreted in terms of the current knowledge of jade formation. Matching of pre-mining surveying with the 1982 surveying is not possible because of unresolved surveying discrepancies. Some jade lenses mapped by Hopwood and Coles (1971), have been obscured by later dumps.

Pre-mining Geology

The pre-mining geology of Hopwood and Coles (1971) (Figure 22) shows abundant leucogranite which is highly altered to a massive chlorite + feldspar rock. As such, it is very similar to chlorite + feldspar rock at Outcrop 69 as well as dykes of altered leucogranite at Outcrops 14 and 52. Where it intrudes dolomitic marble, metasomatic alteration assemblages of tremolite ± chlorite are found along the dyke margins. This appears the case for Outcrops 31-36 also with jade, chlorite and breccias along the altered leucogranite-dolomitic marble contact. As at Outcrop 69, D_4 shear zones traverse the leucogranite and its metasomatic margins. D_4 shear zones vary in strike from N-S to NW-SE. From information on Figure 22, it is not apparent whether jade was formed during intrusion of the altered leucogranite or during D_4 fracturing, shearing and metasomatism.

Post-mining Geology

Geological mapping data from surveying and drilling in 1982 and 1983 respectively are presented in Figures 23 and 24. Extensive dumps and bulldozed (scraped) areas obscure much of the geology. The pattern of jade outcrops is as outlined by Hopwood and Coles (1971) but altered leucogranite is apparently not as abundant, with outcrop restricted to the NE quarry face at Outcrop 32.

As for Outcrops 24 and 114, country rocks at Outcrops 31-36 consist of dolomitic marble, calc-silicate, biotite schist and banded gneiss and are part of the banded calc-silicate gneiss at the base of Warrow Quartzite. Facing data are scarce and partly rely on interpretation of disrupted D_2 isoclinal folds, but regional data suggests an eastward-facing sequence.

Structure

The structural features of Outcrops 31-36 show most correlation with those at Outcrops 24 and 53 i.e. a N-S D_4 or D_5 phase (Outcrop 24) as well as displacement and apparent folding related to SE-trending D_4 shear zones (Outcrop 53).

Layering and gneissosity for both Outcrops 31-33 and 34-36 show a consistent pattern striking about 045^{o}M and dipping about 45^{o}NW (Figure 24). Variations from this are found only in close proximity to D_3 folds or immediately adjacent to D_4 shear zones and related folds.

D_3 folds are rarely seen within the quarries but are common in outcrop of surrounding banded calc-silicate. Folds are open to close, plunge NE and usually have no axial planar schistosity.

D_4 structures are varied. As for nearly all other jade outcrops, D_4 jointing and schistosity are present, particularly within tremolitic and chloritic metasomatic zones. D_4 schistosity is well developed in Outcrop 35. Although both the schistosity and joints strike SE, their patterns are clearly distinguishable (Figure 24). On average, joints dip 70-80^{o}SW whereas the S_4 schistosity consistently dips steep to moderately NE. Where S_4 dip shallows to about 60^o strike tends to be more N-S rather than NW-SE. Most outcrops show sigmoidal patterns in the S_4 schistosity with sinistral sense of shear.

Open, N-plunging folds were observed by Hopwood and Coles (1971) at Outcrops 31-32 and between Outcrops 35 and 36 (Figure 22). These were mapped in 1982 and are interpreted as D_4 rather than D_3 folds. Axial planar structures are N-S with 70-80^{o}E dips whereas S_3 axial planes strike NE (see also description for the adjacent Outcrop 24 where it is possible to distinguish D_3 and D_4 structures). These open D_4 folds tighten within a few metres of D_4 shear zones e.g. at quarry entrance to Outcrop 32. Several D_4 shear zones are observed at Outcrop 32 (Figure 23, Inset) but as observed by Hopwood and Coles (1971) more are expected. Two interpreted D_4 shear zones are shown on Outcrops 35-36. Dolomitic marble changes abruptly to massive chlorite and tremolite across the more easterly of these near outcrop 35.

Diamond Drilling - DDH 15

Diamond drill hole DDH 15 on Outcrop 35 was designed to drill below a large (17 m x 9 m), elliptical pod of chlorite + tremolite + nephrite rocks exposed above the top bench. The zone apparently represents the eastern end of Outcrop 35 as mapped by Hopwood and Coles (1971) (Figure 22). At least 3 pods of nephrite were exposed within this elliptical zone and many of the remaining massive boulders appeared to be chlorite and tremolite coating nephrite.

The 28.15m hole intersected no nephrite. From 2.0 to 18.6 m the core consisted almost entirely of chlorite, tremolite and clinozoisite/epidote (Figure 26) (Plate 14). Neither dolomitic marble nor massive diopside rocks were intersected even though marble crops out in the quarry face 7m away and strikes towards the drillhole. Dolomitic marble, massive diopside if originally present and banded calc-silicate have been extensively metasomatised. Original compositional banding is diffuse with relict phlogopite, diopside and coarse tremolite.

Some altered quartz + feldspar rocks occur within the metasomatic zone from 2.0 - 18.6m and in part may be relict banded calc-silicate gneiss rather than intrusives (6230 RS 364 and 365). However, clinozoisite bands between 9.7 and 15.8m may represent metasomatised feldspar-rich dykes (Plate 14). Altered intrusive is less abundant than expected from mapping by Hopwood and Coles (1971) and restricted to only about 1m intersection at 19m. Alteration is more extensive bordering tremolite + chlorite rocks and exhibits two stages (6230 RS 371) (Plate 34).

Diamond Drilling - DDH 16

Diamond drill hole DDH 16 on Outcrop 32 was designed to intersect two separate jade horizons but was successful only with one.

Jade exposed in the W quarry face at Outcrop 32 at the base of dolomitic marble was keenly sought, being pale green, fine grained and moderately translucent nephrite similar to that shown in Plate 17. However, jade was not intersected at the anticipated 5.8m downhole depth.

A chlorite-rich zone across the quarry floor also contained several pods of nephrite (Figure 23, Inset). The drill hole was designed to test this zone, although previous mining had produced jade with numerous inclusions which was of lesser quality than the pale green, moderately translucent jade exposed in the W wall (Plate 4). Jade intersected in DDH 16 at 10.6 - 11.2m is apparently an extension of a jade outcrop in the quarry floor (Figure 23, Cross Section CD). The remainder of the prospective zone down to 14.6m contained chlorite, tremolite and clinozoisite rocks as well as an unusual clinozoisite + phlogopite schist (Plates 25-27 and Figure 25).

Minor additional nephrite was intersected within dolomitic marble as a 1cm aggregate at 3.20m (Plate 17) and as a thin band of nephrite + chlorite at 10.0m.

About 1.5m of altered microcline + quartz intrusive was intersected at the contact zone between metasomatised dolomitic marble and structurally underlying migmatitic gneiss, in the same setting as in DDH 15 (Plate 34).

Altered Leucogranite

Both drillholes have up to 1.5m of altered, feldspathic leucogranite at the contact of metasomatic zones with migmatite and banded gneiss (Plates 33 and 34). In both cases, metasomatism is more intense closer to the structurally overlying chlorite + tremolite rocks. In neither drill hole, is altered leucogranite as common as expected from mapping by Hopwood and Coles (1971) (Figure 22). However, several leucogranite dykes intrude dolomitic marble and banded calc-silicate in the NE quarry face at Outcrop 32. These are less than 1m wide, are branching (Y shaped) and have metasomatic margins containing chlorite and tremolite, but nephrite was not observed.

Two stages of alteration are observed (6230 RS 371 and 379). The first phase is mylonitisation, marked reduction in grain size from about 5mm to 0.01-0.02mm, and epidotisation with an epidotic S_3-S_m? schistosity. These are followed by and cross-cut by D_4 joints and veins containing epidote and actinolite. Actinolite forms radiating clusters up to 2mm across commonly centred on very thin D_4 fractures 0.02 - 0.04mm wide. Hence actinolite needles penetrate well into neighbouring feldspar. Other phases introduced by metasomatism along D_4 fractures are apatite, a titanate and opaques where apatite and opaques are common accessories in nephrite.

Clinozoisite assemblages

The following petrographic notes are summarised from P97/73 (Nichol, 1974a) and 6230 RS 357, 359, 368, 369 and 377 (Appendix E).

Massive clinozoisite rocks vary in colour from white, orange brown, pink and pale purple and consist of coarse-grained laths and prismatic crystals in radiating aggregates. Crystals are to 4.5mm long. Examples are 6230 RS 357 and 359.

They were formed either by bands of appropriate composition within banded calc-silicate or siliceous dolomitic marble being metamorphosed to massive clinozoisite, or by metasomatism during granite emplacement.

Massive, coarse-grained clinozoisite shows two main styles of alteration. The first is development of a mylonitic banding and chloritic schistosity. Grain size is markedly reduced and bands consist only of granular mosaics of clinozoisite having grain sizes of 0.02 - 0.05mm and 0.2 - 0.4mm. A chlorite (? after phlogopite) schistosity parallels the mylonitic banding (6230 RS 368 and 369). RS 377 exhibits a variation on this theme with a clinozoisite + phlogopite schistosity wrapping around clinozoisite 'augen' to 4mm long. The phlogopite has two forms; coarse flakes aligned in the schistosity and fine-grained aggregates apparently interstitial to the clinozoisite (Plate 27). Typical D_4 joints about 1mm wide, which offset the compositional banding are developed across the mylonitic compositional banding in 6230 RS 369. These are infilled with chlorite aligned diagonally across the joint. A nephrite vein with chlorite and quartz in P97/73 is also interpreted as synchronous with D_4, whereas the earlier mylonitic compositional banding and parallel retrogressive schistosity (6230 RS 368, 369 and 377) are interpreted as D_3.

The second style of alteration is more difficult to date with respect to D_3 and D_4 as S_3 schistosity and D_4 jointing are absent (6230 RS 357 and 359). Coarse-grained clinozoisite exhibits minor marginal replacement by fine-grained epidote, but extensive replacement by fibrous and prismatic tremolite in radiating aggregates to 2mm across. Calcite is apparently an interstitial phase to tremolite, and late-stage calcite veins cross-cut the tremolite + calcite assemblage. The replacement of clinozoisite by tremolite + calcite probably occurred during D_4.

Nephrite

Considerable data on nephrite quality has been obtained by mining an estimated total of 664.5t from parts of Outcrops 31, 32, 35 and 36. Characteristically, jade colour and texture have varied between lenses and even within one outcrop (e.g. Outcrop 32). Some variations can be readily interpreted from geological and drilling data, hence each of the six outcrops are considered separately.

Nephrite - Outcrop 31

Outcrop 31 has not been mined and the current 3 x 1m outcrop is as mapped by Nichol (1974a). The outcrop has received little attention and contains dark green nephrite to semi-nephrite, with abundant coarse-grained prisms of tremolite as well as pyrite. A D_4 foliation, striking 120^oM, is present.

Nephrite - Outcrop 32

Outcrop 32 has been mapped, drilled and sampled in detail. Petrographic data on nephrite, semi-nephrite and tremolite are available from M1-M4 (Appendix B), P 99/73 - P101/73 and P1371/74 (Nichol, 1974a) and 6230 RS 329, 330, 372-375 (Appendix E). The earlier samples cannot be located on the current detailed plan, but petrographic descriptions show many similarities with more recent sampling.

Pale green, translucent jade had been mined along the 'base' of dolomitic marble as exposed in the western quarry face (Plate 4). Nephrite occurs in a zone between coarse-grained, grey marble and banded (quartz-rich) calc-silicate gneiss. Fine-grained green marble is immediately adjacent to nephrite, and the relationships are the same as jade in thin, sheared dolomitic marble at the quarry entrance. Nephrite varies from pale green, translucent, massive and without inclusions to semi-nephrite with a D_4 sigmoidal foliation.

Along the W face of Outcrop 32, nephrite and semi-nephrite also crop out within a 3-5cm D_4 joint striking 120^oM and crossing coarse-grained, grey dolomitic marble. This nephrite and semi-nephrite obviously formed during D_4. Colour is pale green; texture varies from massive to banded (6230 RS 329 and 330). Massive nephrite consists of fibre bundles 0.02mm long ghosting coarse (ex-dolomite) domains of 3-5mm diameter. Even relict multiple lamellar twinning is evident in the coarse domains (6230 RS 329). However, 6230 RS 330 exhibits several stages of tremolite growth and distinct banding. Bands are elongate along the D_4 joint and consist of either:

- fine-grained fibre bundles averaging 0.05mm long with a crude alignment parallel to the joint,
- coarse-grained elongate tremolite to 2mm in a porous network with interstitial calcite, or

- euhedral dolomite to 1mm but recrystallised to smaller grains and with secondary interstitial opaline silica and chalcedony.

Similar D_4 control on nephrite formation is evident in a narrow nephrite-bearing band in DDH16 at 10.05m (6230 RS 372), again entirely within dolomitic marble. However, phlogopite (15%) and chlorite (45% and after phlogopite) are abundant. Relict coarse blocky phlogopite is partly chloritised with chloritisation controlled by and mostly restricted to narrow D_4 fracture zones. Tremolite and chlorite vary from massive to schistose (S_4) and enclose the phlogopite porphyroblasts. In part, tremolite is nephritic forming fibrous mats with grain size less than 0.01mm but ghosting former dolomite or diopside grains up to 4.5mm across.

Nephrite colour is medium to dark green, but Munsell classification ranges from dusky green 5G 3/2, dark greenish grey 5GY 4/1, greyish green 10GY 5/2 and greenish black 5GY 2/1 (Table 4). Tremolite occurs in three distinct forms which would certainly affect polishing characteristics.

1. Nephrite. Microcrystalline fibres, fibre bundles and sheaves with fibre lengths of 0.01 - 0.02mm. This has mostly been described as tremolite 'matrix' in petrographic descriptions e.g. M4 and 6230 RS 373.
2. Large tremolite prisms, to 0.5mm long, commonly in optical continuity over areas of 3 x 2mm. Grain boundaries are irregular, diffuse and grade into finer-grained matrix and mat tremolite.
3. `Mat' tremolite is intermediate between the above two types but forms a distinct, recognisable category. Tremolite forms as small sheaves, elongate fibre bundles or as fibro lamellar-form prisms typically in the range 0.03 - 0.4 mm long. These often form ghost structures and replace dolomite, diopside and/or earlier coarse-grained tremolite which had a 3-5mm grain size. This type was described as 'shred-like' (Appendix B) and at times, tended to define foliations (e.g. M4).

Coarse tremolite prisms are obviously the earliest phase but the relationship of matrix (nephrite) to mat tremolite (semi-nephrite) is difficult to determine.

The pre-nephrite assemblage apparently consisted of phlogopite + dolomite + diopside and probably represents M_1/M_2 assemblage. This was apparently modified and retrogressed prior to nephrite formation with formation of prismatic tremolite, epidote, clinozoisite and? additional phlogopite. Hence the spots and porphyroblasts evident in some hand specimens and in drill core (e.g. 6230 RS 375) are from relict primary phlogopite as well as later but pre-nephrite aggregates of tremolite, epidote, clinozoisite and allanite.

Phases synchronous with nephrite formation are tremolite, chlorite, apatite and the ubiquitous opaques as dusty inclusions and lining D_4 fractures. Opaques range up to about 8% by volume.

Nephrite and semi-nephrite are generally massive and outcrop tends to be less foliated than many others in the Cowell Jade Province. Where foliated e.g. M4, the shred-like `mat' tremolite tends to form two schistosities about 30-40^o apart. This is interpreted as two phases of the S_4 schistosity formed by heterogeneous simple shear under conditions of low bulk strain. Similar sigmoidal and dual foliation patterns are observed at most jade outcrops.

Nephrite - Outcrop 33

Within the 4 x 3 m outcrop, nephrite is massive, pale to medium green but of variable grain size. Microscopically, the grain size variations show the same variations as described above for the main lens at Outcrop 32 i.e. relict coarse prisms, finer mat tremolite and submicroscopic felted matrix tremolite (nephrite) (P1372/74 of Nichol, 1974a). 5-10% clinozoisite is present within P1372/74. The only difference is that P1372/74 apparently contains a fourth generation of tremolite as large prisms and lozenge-shaped prisms which are apparently post-nephrite and have crystallised at the expense of matrix and mat tremolite. Similar post-nephrite crystallisation of coarse tremolite was observed by Farrand (1985) in drillcore at Outcrop 15.

TABLE 4

MUNSELL COLOURS OF NEPHRITE, SEMI-NEPHRITE
AND TREMOLITE IN DDH 15 AND 16

Depth (m)	Rock	Colour
DDH 15		
13.50	Tremolite	Pale green 10G 6/2 - 10G 7/2 grading to greyish green 10 GY 5/2.
DDH 16		
10.74	Nephrite	Between greenish black 5GY 2/1 to dark greenish grey 5GY 4/1.
10.95	Nephrite	Dusky green 5G 3/2 grading to greenish black 5GY 2/1 and dark greenish grey 5GY 4/1.
11.00	Tremolite	Milky opaque band: greyish yellow green 5GY 7/2 grading to greyish green 10GY 5/2.
11.07	Nephrite	Dusky green 5G 3/2.

Nephrite - Outcrop 34

Outcrop 34 consists of subdued bouldery float and outcrop covering an area of 3.3 x 0.8m. Nephrite is pale green but tends to be medium grained and contains zones of pale green to greyish green, opaque tremolite. The variations are to be expected and do not preclude the possibility of high-quality nephrite existing within Outcrop 34.

Country rocks are poorly exposed and consist entirely of banded calc-silicate gneiss, though massive chlorite and altered dolomitic marble are expected at depth.

Nephrite - Outcrops 35 and 36

The two outcrops are considered together as the two-bench quarry and irreconcilable discrepancies with earlier mapping blur the distinction between them. Two features are pronounced for Outcrops 35-36; chlorite is very abundant and D_4 shearing and schistosity are strongly developed.

As at Outcrop 32, nephrite pods are within the much more extensive dark green, chloritic rocks. All rocks including marble exhibit shearing, and sigmoidal D_4 schistosities are evident in chlorite schist. Nephrite and tremolitic rocks tend to form small blocks because late-stage D_4 jointing commonly has spacings of only 5-20cm. The close-spaced joints and blocky fragments indicate late-stage brittle D_4 fracturing rather than the usual D_4 ductile shearing and schistosity development. Shearing is more widespread than the interpreted shear zones shown on Figure 23. Most nephrite, semi-nephrite and tremolite samples examined petrographically show evidence of D_4 schistosity (6230 RS 344, 366, 367 and 370). Several samples reveal prolonged D_4 shearing, schistosity development and folding of earlier structures - more so than jade from other outcrops.

As alteration is so extensive, the pre-nephrite mineralogy is difficult to determine. Structures in outcrop indicate that dolomitic marble strikes into the metasomatic zone. Tremolite schist from within that alteration zone and intersected in DDH 15 at 16.40m, indicates the pre-nephrite assemblage contained phlogopite, diopside and tremolite. Dolomitic marble in the quarry face also contains pyrite. Metasomatism of dolomitic marble as proposed by Parker (1981) where tremolite and calcite are end products is supported by petrography of 6230 RS 344 where:

- clots of (early - formed?) coarse-grained tremolite to 0.5mm contain interstitial calcite
- nephrite fibre bundles of 0.01mm length contain interstitial calcite
- calcite which is mobilised into veins and subsequently folded during continued D_4 shearing.

Jade from Outcrops 35-36 often exhibits a pale green outer skin along D_4 joint surfaces (Munsell colours of pale green 10G 6/2 to greyish green 10GY 5/2) but with an inner, dark green core (Munsell dusky green, dark greenish grey to greenish black). In addition, mottled texture and colours are evident as in semi-nephrite from Outcrop 52 (Plate 36). The hand specimen colour is dependant upon the microstructure. Fine-grained mats of tremolite fibres, averaging only 0.01mm and ghosting previous 2-3mm diopside, tremolite or dolomite grains tend to be dark green and partly translucent. However, domains of coarser tremolite, in aggregates and as discrete grains to 0.8mm, tend to be pale green and milky opaque (6230 RS 346). As found in the other nephrite, this is probably the cause of orange-peel texture from uneven polishing.

Massive and schistose tremolite rocks are common at Outcrops 35-36 but do not have the toughness, colour or polishing characteristics to be classed as nephrite or semi-nephrite. This is caused in part by:

- coarser tremolite such as described above for the pale green, milky opaque zones in mottled jade even though the tremolite is partly fibrous;
- although foliated nephrite may still be well polished, translucent and green it does not exhibit toughness in all directions;
- lack of fibrous texture.

Pale green and greyish green opaque tremolite in 6230 RS 367 at 13.38m in DDH 15 is fine grained but not fibrous. Two forms of tremolite are present but neither can be described as nephrite in terms of colour and ability to take a polish. Both forms consist of equant to poorly elongate tremolite with average length:breadth ratios of only 2:1, with finer grained portions having an average crystal length of less than 0.01mm, which is as fine as fibres in nephrite.

Many of the chloritic, tremolitic and semi-nephritic rocks are schistose, often exhibiting two schistosities, both interpreted as D_4 and formed by continued heterogeneous simple shear. The two schistosities in 6230 RS 366 are only 25^o apart whereas, in the less deformed P99/73 sample from Outcrop 32, they are about $30\text{-}40^o$ apart. Semi-nephrite of 6230 RS 366 is composed of fibre sheaves and bundles only 0.02mm long but aligned in an interlocking network in two identical schistosities. Other samples e.g. P99/73 from Outcrop 32, usually exhibit variable strain with the sigmoidal cross-schistosity in less-deformed zones. At times the less-deformed zones contain clots of coarser-grained aggregates and individual tremolite prisms to about 0.5 - 0.8mm across (6230 RS 344 and 346) suggesting that continued shearing contributes to finer grain size and felted nephrite texture.

Veins of tremolite or calcite ± tremolite tend to be more common than at other outcrops and were openly folded during development of the D_4 schistosity (6230 RS 344, 346 and 367). Calcite veins appear to be earlier, consist of granoblastic grains to 0.7mm, and are openly folded with attenuation of fold limbs. Calcite veins contain minor tremolite which is fibrous and aligned parallel to axial planes and associated cleavage. Tremolite veins are more planar and are obviously late-stage phenomena. Tremolite veins are only 0.1 - 0.2mm wide and contain single fibres extending from wall to wall. Fibres are orientated at a high angle to the vein wall, though in 6230 RS 367 fibres are also oriented so that they are continuous or parallel with the surrounding schistosity. Similar veins of tremolite are observed in other jade outcrops e.g. N end of Outcrop 15 prior to mining in December 1987, but are often up to 10mm wide.

Pyrite also formed as cubes to 15mm across in D_4 chlorite schists. The ubiquitous dusting opaques in nephrite and staining along D_4 fractures are assumed to be goethite or limonite.

OUTCROPS 37-38, TALC DEPOSIT AND ORNAMENTAL MARBLE

REFER Figures 27-29 (Plans 89-178, 89-179, S20830)

Mining and Tenement History

MC 4827, the first claim within the Cowell Jade Province was registered on 17 June 1965 to H.A. Schiller. However, the claim was for ornamental marble and at that time, the four jade occurrences (Outcrops 6, 37-39) had not been discovered. Schiller mined 30t of marble from near jade Outcrops 37 and 38 in 1965. The first recorded production of nephrite was two years later. 18kg of nephrite and 136kg of marble from MC 4827 and 4926 were sold to Pacific Nephrite Company, USA (Olliver, 1984). About 0.1t of jade was also mined by Schiller in 1968, but although nephrite is still exposed the outcrop has not been mined for jade since.

MC 4827 was transferred to Jade (Australia) Pty Ltd on 27 July 1972 and converted to ML 4128 on 10 September 1973. Under the Mining Act, 1972 as amended, marble for ornamental purposes was classified as an extractive mineral and EML 4454 was registered on 3 March 1975. ML 4128 and EML 4454 were transferred to Cowell Jade Pty Ltd on 16 December 1976. Both are currently held by Gemstone Corporation of Australia Ltd.

In 1976, trial mining techniques of blasting and drilling holes by thermic lance and Cobra drill were tested at Outcrop 37; results are presented in Scott et al (1978). None of the carvings subsequently crafted at the O'Halloran Hill College of Further Education were apparently of jade or talc from Outcrop 37.

Carving-grade green and grey-green talc have been known and bulldozed since 1965 (Steel, 1967). Production details are incomplete but quantities are small. However, 8t of talc were mined by backhoe by Gemstone Corporation from near Outcrop 37 in April 1987, including a 1t boulder. 120 kg of carving-grade talc was recovered in early 1968.

Geological Mapping

The deposit was examined in 1965 at a time when ornamental slabs of serpentinised marble were required for the Melbourne market. Although colour patterns (light grey dolomite and yellow green serpentine) were observed to be irregular and blotchy, 'this enhances their appearance and hence economic value' (Steel, 1967). In 1965, the deposit had already been worked by bulldozer and blocks to 5t had been recovered. Reserves were assessed at not less than 32 000t. A band of dark-green talc, about 3m wide and traceable for 60-70m, had also been partly bulldozed.

Mason (1968) surveyed and mapped the deposit in detail. By then jade outcrops 37 and 38 had been discovered and 9 jade samples examined petrographically. Conclusions from his mapping include:

- high quality nephrite was apparently related to the present ground surface (but no evidence was presented to support his conclusion)
- reserves of marble were assessed for each of the categories yellow, green and white (actually light grey)
- abundant E-W fractures were observed with dominantly left-handed (sinistral) displacement
- only 20% of the assessed reserves were considered suitable for ornamental slabs because of the abundant and closely-spaced (D_4) joints
- aplite and pegmatite dykes intruded parallel to the E-W (D_4) fractures.

Additional petrography of serpentine marble, nephrite, diopside + nephrite and chlorite + tremolite samples was carried out during reconnaissance geological mapping of the Cowell Jade Province (Nichol, 1974a). No additional geological data were obtained during the trial mining program in 1976 (Scott et al, 1978).

In 1983 when green marble was sought for use in New Parliament House, Canberra, the quarry was re-mapped and surveyed by D.A. Young and A.J. Smith (SADME). Additional geological data were collected by the authors and Andi Sulaeman, Wilher Simandjuntak and Sumitra Atmanwinata in April 1987 during mining of talc by Gemstone Corporation.

Site Geology

The essentially 'pre-mining' geological mapping of Mason (1968) Figure 27 shows many similarities to the mapping of 1983-1987, Figure 28.

Stratigraphy

The sequence appears to face east and consists of basal Warrow Quartzite units unconformably overlying Archaean Miltalie Gneiss (Figure 28).

Miltalie Gneiss consists of coarse-grained, leucocratic, quartz + feldspar + biotite gneiss with abundant pegmatite. Grain size is distinctly coarser than in migmatitic gneiss within Warrow Quartzite. Gneissic banding is broad - often 1-2m thick. The contact with Warrow Quartzite is apparently unconformable but was not mapped in detail; gneissic layering in units both above and below the presumed unconformity are apparently parallel. The unconformity is apparently marked by a quartzitic unit 1-2m thick.

Units above the unconformity consist of quartzite (massive to flaggy), podded sillimanite gneiss grading to sericite schist, dolomitic marble, banded calc-silicate gneiss (locally retrogressed and epidote rich) and migmatite gneiss. All are interbedded and quartz content of units apparently increases eastwards. All units are interpreted as part of the banded calc-silicate gneiss at the base of Warrow Quartzite, grading eastwards into the more typical Warrow Quartzite lithologies including their migmatised equivalents. Additional details of each lithology are provided on the Legend for Figure 28.

Structure

Lithological layering and gneissosity predominantly strike at 20-30^{o}M and dip eastwards (Fig. 29), hence the sequence is apparently upright, facing and dipping east. However, some recordings are west dipping and J. Johnson (pers. comm. in Mason, 1968) suggested that the quarry was located on a west limb of a N-plunging anticline, but this is probably a regional D_3 anticline. Tight to isoclinal D_2 folds are probably present and the S_2 gneissosity is strongly developed - at times S_2 is demonstrably across S_0/S_1 layering and gneissosity. Geological mapping by Mason (1968) and the authors in 1983-1988 failed to locate dolomitic marble north of the quarry. Detailed observations by D.A. Young in 1983 at the quarry face, 25m south of Station A, but not recorded here suggest that a D_2 hinge is exposed and is the most probable explanation why dolomitic marble does not extend further to the N-NE.

D_3 folds with a retrogressive S_3 schistosity are also present, particularly in sericite schist after podded sillimanite gneiss. Folds are open, N-plunging with moderate-to-steep fold axes plunging 45-65^o towards 020^{o}M and consistently have Z-vergence. Short limb orientations typically strike 135^{o}M (Figure 29). S_3 schistosity in podded sillimanite gneiss grades to a mylonitic schistosity. Nephrite jade outcrop also contains a schistosity of identical orientation to S_3 which may be a relict S_3 schistosity rather than an S_4 schistosity developed broadly synchronous with jade formation i.e. D_4.

Mason (1968) observed a closely-spaced set of D_4 cross-fractures and joints, dominantly with sinistral displacement. These are consistent with observations from the current 1983-1988 geological program for much of the northern part of the Cowell Jade Province and are also consistent with the sense of shear determined from sigmoidal foliations (Flint et al, 1988). However, Mason (1968) also mentioned aplite and pegmatite dykes as having been intruded along these (D_4) fractures but they were not observed during mapping in 1983, and are consequently not shown on Figure 28.

The prominent D_4 fracture adjacent to the nephrite jade outcrop and which has obviously controlled metasomatic activity strikes at 140^oM. The adjacent nephrite and semi-nephrite contains a D_4 crenulation, developed on a relict S_3? schistosity, which has a subparallel strike at 135^oM. D_4 joints within nephrite and semi-nephrite are of somewhat variable orientation but strike within the range 100^o-160^oM.

Nephrite

The nephrite outcrop as mapped (Figure 28) consists of both nephrite and semi-nephrite in a lens 5 x 2m, and is apparently Outcrop 37 rather than Outcrop 38 of Nichol (1974a, 1977) and Scott et al (1978). The jade is of variable quality with a range of grain sizes (P870/66 to P878/66). The typical fine to very-fine-grained nephrite varies from massive to orientated (presumably S_4 schistosity) and contains coarser individual crystals and crystal aggregates with grain sizes in the range of 0.4-1.5mm but which can still be fibrous. Fractures are iron stained and accessory phases are opaques, apatite and chlorite. Presumably the uneven grain size causes the orange-peel texture on polished surfaces, identical with that of semi-nephrite from Outcrop 52.

Colour is variable but does include some nephrite with a green rather than yellow-green hue and with slightly higher chroma i.e. about Munsell 5G 3/4. Despite that, the tone is still quite dark.

Mason (1968) interpreted that 'better quality nephrite appears to be related to weathering processes at the present ground surface', but supporting evidence was not cited. However, the 1983-1988 mapping clearly demonstrates that the nephrite lens is within a tremolite + chlorite + clinozoisite metasomatic zone with solution activity controlled by a D_4 fracture (Figure 28). Metasomatism also preferentially extends along strike of dolomitic marble as previously demonstrated at the Ullabidinie jade occurrence (Parker, 1981).

Talc

Carving-grade talc at Outcrop 37-38 is also interpreted to have formed during D_4 metasomatism and an additional D_4 fracture is likely in the vicinity of the talc workings, but direct supporting evidence is lacking.

OUTCROPS 40-44

REFER Figures 30-32 (Plans 88-88, 88-87, 88-428)

Mining and Tenement History

Outcrops 40-44 were first pegged by E.M.G. Swain and registered as MC 4925 on 21 February 1966 however, the claim lapsed on 27 January 1967. The area was repegged shortly after by G.E. Swain and registered as MC 5089 on 16 March 1967. MC 5089 was converted to ML 3426 on 1 July 1968 (Olliver, 1984).

An option to purchase Swain's ML 3426 was obtained by Spinifex Exploration Pty Ltd (an associate company of Murumba Minerals N.L.) but was not exercised and expired in January 1971 (Hopwood, 1970; Hopwood and Coles, 1971).

In early 1973, Australian (Nephrite) Jade Mines Pty Ltd was formed by Swain and obtained ML 3426 on 26 July 1973. In June 1973, Centamin N.L. obtained the right to explore, mine, extract and market jade on all tenements held by Australian (Nephrite) Jade Mines Pty Ltd but the indenture was cancelled in November 1979. ML 3426 was acquired immediately (21 November 1979) by Cowell Jade Pty Ltd. The lease is currently held by Gemstone Corporation of Australia Ltd.

Swain mined an estimated 1.9t of nephrite by backhoe from Outcrops 40-43 during 1968-1972 (Olliver, 1984). Cowell Jade Pty Ltd mined about 1t of jade from Outcrop 44 during 1985. Barnes et al. (1986) considered Outcrops 40, 41, 42 and 44 as possibly mined out.

Geological Mapping

Hopwood (1970) mapped and drilled Outcrops 40-43 with five diamond drill holes. Drilling failed to locate extensions to the surface outcrop and the option that Spinifex Exploration Pty Ltd held with Swain lapsed. Effort was redirected to Outcrop 55 following the successful drilling of DDH6. However, this early grid mapping did observe that:

- N-plunging isoclinal folds were abundant (i.e. D_2 and re-activation during mylonitic D_3)
- cross-faulting and spatially associated small-scale kink-like folds with steep fold axes were present (i.e. D_4 folding and fracturing)
- hybrid pegmatite of coarse K-feldspar with irregular mottled inclusions of chlorite aggregates were present and referred to as P/G rock.
- dolomitic marble and tremolite/nephrite had a close spatial association.

Hopwood's (1970) mapping data have been slightly modified and included as Figure 30.

Mapping by Centamin N.L. in 1973 under their indenture with Australian (Nephrite) Jade Mines Pty Ltd was less detailed but their data are included as Figure 31. Despite the earlier unsuccessful drilling of five diamond drill holes totalling 127.39m on Outcrops 40-43, Centamin (in 1973) drilled another five diamond holes totalling 61.70m at Outcrops 41-43. This drilling was also unsuccessful.

The fact that such an extensive mapping and drilling effort by Spinifex Exploration Pty Ltd and Centamin N.L. took place on small outcrops with limited production (only 1.9t at that time), seems to suggest the nephrite must have been of high quality (? paler green and translucent) to have warranted that attention and effort, though the details have not been recorded.

Nichol (1974a) and Scott et al (1978) recorded brief comments on the outcrops along with petrographic examination of samples from Outcrops 40 and 43.

ML 3426 was not mapped by the authors during regional geological mapping of the Cowell Jade Province. Outcrop 44 was mapped with tape and compass by R.S. Robertson (Senior Geologist, SADME) and D.J. Flint in March 1985 during backhoe mining by Cowell Jade Pty Ltd. Cross sections were prepared for the ten diamond drill holes on Outcrops 40-43 and the data interpreted (Flint and Dubowski, 1986, Plates 7-14).

All available data for Outcrops 40-43 are presented on Figure 30 adapted from Hopwood (1970). The tape and compass survey of Outcrop 44 is included as Figure 32.

Site Geology

Units exposed within ML 3426 are dominated by quartzite with interbanded migmatite gneiss and pegmatite. Hybrid pegmatite or altered intrusive is abundant, cropping out close to dolomitic marble and jade outcrops. Massive and schistose talc, chlorite and epidote rocks are present in addition to the tremolite and jade. Typical SE-striking D_4 fracture zones are abundant, and apparently displace Outcrop 40 about 120m eastwards from the line of Outcrops 41-44.

Stratigraphic facing is uncertain (?eastward) and relies on interpretation of regional data including isoclinal D_2 folds and D_3 mylonite zones. Warrow Quartzite is abundant but the dolomitic marble may represent either attenuated Katunga Dolomite or the basal banded calc-silicate gneiss unit of Warrow Quartzite.

Layering and gneissosity strike at about 020^oM and dip 80^o westerly but unmapped (D_2) isoclinal folds are abundant (Hopwood, 1970). The area is close to the hinge zone of a regional D_2 fold. The folds of Hopwood (1970) apparently plunge at about 15-30^o towards about 020^{o}M, with axial planes possibly dipping steeply east. Fold styles appear similar to that at Outcrops 45 and 109, suggesting that D_3 folding may have re-activated D_2 structures.

Nephrite - Outcrop 40

Outcrop 40, a 3 x 2m pod with talc schist and massive coarse-grained tremolite (Nichol, 1974a) crops out between dolomitic marble and hybrid pegmatite (Hopwood, 1970). Massive tremolite rock (tremolitite) contains relict, coarse-grained, granular tremolite which is 4-8mm across and partly aligned to define a schistosity. Recrystallisation has produced a fibrous, felted texture but with a grain size of 3-6mm; too coarse to be classified as nephrite (Nichol 1974a (P1355/74)). Scott et al. (1978) described the jade as pale green with tremolite inclusions.

Doubt exists as to the location of DDH1. Hopwood (1970) showed the pre-drilling (proposed) position on Outcrop 40, whereas Centamin (1973) and Nichol (1974) indicate that DDH1 was drilled on Outcrop 41. None of the holes have been surveyed since drilling, but several drill collar positions are evident at Outcrops 41 and 42. For this report and in Flint and Dubowski (1986), DDH1 is assumed to be located at Outcrop 40.

DDH1 apparently drilled across the hinge of a tight D_2 fold which has been re-orientated - either by D_3 folding or by local folding during D_4 adjacent to SE-striking D_4 fractures. Dolomitic marble is in contact with hybrid pegmatite (P/G rock or chlorite + feldspar rock) with bands of calcite + chlorite schist and laminated calcite + chlorite + feldspar rock (Figure 29, Cross Section AB; Nichol, 1974a; Flint and Dubowski, 1986, Plate 8). Calcite + chlorite schist bands may represent metasomatised impure dolomitic marble, indicating bands of altered dolomitic marble within hybrid pegmatite. DDH1 was the minimum depth required to test Outcrop 40; another 10m of drilling would have tested the deposit more thoroughly.

Nephrite - Outcrop 41

Nichol (1974a) had recorded Outcrop 41 as a 1 x 0.1m band of nephrite in dolomitic marble. Scott et al (1978) state that the nephrite was dark green and contained some black Mn or Fe staining, presumably along fractures. Hopwood (1970) showed several small pits and DDH2 was angled westwards under the pits. Regionally, layering dips steeply west (70-80^o) so the drilling was unlikely to be successful unless D_2 folds are present. However, calcite + chlorite schists were intersected directly below outcrop of jade and in the contact zone between quartzite and (weakly) hybrid pegmatite (Figure 29, Cross Section CD; Flint and Dubowski, 1986, Plate 10). The drill hole also probably crossed two D_4 fracture zones as indicated by brecciated quartzite.

Calcite + chlorite schists in DDH2 are probably metasomatic equivalents of dolomitic marble containing nephrite in outcrop, but the interpretation of Cross Section CD (Figure 30) requires east-dipping layering from D_2

folding. Massive hybrid pegmatite (chlorite + feldspar rock) is more abundant in DDH1 than predicted from outcrop, suggesting extensive replacement (? stoping) of dolomitic marble by pegmatite.

Nephrite - Outcrop 42

Nichol (1974a) described Outcrop 42 as a 3 x 2m pod. Scott et al (1978) described the jade as pale green but apparently soft, perhaps weathered. Although relatively small, the outcrop was the focus of attention in the early 1970's with 4 diamond drill holes - DDH3 and 4 by Analytical Exploration/Spinifex Exploration and DDH12 and 13 by Centamin N.L. (Nichol, 1974a).

None of the four diamond holes intersected jade, or even tremolitic rocks. All four intersected mostly quartzitic lithologies. Limited structural data of Hopwood (1970) suggested an easterly dip and all four drill holes were planned accordingly, but this interpretation may have been incorrect. The calcite + chlorite schist band intersected in DDH3 and 4 dips eastward but other drilling data are more indicative of westerly-dipping layering. None of the four drill holes test the western side of the jade outcrop. In fact, no drill hole in the Cowell Jade Province which is inclined westwards has successfully intersected nephrite.

D_4 fractures are evident in outcrop and vein quartz is orientated along one fracture 20m SW of Outcrop 42. Both would have promoted metasomatism of dolomitic marble and nephrite formation, but the drilling revealed that below and east of Outcrop 42 was mostly quartzite. Hybrid pegmatite was intersected in DDH3 9-10m below the pit on Outcrop 42.

Nephrite - Outcrop 43

Nichol (1974a) described Outcrop 43 as a 9 x 2 m lens with nephrite containing hematite inclusions. Scott et al (1978) recorded the jade was dominantly dark green.

Petrography of two nephrite samples from Outcrop 43 (Nichol, 1974a, P242/73 and P1366/74) revealed that the jade was medium to dark green, partly mottled and contained inclusions of hematite, goethite and epidote. Nephrite was composed of the typical fine-grained felted mat of fibres with fibre lengths in the range 0.003 - 0.1mm. Mottled texture resulted from coarser grained tremolite, both as relicts of former tremolite grains 1-5mm across and as late-stage, apparently post-nephrite regrowth of tremolite to 1mm. Also present as impurities were hematite to 0.025mm, chlorite flakes and epidote grains to 1mm across. Both samples were cracked with incipient limonite stained arcuate flakes which caused the rock to break into lensoid shapes. Lensoid fracturing is observed in other jade outcrops such as Outcrop 35, and is consistent with D_4 simple shearing. Although fractured, the jade is otherwise massive and non-foliated.

Petrographic samples given in Nichol (1974a) (P242/73, P1366/74) were collected after the 1968-1972 mining of 1.9t from Outcrops 40-43. The quality of nephrite shown by the petrographic samples probably do not match that of jade mined. Presumably the quality of surface outcrops prior to mining was higher, as the drilling of four diamond holes totalling 62.73m was considered warranted. DDH5 was drilled by Analytical Exploration / Spinifex Exploration in 1970; DDH 9, 10 and 11 were drilled by Centamin N.L. in 1973. Again, drilling was unsuccessful with jade, described as `minor jade fragments', intersected in only one hole (DDH11) (Nichol, 1974a).

Interpretation of the drilling is difficult as near-collar core rarely matches the mapped outcrop. For example, DDH10 is along strike of dolomitic marble yet the first 3m intersected feldspathic gneiss; DDH11, apparently spudded in outcrop of massive tremolite yet the first 4.5m of core was quartzofeldspathic gneiss. Some of the drill holes left little to chance and were spudded only 1.3m from jade outcrop! An interpretation of the drilling is presented in Cross Section KL (Figure 30) and in Flint and Dubowski (1986, Plate 14) based on the data and drill hole locations as recorded by Hopwood (1970), Centamin (1973) and Nichol (1974a).

All drill holes intersected combinations of calcite + chlorite schist, chlorite schist, massive epidotite, serpentine + chlorite schist, talc schist, and massive tremolite ± actinolite rocks. That is, the typical range of metasomatic products from either emplacement of (now) hybrid pegmatite or from solution activity along D_4 fractures. D_4 fractures were not mapped at Outcrop 43 (Hopwood, 1970) but are probably present.

All metasomatic, retrograde assemblages are between contacts of dolomitic marble/quartzofeldspathic gneiss or dolomitic marble/hybrid pegmatite (chlorite + feldspar rock). Quartzofeldspathic gneiss is interpreted as migmatite gneiss, migmatised Warrow Quartzite and essentially equivalent to isoclinally folded quartz + mica schist in outcrop (P 1356/74 of Nichol, 1974). DDH11 in particular intersected 3.5m of massive tremolite (not nephrite and semi-nephrite) ranging in colour from white (?pale green) to dark green with 'minor jade fragments'.

Metasomatic zones are extensive in the vicinity of Outcrop 43, but the four drill holes tested only a very small area surrounding one jade outcrop. At Outcrop 35, massive jade grading to coarser tremolite rocks is found throughout such metasomatic zones. Because current knowledge is inadequate to predict nephrite distribution within these zones, Outcrop 43 is still considered to have potential to yield nephrite.

Nephrite - Outcrop 44

Nichol (1974a) described Outcrop 44 as a 4x3m pod, although Centamin (1973) mapped two pods about 50m apart along strike of dolomitic marble (Figure 31). A second jade outcrop observed when mapping the backhoe pit, about 20m N, tended to be coarse grained and was, at best, only semi-nephrite.

Nephrite pods were small and cropped out along the contact of dolomitic marble and quartz-rich schist of Warrow Quartzite. Small pods that existed prior to backhoe mining cropped out over a 5m strike-length but would not have formed a 4x3m lens as described by Nichol (1974a). However large boulders i.e. about 250kg had been removed by hand mining prior to geological mapping.

Some of the nephrite collected by hand-mining and to a lesser extent from backhoe mining are reported to have been absolutely black rather than the more typical green black or the rare blue black of Outcrops 69 and 15. In addition, the black nephrite was very fine grained and homogeneous producing a brilliant polish. Coarse-grained, green epidote inclusions to about 20mm across were present, but added attractive colour.

Nephrite quality varied rapidly and much of the material recovered was at best only semi-nephrite grade. Varieties included dark green black nephrite but most boulders contained coarser-grained, massive tremolite which ranged from pale green and milky opaque to dark green and ?actinolitic. Rare pieces contained isolated tremolite needles to 20mm long in a nephrite and semi-nephrite matrix.

The eastern wall of the backhoe pit exposes predominantly schist with retrograded ?sillimanite clots, but minor coarse-grained calc-silicate is also present. The western wall contains weathered calc-silicate, mostly as massive tremolite boulders to 0.5m diameter. No unaltered dolomitic marble is exposed. All lithologies are deeply weathered, stained by yellow goethite/limonite and most boulders contain coatings of secondary carbonate.

Prominent D_4 fractures were not observed, nor was hybrid pegmatite, although exposure is generally poor. Metasomatic alteration is limited by comparison with other localities such as Outcrop 43 and the controls to jade formation are not apparent.

OUTCROPS 45 AND 109

REFER Figures 33-34 (Plans 88-89, S 20218)

Mining and Tenement History

Outcrops 45 and 109 were first pegged by Australian (Nephrite) Jade Mines Pty Ltd and registered as MC 194 on 26 June 1973. MC 194 was converted to ML 4339 on 10 December 1973. From June 1973 to 4 July 1979, Centamin No Liability had an indenture agreement to explore, mine, extract and market jade on all tenements held by Australian (Nephrite) Jade Mines Pty Ltd. Following cancellation of the indenture, ML 4339 was transferred to Cowell Jade Pty Ltd on 21 November 1979. The lease is currently held by Gemstone Corporation of Australia Ltd.

There is no recorded production from either outcrop though both have small prospecting pits from hand mining by pick, shovel and crowbar.

Geological Mapping

Under the indenture agreement with Australian (Nephrite) Jade Mines Pty Ltd, Centamin N.L. mapped MC 194/ML 4339 in September 1973 and identified six small separate jade lenses, the largest of which was about 15m long (Centamin, 1973).

Follow-up mapping by Nichol (1974a) failed to locate the same outcrops and only one was identified; Outcrop 45 which was 0.2x0.2m. However, Barnes et al. (1980) located another outcrop - Outcrop 109 which was described as 2 x 0.2m.

Additional data were collected by the authors during regional geological mapping of the jade province in 1982-1985. Available data have been combined and are presented as Figures 33 and 34.

Site Geology

The sequence at Outcrops 45 and 109 consists of gneissic augen granite of Miltalie Gneiss and massive quartzite and banded calc-silicate gneiss comprising lower units of overlying Warrow Quartzite (Figure 33). The broad stratigraphic facing is westwards but is locally reversed by abundant D_2 folds. The exact position of the unconformity was not mapped and is in part obscured by Kimban Orogeny migmatisation and D_3 mylonitisation.

The unconformity corresponds to either:

- the eastern limit of banded calc-silicate gneiss, or
- the western limit of gneissic augen granite.

In between the two limits is a 10-20m zone of migmatite gneiss.

Structure

D_2 folds are particularly abundant, as Outcrops 45 and 109 are only about 100m east of a regional D_2 synformal fold hinge. D_2 folds are more abundant and more readily observable than at any other jade outcrop.

D_2 folds are tight to isoclinal. Layering and S_1 gneissosity consistently strike at 015-024^{o}M but exhibit distinguishable limb orientations about 15-20^o apart (Figure 33). Where one orientation is dominant in outcrop, then the D_2 vergence is consistent and reverses where the other orientation is dominant. Symmetrical folds are common. Typical fold symmetry is sketched in Figure 33. (Folds shown on Cross Section FF' (Figure 33) are inaccurately depicted as perfectly isoclinal).

Fold axes plunge NNE, averaging about 35^o towards 010^{o}M, although there is some scatter of the data some and isolated SSW plunging folds. Axial planar structures are variably developed, and in places form a gneissosity. The variation in axial planar structures combined with fold axes reversals, suggest that D_3 folds are present and have re-activated D_2 structures. Re-activation has changed the fold profiles so that some folds are more open than shown in Figure 34.

Mica-rich portions of migmatite gneiss between massive quartzite and dolomitic marble are in part schistose and mylonitic, suggesting that D_3 mylonite zones may also be present but have not been mapped.

D_4 features exhibit many similarities to those at other jade outcrops. The ubiquitous D_4 joints strike about 120^{o}M and dip steeply SW (Figure 34). One outcrop shows a return to ductile deformation after the brittle jointing, with open folding of the D_4 joint. Fold limb orientations of the D_4 joints are 81^o towards 200^{o}M and 49^o towards 349^{o}M, with an apparent axis of rotation plunging 30 towards 285^{o}M. The pole to the joint plane has been rotated about 60^o. One fracture cleavage is present, and like S_4 schistosities in other jade outcrop, it has the same strike as typical D_4 joints but dips steeply NE rather than paralleling the joint's steep SW dip (Figure 34). One outcrop exhibits a very late, planar joint dipping shallowly NNE which cross-cuts the folded S_4 joint. Similar late, shallow NNE dipping D_4 joints were observed at Outcrop 76 (Figure 48).

A quartz vein striking 170^{o}M, is interpreted to have intruded along a D_4 fracture zone which displaces the dolomitic marble with dextral offset. Gneiss units are strongly epidotised to the north of the fault (epidotic quartzite unit) but apparently not epidotised south of the fault. Solution activity away from D_4 fracture zones is often observed to be restricted to one side of the fracture.

Nephrite

As the outcrops are small and of low quality, they have received little attention. No attempt was made by the authors to examine all the outcrops apparently found by Centamin N.L. in 1973.

Outcrop 45 is 5x0.6m but consists of massive, coarse-grained tremolite. The texture is jade-like but very coarse with radiating aggregates to 10-20mm across as well as a coarse-grained interwoven mat texture. Outcrop is at the contact of dolomitic marble (eastwards) and mica-rich gneiss (westwards), but this observation is not consistent with mapping by Centamin N.L.

Outcrop 109 is similar, consisting of coarse radiating aggregates (10-20mm across) as well as fine and coarse-grained interwoven mats of tremolite fibres. The tremolite rocks vary from massive to locally schistose. The age of the schistosity was not determined, but tends to be mylonitic and orientated approximately parallel to layering. Outcrop 109 like Outcrop 45 is at the western limit of a dolomitic marble bed.

Pegmatite containing epidote veining crops out in migmatite gneiss immediately west of both outcrops.

OUTCROP 52

REFER Figures 35-36 (Plans 88-90, S 20219)

Mining and Tenement History

Outcrop 52 was first pegged as MC 706 which was registered on 23 September 1975 to Jade (Australia) Pty Ltd and subsequently converted to ML 4578 on 13 May 1976. Along with other assets of Jade (Australia) Pty Ltd, this lease was acquired by Cowell Jade Pty Ltd (now Gemstone Corporation of Australia Ltd) on 16 December 1976 and was still current as at 30 June 1988.

Samples from Outcrop 52 were collected by Scott et al (1978) during the trial mining program and carved at the O'Halloran Hill College of Further Education. Three pieces were carved by David Dowie and Alan Lowrie in jade that ranged between pale green and dark green. Both Nichol (1974a) and Scott et al. (1978) described the lens as 5 x 1 m.

In 1978, about 300-350 kg of 'good, green jade' was reportedly mined by pick and crowbar by a party other than the leaseholder. It was the quality and colour, green to yellow-green, fine grained and deeply translucent jade that gave Outcrop 52 the reputation of being able to provide top-quality nephrite. Hence, Cowell Jade Pty Ltd quarried the remainder of Outcrop 52 in 1981, although the resultant quarry was 6m deep (Figure 35) mining was rapid, and what jade did exist, was blasted directly onto the dump. Hand sorting collected 1t jade (Olliver, 1984) of which only 20-50 kg was top-quality, yellow-green, translucent nephrite (H. Carmody, 1985, pers. comm.).

Little jade remains and the deposit has been regarded as worked out.

Geological Mapping

Geological mapping by the authors was in November 1985 with theodolite surveying by A.J. Smith (Field Assistant). Additional sampling in 1987 was by Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata (6230 RS 415 - 418).

Site Geology

Stratigraphic data is scarce as only 50-60 m of stratigraphy was mapped. Preliminary interpretation is that the host dolomitic marble is at the base of Warrow Quartzite. Regional mapping data suggests that the sequence faces westwards and hence from west to east consists of:

Migmatite Gneiss - ? Warrow Quartzite
Dolomitic Marble - ? Warrow Quartzite (basal)
Migmatite Gneiss - ? Archaean Miltalie Gneiss

However, migmatite gneiss was not differentiated during the 1982 mapping. Migmatite on both the NW and SE sides of the dolomitic marble consists of pinkish red, massive, coarse-grained segregations of quartz and feldspar with biotite-rich gneissic melanosomes.

Dolomitic marble is typically coarse-grained with a primary grain size of 2-5mm, grey, dark brown on weathering surfaces but relatively free of non-carbonate phases (serpentinised olivine, diopside etc).

Nephrite crops out not only in the quarry but also in four small separate outcrops (Figure 35). As at many other outcrops, the largest lenses tend to be along or near the eastern (footwall) contact of the dolomitic marble. Jade formation appears to be controlled by:

- alteration and metasomatism during intrusion of granite (RS418), and/or
- metasomatism during D_4 fracturing.

Tremolite + chlorite alteration assemblages exist:

- along the footwall contact of dolomitic marble (Figure 35),
- as bands parallel to layering,
- along a prominent D_4 shear zone exposed in the middle of the quarry face,
- and adjacent to an altered intrusive dyke or sill (Figure 35).

Although a D_4 quartz vein traverses dolomitic marble, there is no alteration or metasomatism with associated formation of tremolite, nephrite or chlorite as might be expected.

Structure

All units dip relatively uniformly NW i.e. strike 045^{o}MN and dip 60^{o}NW (Figure 35). D_3 folds were not observed within the mapped area.

Tremolite + chlorite rocks vary from massive to schistose, but where schistose apparently contain only D_4 schistosities. The D_4 schistosity is not only variable in orientation but along the footwall contact of dolomitic marble, two schistosities are present. One strikes 020^{o}M whereas the other has a more typical E-W S_4 orientation. The 020^o schistosity may be S_3 but is very similar to the D_4 020^{o}M tremolite + chlorite schistosity at Outcrop 24. Both tremolite + chlorite schistosities as well as adjacent S_1/S_2 gneissosity are gently folded about an axis plunging 66-70^o towards 270^{o}M.

D_4 jointing strikes more consistently at about 125^{o}M, in contrast to the S_4 schistosity which is E-W. 10m N of the quarry, a narrow quartz vein parallel to the jointing has a foliation which parallels both the vein and joints.

Altered Adamellite

In the middle of the NE quarry face mostly obscured by scree, is an altered adamellite (Enlargement, Figure 35) similar to others exposed in quarries at Outcrops 14, 32 and 69. The altered adamellite (6230 RS 418) is coarse grained, has been strongly deformed and recrystallised, and contains 15% of late-stage (post-deformation) tremolite or actinolite in acicular, radiating aggregates. Epidote (?) forms fine-grained aggregates to 1mm across. The tremolite/actinolite is concentrated along late-stage fractures and post-dates most of the deformation and recrystallisation. Massive tremolite and chlorite form adjacent to the intrusive and these zones also contain minor nephrite (Figure 35), immediately adjacent to a D_4 tremolite schist band. As at Outcrop 69, the combination of altered granite or adamellite with prominent D_4 fracturing seems to be a key to jade formation. The original 5 x 1 m outcrop and adjacent rock which would probably have provided confirmatory evidence have been completely removed.

Nephrite

Nephrite still exposed within the quarry and up to 30m away along strike of dolomitic marble, is variable in quality but tends to be consistently pale coloured. Colours range from pale creamy green, through light green to medium green. Dark green to green black jade appears to be absent and the jade is apparently consistently low in iron content. Of particular note is 6230 RS 343 which is the palest-coloured jade so far found at Cowell. The colour is of a yellow hue with very light tone and low degree of saturation, (about Munsell 10Y 9/1 - pale greenish yellow). 6230 RS 343 is identical with very pale nephrite or semi-nephrite from adjacent Outcrop 53 (i.e. 6230 RS 426) and is the closest yet found at Cowell to a `mutton-fat' colour. 6230RS343 exhibits colour mottling caused by dual tremolite grain sizes within the nephrite. Coarse-grained, elongate tremolite grains up to 1mm in length are concentrated in discrete patches. Between these are massive aggregates of fine-grained, randomly-orientated tremolite fibres with an average grain size of 0.01mm. Dusty opaques are unusually abundant at 8%, and ovoid apatite is present in trace amounts.

Translucent, pale to medium, yellow green jade was collected from a small pod less than 1m long, 8m from the quarry face (6230 RS 350). Although of good colour, a saccharoidal texture was evident and samples did not polish evenly. Petrographic examination revealed at least three generations of tremolite. Initial elongate and coarse-grained tremolite ranges up to 1.5mm in length but exhibits substantial replacement by typical nephrite as fibrous mats of fine tremolite of only 0.01mm average grain size. Within many mats, tremolite fibres are often aligned and this tremolite 'schistosity' has been crenulated or kinked. Coeval with this kinking, is recrystallisation of coarser, prismatic tremolite with a common grain size of 0.1 - 0.5mm. The earliest coarse-grained tremolite probably formed during D_3, with formation of nephrite and later recrystallisation during D_4.

A sample from the footwall contact of dolomitic marble exposed in the quarry (6230 RS 349) is very similar. Colour mottling of hand specimens is again due to partial replacement of coarse-grained tremolite up to 5mm by fine-grained mats of fibrous tremolite, with an average grain size of 0.04mm. Fibrous tremolite in the mats is commonly aligned forming an S_4 schistosity which has been crenulated. The crenulation is regarded as late D_4 and correlates with the open folding phase (fold axis 66^o towards 270^oM) which folds two schistosities observed in tremolite in the quarry.

Pale green nephrite grading to semi-nephrite from the dump is very similar i.e. 6230 RS 360 and RS 416. However, two additional dump samples show variations on this theme.

6230 RS 417 is classed as `massive tremolite' too coarse-grained for nephrite or semi-nephrite. Although 'coarse', it still has a nephritic texture of felted to interlocking crystals but the amphibole is weakly prismatic to acicular and up to 1mm long. Minor (3%) carbonate is intergrown with tremolite. Skeletal pyroxene (probably diopside) to 2mm exhibits marginal replacement by tremolite. This is the only diopside/pyroxene recorded at Outcrop 52 though the early, coarse-grained phases in other samples which are substantially replaced by mats of fibrous tremolite, may have contained diopside in addition to the observed relict coarse tremolite.

The second dump sample to show variation is 6230 RS 351, which is semi-nephrite but of a darker green colour. It too is schistose with an S_4 schistosity consisting of elongate augen of early, coarse-grained tremolite variably replaced by and within a matrix of fibrous mats. The fine, fibrous tremolite is often aligned - also in S_4. Again, this schistosity has been crenulated. Epidote/clinozoisite is present to 10%, mostly as elongate clusters parallel to the S_4 schistosity. Minor subhedral clinozoisite, to 0.4mm long, is orientated parallel to the foliation and apparently recrystallised at a late stage of development of the S_4 schistosity. This clinozoisite apparently recrystallised at the same time as the late-stage prismatic tremolite of 6230 RS 350.

Hence the ubiquitous colour mottling of nephrite, semi-nephrite and coarser tremolite from Outcrop 52 is apparently textural with early, coarse-grained tremolite and diopside partially replaced by mats of fine, fibrous tremolite showing typical nephrite texture. This is independent of the intensity of the S_4 schistosity. Although interpreted here as a textural control to the colour mottling, compositional control is also possible but chemical data are not available.

OUTCROPS 53, 99-100 AND 116

REFER Figures 37-41 (Plans 89-181, 89-186, 89-180,
89-183, 89-185)

Mining and Tenement History

Outcrop 53 was first pegged by B. Stadler and registered as MC 703 on 16 September 1975. The claim was converted to ML 4524 on 27 April 1976 and subsequently transferred on 19 December 1978 to Nephrite Australia Pty Ltd, but cancelled on 3 November 1980.

Production was by Stadler in 1976 and 1977 when a total of 38t of green jade was mined (Olliver, 1984). No additional details are available of the jade's quality, though the outcrop had the reputation of yielding good-quality, bright-green jade. At the same time as mining Outcrop 53, a nearby but separate outcrop was bulldozed. This has been designated Outcrop 116 by the authors.

Outcrops 99-100 have a very similar history to Outcrop 53. They were first pegged by B. Stadler and registered as MC 765 on 21 June 1976. The claim was converted to ML 4568 on 25 February 1977 and subsequently transferred to Nephrite Australia Pty Ltd on 19 December 1978 but cancelled on 3 November 1980. Mining of Outcrops 99-100 was by Stadler in 1977 and 15t of jade were recovered, but again, details of the quality are not known.

Geological Mapping

Nichol (1974a) described Outcrop 53 as a lens 0.2 x 0.02m within dolomitic marble. Production of 38t is certainly more than expected from original outcrop dimensions but is consistent with geological mapping - see following section 'Site Geology'. Outcrops 99-100 were not mapped by Nichol (1974a) during initial reconnaissance mapping, but were recorded by Scott et al (1978). Outcrop 99 was described as pale green jade with pre-mining dimensions of 1.5 x 0.5m. Outcrop 100 consisted only of dark green jade float.

All four outcrops were mapped by the authors and W. Simandjuntak and A. Sulaeman in March 1987. The bulldozer cut to the NE of Outcrop 53, with some jade exposed, was identified as Outcrop 116. Mapping data are presented as Figures 37-41. Eight samples were collected; three were tested by XRD (6230RS 414, 425 and 426 - Appendix D) whereas all have had thin sections prepared but not petrographically described in detail. Samples are 6230RS414 and 423-430 inclusive.

Site Geology

Outcrops 53, 99-100 and 116 illustrate several features of interest which are either not present or rarely observed at other jade outcrops which have been mapped.

1. D_4 folds are abundant, and contrast with the brittle jointing and faulting normally observed.

2. S_4 is developed as a schistosity, axial plane to folds and a close-spaced fracture cleavage.

3. A N-S folding phase (D_5) is superimposed on D_4 structures.

4. D_5 folding has apparently influenced jade formation at Outcrop 116.

5. Jade remaining at Outcrop 53 suggests at least some of the jade formed by retrogression of diopside.

6. Intrusion of dykes of porphyritic adamellite during D_4.

Stratigraphy

Neither a definitive sequence of units nor a stratigraphic facing has been established.

Lithologies present are dolomitic marble, retrograded sillimanite gneiss, banded calc-silicate gneiss, amphibolitic gneiss, massive diopside, a variety of quartzofeldspathic to micaceous gneisses and granodiorite gneiss.

The grey to pink, massive, granodiorite gneiss cropping out to the east of Outcrops 53 and 116 is identical with gneiss at Outcrop 16 and has been interpreted as equivalent to Archaean Miltalie Gneiss. Contact relationships of this unit to the dolomitic marble, sillimanite gneiss etc were not observed.

Structure

The key points to the structure at these four outcrops are:

- interpreted D_2 folds
- abundant D_4 folds, and
- a weakly developed D_5 folding phase.

Outcrops 53, 99-100 and 116 are located near or on the hinge of a regional, D_2, isoclinal fold. Available limited data, suggests that Outcrops 99-100 may be located on the west limb of the synform with Outcrops 53 and 116 on the eastern limb. D_2 isoclinal folds were mapped near the SW corner of the quarry at Outcrop 53. Additional D_2 folds are interpreted as having caused the repetition of the dolomitic marble at Outcrops 53 and 116 and 99-100. S_1 and S_2 data were not recorded separately but multiple foliations in retrograded sillimanite gneiss suggest that confirming evidence should be present.

Stereographic projections of lithological layering and undifferentiated S_1/S_2 gneissosity show a pattern dominated by superimposed D_4 folding (Figure 38) i.e. NE and N-striking limbs of D_4 folds. However, the NE-striking limbs tend to form a two-point maxima no more than 20^o apart, which is interpreted to reflect tight to isoclinal D_2 folds.

D_4 folds are more strongly developed than in any other outcrop mapped. Folds are gentle to open and with a distinct kink style. Mesoscopic folds typically have a 20-50m wavelength (Figure 37). Folds plunge steeply to the NW, averaging about 75° towards 315°M. There is little difference between fold axes measured directly and pronounced rodding lineation formed on sillimanite gneiss by an intense close-spaced, fracture cleavage (Figure 38). S_4 is represented by a schistosity and a close-spaced fracture cleavage. Rather than being uniformly distributed, both are strongly concentrated and largely restricted to hinge zones of folds. Hinges are often marked by a planar 1-2m zone of sericite, chlorite or talc schist with a strongly-developed schistosity or intense fracture cleavage. The average S_4 orientation strikes 115°M and dips 85°N.

Separate plots of S_4 data based on the type of axial plane structure (schistosity, fracture cleavage or axial plane) show almost no differences in orientation, although there are occasional fracture cleavages with no corresponding schistosity of the same orientation. One such set at Outcrop 53 dips 55° towards 180°M, and another at Outcrop 99-100 and dips 85° towards 300°M (Figure 38). S_4 schistosity at Outcrops 99-100 show the same spread in orientation as at Outcrops 53 and 116.

Porphyritic adamellite dykes were apparently emplaced broadly synchronous with D_4 (see following section 'Porphyritic Adamellite').

Another phase of very similar but less intense characteristics is superimposed on the D_4 folds and S_4 fabrics. Folds are rarer, axial planar structures are more commonly a fracture cleavage than schistosity and include a crenulation of the S_4 schistosity. Although described here as D_5 to more clearly distinguish its effects from D_4, it should be noted that D_5 has the same style as D_4 and that Parker (1981) described two S_4 structures. Those two structures, S'_4 and S''_4 are probably the same as S_4 and S_5 of this report and both may be broadly synchronous with D_4.

D_5 folds are characterised by N-S axial planes (strike 170°M, dip 75°W). Axial planar structures are schistosity, fracture cleavage and kink folds. Folds plunge shallowly at 5-20° towards 350°M. At Outcrop 116, jade may be controlled by the position of a D_5 hinge. The intensity of D_5 structures is apparently related to a regional N-S fault through Ulbana Reservoir and the Cowell Jade Province (Parker, 1981, Figure 14). This is located immediately west of Outcrops 99-100. Similar folding in proximity to the N-S fault, though not always interpreted as such, is evident at several other jade outcrops as follows:

1. Open N-plunging fold in layering at Outcrops 35-36. (This is probably more evident on pre-mining geological mapping shown in Figure 22).

2. At Outcrop 24 N-NE trending schistosities in chlorite + tremolite rocks and open folds had previously been interpreted as possible D_3/S_3 features.

3. N-S fault and subparallel foliation at Outcrop 114.

Nephrite

Small quantities of nephrite are exposed at Outcrops 53, 99 and 116; all outcrops contain favourable structures which may have controlled formation of further jade.

Outcrop 53 had a reputation for yielding green rather than dark green or black jade. Dump specimens show jade with a green rather than the more typical yellow-green hue. Jade is commonly in bands only 1-2cm thick along contacts of diopside and dolomitic marble, suggesting formation by retrogression of diopside rather than metasomatism of dolomitic marble. Jade is also found along dolomitic marble/gneiss contacts and in narrow zones or fractures parallel to other S_4 structures. In all cases, massive nephrite and semi-nephrite grade to the more abundant schistose tremolite with the S_4 schistosity trending about 115°M. Where the foliation is sigmoidal and both S and C surfaces are present, the sense of displacement on 115° structures is dextral. Additional data on tremolitic rocks are provided on the detailed geological plan (Figure 39).

The only petrography available for tremolitic rocks is semi-nephrite of 6230RS427. As well as the more typical fine-grained, nephritic texture the sample contains relict diopside to 1mm, and clinozoisite and coarse tremolite fibre aggregates. A late-stage, post-nephrite vein contains clinozoisite and muscovite.

Two samples (6230RS425 and 426) from the contact of dolomitic marble were tested for white nephrite by XRD (Appendix D). 6230RS425 was found to be a mixture of fine-grained, microcline and clinozoisite. However 6230 RS 426 contained dominantly amphibole, and is believed to indicate a possibility of finding white nephrite at Cowell. 6230 RS 426 is very similar to very pale, greenish yellow semi-nephrite from nearby Outcrop 52 (i.e. 6230 RS 343). Although yellow in hue, the tone is very light and chroma or saturation very low, so that the Munsell colour is about pale greenish yellow, 10Y 9/1. Sample 6230 RS 426 is from 25m S of the Outcrop 53 quarry was immediately adjacent to a D_4 quartz vein cross-cutting dolomitic marble.

Although exposure is poor, D_4 vergances at Outcrop 99-100 consistently differ north and south of the quarry, indicating it may be located on the hinge of a larger D_4 fold. Nephrite is again evident both in retrogressed massive diopside and within dolomitic marble in narrow schistose bands with ?S_3 mylonitic schistosity. If the schistosity is related to the regional N-S faulting (D_5), then displacement is sinistral - as interpreted by Parker (1981). Most of the jade mined however would have formed from retrogressed massive diopside which forms a bed up to about 4m thick. Nephrite still exposed in the backhoe pit tends to be translucent, but contains coarser tremolite prisms (1%) (6230 RS 490).

Sample (6230 RS 414) from 30m N of Outcrop 99 was tested by XRD for white nephrite but proved to be dominantly epidote/clinozoisite (Appendix D).

Outcrop 116 is small. An exposure 30x10cm in the pit is and located along the contact of dolomitic marble and hybrid pegmatite. It lies within a narrow zone of D_5, N-S folds and is also on the possible extension of a D_4 shear zone (Figure 41). Hence it occurs in a situation with many factors favourable for jade formation. The nephrite tends to be dark green and can contain two foliations -S_4 and S_5.

Chlorite Schist

Chlorite schists are abundant, particularly at Outcrop 53 and are at least in part retrogressed gneissic amphibolite. As large jade outcrops (e.g. Outcrops 15 and 32-36) tend to occur in zones of extensive metasomatism and retrogression, they are associated with large masses of chlorite schist. Chlorite schist (e.g. 6230 RS 423) normally contains a well-developed S_4 schistosity and grades into tremolite schist. 6230 RS423 is unusual in that it contains tremolite needles to about 30mm elongate in the schistosity. Both tremolite needles and smaller prisms apparently formed early during D_4.

Porphyritic Adamellite

Although metasomatism along D_4 structures is commonly extensive, quartz and pegmatite veining are rarely observed along the fractures. Outcrop 116 however shows a striking example of porphyritic adamellite dykes apparently emplaced along D_4 faults (Figure 41). Equivalent porphyritic adamellite has only been observed at Outcrop 16 (6230RS200) and west of Outcrop 32 (not included in area mapped in detail).

Emplacement is apparently early D_4, as dykes are unusually elongate along the S_4 direction and preferentially located at D_4 fold hinges, and one dyke is apparently sheared by and slightly displaced along S_4.

The porphyritic adamellite dykes are about 2m wide and often have a poorly-defined to vague S_4 schistosity. Microcline and plagioclase phenocrysts to about 8mm long are set in an adamellitic matrix with an average grain size of about 0.5mm. Biotite is present to several percent and superimposed S_4 fractures are infilled with epidote.

OUTCROPS 55-57

REFER Figures 42-44 (Plans 88-91, 88-429, S 20220)

Mining and Tenement History

MC 5206 over Outcrops 55-57 was first pegged by H.A. Schiller and registered on 11 January 1968. The claim lapsed on 18 August 1967, was re-registered as MC 5308 on 12 September 1968, transferred to Jade (Australia) Pty Ltd on 25 July 1972 and converted to ML 4130 on 10 September 1973. All of the assets of Jade (Australia) Pty Ltd were acquired by Cowell Jade Pty Ltd with transfer of the lease on 16 December 1976. The lease is currently held by Gemstone Corporation of Australia Ltd.

Several kilograms of jade were taken from Outcrop 55 during Stage III of a trial mining program in September to October 1976 conducted by SADME (Scott et al., 1978). However, the trial mining pit is 50m SSW from the main outcrop of Outcrop 55. Several samples were carved at the O'Halloran Hill College of Further Education (Scott et al., 1978).

Following SADME geological mapping, Gemstone Corporation mined 37t of green jade from immediately east of the collar of DDH6.

Geological Mapping

Murumba Minerals N.L. in 1970-71, under an option to purchase MC 5308 from H.A. Schiller, geologically mapped MC 5308 (Hopwood and Coles, 1971). Investigations included one diamond hole at Outcrop 55 (DDH 6, 17.52m) which, with four intersections of jade is the most successful of the 17 holes drilled for jade in the Cowell Jade Province. Drill hole log for DDH6 is included in Hopwood and Coles (1971) but more details are available in Nichol (1974a). Geological mapping of Hopwood and Coles (1971) has been slightly modified and represented here as Figure 42.

Outcrops 55-57 were remapped in April 1987 by Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata and the authors. EDM surveying, was by M.W. Flintoft (Field Assistant, SADME). A preliminary interpretation of a cross-section through DDH6 and Outcrop 55 was presented in Flint and Dubowski (1986). A revised interpretation of the geology is included as Figure 43.

The estimated size of Outcrop 55 has varied with each mapping program. Hopwood and Coles (1971) showed seven separate outcrops the largest being 30m long and separated by only a few metres from another lens 27m long (Figure 42). Another 5 lenses cropped out over the next 80m of strike. The two largest outcrops were apparently combined by Nichol (1974a) who recorded Outcrop 55 as 60 x 0.5m. However the 1987 SADME mapping revealed much smaller outcrops. The main outcrop on the northern end is only 7m long with other smaller lenses or occurrences which crop out southwards along the marble/gneiss contact.

Topographic details of Figure 43 are now outdated, because Gemstone Corporation has since mined jade from between DDH6 and the previously exposed jade.

Site Geology

The sequence of units at Outcrops 55-57 is in two parts. To the west of Outcrop 55 and to the west of a mylonite zone (Figure 43) is a sequence of:

Banded Iron Formation - Lower Middleback Jaspilite
Dolomitic Marble - Katunga Dolomite
Quartzite - Warrow Quartzite

The sequence dips westwards (Figure 43, Cross Section AB), but, is indicated by the above interpreted stratigraphic correlations to face eastwards. Southwards along strike, these units strike into and are offset across a major mylonite zone.

East of the mylonite zone is a completely different sequence consisting of (from west to east):

Migmatite Gneiss -
Dolomitic Marble -
Gneissic Amphibolite and Migmatite-
Dolomitic Marble -

Facing data are absent, but the present authors assume the sequence faces east. Parker et al. (1981) from exposures immediately north in Minbinnie Creek interpreted the 'Gneissic amphibolite and migmatite' unit as Archaean and the dolomitic marble hosting Outcrop 55 as basal Warrow Quartzite, which inferred a westward facing. The current stratigraphic correlation is uncertain; the sequence represents either Cook Gap Schist or perhaps even a thick, carbonate facies of Upper Middleback Jaspilite, despite iron oxides being present in trace amounts only.

Two dolomitic marble units in the eastern sequence are believed to be separate stratigraphic units, and not structural repetition of a single bed. The two units are continuous along strike, and both host nephrite occurrences for about 3km of strike length.

Both the ?upper sequence of four units and the lower quartzite - dolomitic marble - iron formation succession dip moderately to steeply westwards.

S_1/S_2 structural data indicate a consistent N-NE strike of 025°M for all units (Figure 44). Open D_3 folds with axial planar crenulations are common in mica schist bands within the quartzite unit along and west of the western boundary of ML 4130. Most units, including pegmatite, are in part mylonitised, indicating that most if not all pegmatite was intruded prior to or during D_3. The mylonitic foliation has essentially the same orientation as S_1/S_2 layering (Figure 44).

Nephrite and semi-nephrite have two strong spatial controls on outcrop which is:

- along or in very close proximity to dolomitic marble/gneiss contacts, and
- within dolomitic marble immediately adjacent to a significant D_4 fracture (Outcrop 55).

The first of these controls is an interpreted S_3 tremolite schistosity, visible in nephrite along marble/gneiss contacts, particularly Outcrop 56. Apparently pods of tremolite and possibly some jade, existed during D_3. This schistosity is indistinguishable from typical S_3 mylonitic foliation in adjacent rocks (Figure 44). Parker et al. (1981) reported a foliation in Outcrop 55, striking 355°-005°. This is interpreted as a D_4 foliation, and is not to be confused with an earlier ?S_3 tremolitic schistosity. Parts of Outcrop 56 contain both schistosities. None of the many lenses comprising Outcrop 55 contain the S_3 schistosity.

The second and more obvious control is D_4 fracturing with faulting and abundant D_4 dissolution planes. This is apparently the primary control at Outcrop 55. Most outcrops contain a dominantly N-S, S_4 schistosity which is observed by Parker et al (1981). In places strike varies to NW-SE, subparallel to D_4 joints (Figure 44). One small outcrop SW along strike from the main mass of Outcrop 56, contains finer-grained nephrite recrystallised in narrow bands parallel to D_4 joints.

The largest jade lens (Outcrop 55) is immediately adjacent to a D_4 fault which displaces the dolomitic marble as quartzite and pegmatite crop out along strike of dolomitic marble. D_4 fracturing has permitted introduction of SiO_2 - rich solutions along the fracture and into adjacent dolomitic marble. It is no coincidence that the largest jade lens (free of any S_3 schistosity) is adjacent to the largest D_4 fracture on ML4130.

Some nephrite outcrops, regardless of whether an S_3 schistosity is present or not, contain inclusions of relict diopside. Some jade has apparently formed from uralitisation of diopside. Some of the diopside, being very coarse grained, (20-50mm) is M_1/M_2. Coarse-grained diopside was exposed in nephrite in the creek bed at Outcrop 55 (Plate 18) and is apparently more abundant in the core of DDH 6 (Figure 43, Cross Section CD).

Other jade outcrops such as Outcrops 14 and 69 contain dykes of altered leucogranite, hybrid granite or pegmatite which apparently partly control jade formation. Their influence at Outcrops 55-57 is not obvious. Altered leucogranite and gneiss were observed:

- adjacent to nephrite at the Trial Mining Pit,
- in DDH6 immediately adjacent to talc and nephrite, and
- adjacent to nephrite on southern extensions of Outcrop 56 (6231 RS 208).

Typically, these rocks contain the primary, coarse-grained, quartz and feldspar with late stage:

- aggregates of radiating acicular amphibole (?actinolite) to 1mm long
- xenomorphic to subidiomorphic epidote to 1mm, and
- aggregates of fine flaky chlorite with lesser coarse-grained, chlorite to 1.5mm.

The role of these altered leucogranite dykes on jade formation appears minor and certainly less significant for Outcrops 55-57 than that of pre-existing D_3 tremolite schist lenses, D_4 fracturing and silica metasomatism with uralitisation of diopside.

Diamond Drilling (DDH6)

The diamond drillhole (DDH6) of Murumba Minerals N.L., drilled in 1970-1971, was relogged and the revised interpretation and cross section is included as Figure 43, Cross Section CD. The previous interpretation (Flint and Dubowski, 1986, Plate 16) was based on Hopwood and Coles' (1971) surface geology and Nichols' (1974a) geological log. The drillhole collar was easily discernible during surveying and mapping in 1987.

The hole had four intersections of nephrite and semi-nephrite totalling 3.7m. Thickness and number of intersections were greater than expected from the surface geology, and apparently included one lens completely obscured by alluvium. Metasomatism of dolomitic marble and alteration/uralitisation of diopside is more extensive than predictable from surface outcrop. In addition, mapping of ML4130 suggested that dolomitic marble and diopside should continue westwards under the alluvium as far as the mylonite (Cross Section CD) and that additional jade lenses could be obscured by the alluvium. In December 1987 Gemstone Corporation of Australia removed the alluvium to reveal one additional jade lens approximately 2-3m west of the first DDH6 jade intersections. 37t of jade were removed from that lens and the first two lenses encountered in the drillcore. The main jade lens, as exposed in the drill core and interpreted on Cross Section CD, was not mined.

The associations intersected in DDH6 are typical for those outcrops containing lighter-coloured jade and presumably low iron content. Chlorite-rich rocks are essentially absent; talc is present instead with one band over 1m thick. Diopside is abundant and in part obviously altered to jade.

OUTCROPS 58-61

REFER Figure 45 (Plan 88-92)

Portions of Outcrops 60 and 61 were pegged by L.E. & B.L. Griffen, along with Outcrops 62-68, and registered as MC 5304 on 31 August 1968. The claimholders were plainted by Arminga Geological Research and Exploration Pty Ltd (an associate company of Murumba Minerals N.L.) in July 1970 but the plaint was dismissed (Olliver, 1984). However, after negotiations MC 5304 was cancelled on 16 October 1970 and repegged by Murumba Minerals N.L. as MC 6748, registered on 7 November 1970. On 25 July 1972, Jade (Australia) Pty Ltd acquired MC 6748 from Murumba Minerals N.L. and the claim was converted to ML 4131 on 10 September 1973.

At about the same time, Outcrops 58 & 59 to the north and the remaining portions of Outcrops 60 and 61 were pegged for the first time by Australian (Nephrite) Jade Mines Pty Ltd. MC 195 was registered on 26 June 1973 and converted to ML 4340 on 10 December 1973.

Cowell Jade Pty Ltd acquired both leases:

- ML 4131 from Jade (Australia) Pty Ltd on 16 December 1976, and
- ML 4340 from Australian (Nephrite) Jade Mines Pty Ltd on 21 November 1979.

Both leases are currently held by Gemstone Corporation of Australia Ltd.

There is no recorded production specifically from Outcrops 58-61, though 0.3t of jade were recovered by Griffen in 1968-1970 from Outcrops 61-67.

Geological Mapping

Under an option agreement with Australian (Nephrite) Jade Mines Pty Ltd, Centamin N.L. mapped and diamond drilled MC 195 (subsequently ML 4340) during August - September 1973 (Centamin, 1973). DDH7 of 15.0m and DDH8 of 17.15m were both drilled on Outcrop 60. Geological mapping of the Cowell Jade Province by Nichol (1974a) included logging of the drill core which unfortunately, is no longer available.

A backhoe pit was dug on Outcrop 60 in 1976 during stage III of a trial mining program (Scott et al., 1978). Samples were collected but none of the carvings crafted at O'Halloran Hill College of Further Education apparently consisted of material from the pit.

Additional geological data were collected by the authors during mapping of the Cowell Jade Province in 1982-1985 and this included re-interpretation of DDH7 and 8. All available data are presented in Figure 45 and summarised below.

The original mapping of Nichol (1974a) did not position outcrops with respect to tenements. Only two outcrops (labelled Outcrops 58 and 60) were mapped within MC 195 (ML 4340) by Centamin N.L. However, later plans showing the interpreted positions of Nichol's outcrops within tenements (Scott et al., 1978; Barnes et al., 1980; Olliver, 1984) all show Outcrop 59 within ML 4340 between Outcrops 58 and 60. Additional detailed mapping is required to locate Outcrop 59.

Site Geology

Little detailed data are available for Outcrops 58-61. Outcrop consists of two horizons of dolomitic marble and interbedded banded calc-silicate with undifferentiated gneisses.

The two dolomitic marble horizons extend outside of ML 4340. The more easterly horizon extends northwards to Outcrops 55-57 and the western horizon extends southwards past Outcrops 68-72. Both horizons are laterally continuous for 3km and are probably separate stratigraphic horizons. By analogy with Outcrops 55-57, the exposed units are probably equivalents of Upper Middleback Jaspilite or perhaps Cook Gap Schist. Gneisses in the vicinity of Outcrops 58-61 are undifferentiated and consist of granitic gneiss, migmatite and layered gneiss with leucocratic segregations and pegmatite.

Structure

Layering strikes about 025^{o}M with steep westerly dips of 75-80^{o}. Outcrop patterns suggest the presence of isoclinal D_2 folds which have been interpreted for Cross Section XY (Figure 45).

Nephrite

Mapping data are insufficient to elucidate jade formation controls for Outcrops 58-61. Neither altered feldspathic pegmatite nor D_4 fractures have been mapped, though both are probably present.

Outcrop 58 was described as a pod of predominantly dark green jade (Nichol, 1974a) with coarse-grained inclusions of tremolite (Scott et al., 1978). Dimensions were not given but mapping by Centamin N.L. suggests a jade pod about 17m long (Centamin, 1973) though much of that may be tremolitic rather than nephritic.

Outcrop 59 was not mapped by Centamin in 1973, nor were dimensions provided in Nichol (1974a), Scott et al. (1978) and Barnes et al. (1980). Jade was described as dark green to black (Nichol, 1974a) and predominantly medium grained (Scott et al., 1978).

Outcrop 60 consists of a 7x2m lens of dark green jade (Nichol, 1974a) which is fine grained (Scott et al., 1978). Surface outcrops are massive and weathered surfaces are paler and distinctly grey i.e. pale to medium greyish green. The jade is opaque when greyish and tends to be slightly sugary, indicating areas of granular rather than fibrous tremolite. In DDH7, the jade lens was intersected 6-11m below the surface and was described as fractured, limonite-stained and coarser grained than in outcrop (Centamin, 1973; Nichol, 1974a). Hence in drill core, the quality was only that of massive tremolite rather than nephrite. Colour was also darker, apparently because of talc or chlorite inclusions, near the footwall contact of the jade lens. The most distinctive feature is the degree of fracturing, which is unusual by comparison with other jade outcrops.

DDH8 at Outcrop 60 was less successful, intersecting only a 0.1m thick band of semi-nephrite at a hanging wall contact of dolomitic marble at about 2m depth. Although folds have been interpreted in Cross Section XY (Figure 45), DDH8 was apparently not deep enough to properly test downdip extensions of Outcrop 60. The hole bottomed in quartz + feldspar gneiss which may correlate with gneiss at the beginning of DDH7. Tremolite grading to semi-nephrite intersected in DDH8 at 15-16m was described as colourless to pale green and medium grained (Centamin, 1973; Nichol, 1974a). As with many other outcrops, the quality of jade varies rapidly, so Outcrop 60 still has potential to yield high-quality nephrite.

Outcrop 61 was described as a 20x1m lens of predominantly dark green jade (Nichol, 1974a) but with lighter coloured, apparently coarser-grained patches (Scott et al., 1978). Mapping by Centamin (1973) suggests the outcrop is about 15m long and partly split into two bands. Weathering surfaces are paler, opaque and greyish green. Portions of the lens are like Outcrop 60 and contain some granular rather than fibrous tremolite, hence quality is distinctly variable.

OUTCROPS 68-71

REFER Figures 46-47 (Plans 88-93, S 20221)

Mining and Tenement History

Outcrops 68-71 were first pegged by J. & S.E. Greening as MC 5305 which was registered on 31 August 1968 and cancelled on 16 October 1970 (Olliver, 1984). Less than 1t of jade was mined. Murumba Minerals N.L., who had unsuccessfully plainted J. & S.E. Greening repegged the outcrops as MC 6749 which was registered on 7 November 1970 and subsequently transferred to Jade (Australia) Pty Ltd on 25 July 1972. MC 6749 was converted to ML 4132 on 10 September 1973 and subsequently transferred on 16 December 1976 to Cowell Jade Pty Ltd (now Gemstone Corporation of Australia Ltd). All of the major mining has been by Cowell Jade/Gemstone Corp since 1978 with 327t produced. Mining by Gemstone Corp by David Linke Contractor Pty Ltd in December 1987 recovered 122t of black jade. Prior to the 1987 mining, the quarry on Outcrop 69 was the deepest quarry in the Cowell Jade Province with the working face 10m high.

Geological Mapping

A sample of serpentine marble, (P1357/74) was collected by Nichol during reconnaissance geological mapping apparently from the N side of Outcrop 69 (Nichol, 1974a). During 1980, two samples of nephrite (6321 RS 24, 25) collected from Outcrop 69 by D.C. Scott (Senior Geologist, SADME) were included in a suite examined petrographically and by electron microprobe at AMDEL to determine the reason for the white/pale coloured rinds (Appendix E).

Outcrops 68-71 were mapped by the authors and A.J. Smith (Field Assistant, SADME) on 12 November 1982. Cowell Jade Pty Ltd used a backhoe to mine several tonnes of jade from a northerly extension of Outcrop 69 on 18 March 1985. The backhoe pit was mapped by D.J. Flint and R.S. Robertson (Senior Geologist, SADME). In July 1987 a suite of samples from Outcrops 69, 24, 32, 52 and 114 was provided to M. Swain and H. Jaeger (Division of Materials Science and Technology, CSIRO, Victoria) for strength and fracture toughness tests and TEM/SEM studies (Lai et. al., 1988).

All mapping data are presented on Figure 46 but the earlier samples of Nichol (1974a) and Scott (Appendix E, AMDEL Report GS 3146/80) could not be located on the detailed plan. Subsequent to preparation of Figure 46, Gemstone Corporation recovered 122t of jade from Outcrop 69 and the northern wall of the quarry has been changed so that the present quarry is about twice as wide as that shown on Figure 46. The western face remains at about 10m high.

Site Geology

The sequence at Outcrops 68-71 dips steeply westward but is interpreted to be east facing. It consists of migmatite gneiss interbanded with two dolomitic marble horizons; from west to east:

Migmatite gneiss (East, ?upper)
Dolomitic marble
Migmatite gneiss
Dolomitic marble
Migmatite gneiss (West, ?lower)

Stratigraphic position of the dolomitic marble horizons is probably Katunga Dolomite or carbonate facies of Lower Middleback Jaspilite.

Migmatite gneisses are undifferentiated but regional mapping of the Province suggests that the more massive quartzofeldspathic gneiss which grades to foliated granodiorite gneiss along the western boundary of ML 4132 is probably part of Miltalie Gneiss or equivalent to Plug Range granodiorite gneiss i.e. metamorphic age of 1697 ± 65 Ma but a formation age of 2150 Ma (Webb et al., 1986). The boundary between interpreted Miltalie Gneiss and migmatised Hutchison Group west of the dolomitic marble was not mapped and is not shown on Figure 46. The boundary which approximates the western boundary of ML 4132 is expected to be mylonitised so that all of Warrow Quartzite is missing. In general, migmatite gneiss is banded with massive, leucocratic, quartz + feldspar bands or sills alternating with foliated quartzofeldspathic gneiss and biotite gneiss. Bands vary from a few centimetres to several metres thick with coarse banding dominating. Quarry walls at Outcrop 69 expose rare isoclinal folds with S_2 gneissosity apparently crossing (S_0) composition banding and an earlier (S_1) gneissosity. 2-3 m wide zones of extensive D_3 mylonitization are visible in migmatite gneiss, particularly in the central zone of the N wall at Outcrop 69.

Dolomitic Marble

Two dolomite horizons are present, one less than 5m and the other 10-20m thick. They are separated by 10-15m of migmatite gneiss and biotite gneiss, but continue along strike as two distinct horizons for at least 3km. Both appear identical in outcrop style and petrography and are discussed together. Both horizons host nephrite lenses.

Dolomitic marble is massive and coarse grained with primary grain size of 2-5mm. Fresh dolomitic marble is grey but weathered surfaces are dark brown. Dolomite is the dominant carbonate, far exceeding calcite (P1357/74 in Nichol, 1974a). Disseminated within dolomite and occasionally concentrated in bands defining a S_1/S_2 gneissosity, are:

- M_1 and M_2 olivine and diopside
- retrogressive serpentine, tremolite and chlorite.

Olivine of P1357/74 is retrogressed completely to fine-grained (<1mm) serpentine and dolomite. Recrystallisation of coarse-grained, M_1/M_2 dolomite along grain boundaries, presumably during D_3 or D_4, produced new, equant dolomite grains 0.1-0.2mm across.

Local areas of dolomitic marble enriched in tremolite, diopside, chlorite and serpentine are classified as calc-silicate. This has only been done at Outcrops 68 and 70 i.e. along the eastern (?upper) contact of the eastern dolomitic marble horizon (Figure 46).

Leucogranite

The leucogranite, along with D_4 jointing, has apparently had a major influence on jade formation at Outcrop 69. Poor exposure restricts any comment on whether the leucogranite is as important at Outcrops 68, 70 and 71. Altered leucogranite is exposed only on the western wall of the quarry at Outcrop 69 and in the small backhoe pit about 15m to the NE.

Leucogranite is within a steeply-dipping dyke, up to 2m wide, which cross-cuts dolomitic marble. It cannot be traced outside the quarry (Figure 46). Lack of good exposure prevents detailed assessment of the timing of intrusion. The dyke in the main quarry strikes N-NW, is obviously post D_1 and D_2, but is cross-cut by D_4 joints and shear zones. Timing is, therefore, post-D_2 and may be as late as and broadly synchronous with D_4. Exposure in the backhoe pit shows the same relationships - massive, altered leucogranite cross-cut by closely-spaced D_4 joints/shear zones.

Although described as leucogranite, petrography of 6231 RS 98 and 150 classify the rock as hydrothermally altered diorite and granodiorite. The texture is dominated by coarse-grained plagioclase (albite-oligoclase) with interstitial fine-grained biotite and chlorite which either completely replaces an earlier ferromagnesian phase or plagioclase (Plate 30). Primary plagioclase has an average grain size of 5mm but deformation and recrystallisation has produced deformed twinning as well as abundant finer-grained (<1mm) plagioclase along grain boundaries. Plagioclase is cloudy (RS98) but with sericitic alteration developed in RS150. Biotite and chlorite flakes of <0.05mm form massive, fine-grained aggregates, interstitial and ?replacing plagioclase. Both minerals formed after plagioclase, presumably by introduction of hydrothermal fluids.

Introduction of additional hydrothermal fluids subsequent to formation of biotite and chlorite, resulted in radial aggregates of acicular tremolite centred on the junctions of several large plagioclase grains or on fractures. Individual tremolite needles range up to 1mm and cross-cut both plagioclase and biotite/chlorite aggregates. The degree of alteration, and hence biotite and chlorite abundance, varies rapidly in the exposed dyke at Outcrop 69 - an observation repeated at other jade quarries and also in drillcore. Biotite and chlorite are most abundant where jade is also present marginal to the dyke. Conversely, where the 'altered diorite' is little altered and leucocratic then there is no jade adjacent to the dyke. Obviously, hydrothermal activity during dyke emplacement, was a key factor controlling both alteration within the leucogranite and jade formation in adjacent dolomitic marble.

Tremolite

Massive coarse-grained tremolite rock, crops out along margins of the leucogranite dyke and is transitional into jade. Tremolite is massive, coarse-grained and light green, with a texture similar to the microtexture of jade i.e. randomly oriented aggregates and bundles of acicular tremolite, often as radial intergrowths. Pyrite is locally abundant, as crystals to about 10mm and oxidation stains surrounding tremolite and adjacent dolomitic marble.

Boundaries between massive tremolite and dolomitic marble are distinctly lobate, suggesting hydrothermal solutions emanating from the leucogranite dyke percolated into dolomitic marble along a lobate reaction front. Dolomitic marble has been metasomatised to an assemblage of tremolite pyrite. Staining from weathered pyrite is concentrated at the reaction front boundary. Pyrite is apparently more abundant in the coarsely crystalline tremolite than in the finer-grained equivalent (nephrite) closer to the leucogranite dyke.

Nephrite

Nichol (1974a) estimated that jade outcrop of Outcrop 69 was 42 x 4m. Current mapping shows the same total strike length but outcrop is not continuous between the main quarry and the backhoe pit (Figure 46). When mapped in 1982, the quarry was 16m wide but in December 1987 Gemstone Corporation doubled the quarry width by extending northerly to expose the jade lens for a strike length of about 30m. Total production for Outcrop 69 is 328t. The remaining jade exposed in 1982 was concentrated along the contact margins of leucogranite and dolomitic marble as well as immediately adjacent to D_4 fractures in dolomitic marble (Figure 46). Close-spaced D_4 fractures, joints and shear zones cross-cut the leucogranite dyke and adjacent jade and tremolite with apparent recrystallisation of earlier tremolite and/or jade into finer-grained jade. Jade is variable in grain size but tends to be finest in zones parallel to D_4 fractures. The three controlling factors at Outcrop 69 i.e. dolomitic marble host rock, cross-cutting leucogranite dyke and D_4 joints are all steep to vertical, and so their intersections plunge steeply westwards (see Figure 46, Cross-sections AB and CD). Mining in December 1987 showed that jade extended 10m below the original outcrop and was still exposed in the quarry floor.

December 1987 mining also revealed that portions of the jade lens which strike parallel to layering in dolomitic marble are offset 10cm to 1m across successive D_4 joints, suggesting jade formation is pre- to syn-D_4. In addition, exposed jade widths show considerable variation, whilst orientation of the jade lens seems consistent across D_4 joints, suggesting that both jade formation and offset were during D_4. However, the quarry has not been mapped since mining in December 1987 and the above preliminary observations and interpretations are inferred from information provided by staff of Gemstone Corporation.

The nephrite and semi-nephrite of Outcrop 69 are dominantly green but generally in dark tones producing a dark green to black appearance. Grain size is variable with apparently irregular distribution, though the finest-grained jade appears to be in zones or bands parallel to D_4 joints. Certainly Outcrop 69 has the reputation of yielding massive, very fine-grained, black jade marketed as Premium Black. Weathering rinds on Premium Black are in pale grey and grey green hues, often with appealing colour variations and are in great demand. The thin (surficial) weathering skin for Outcrop 69 is dark red to reddish-brown and characteristic for any/all outcrops of jade with a high iron content.

Petrography of three samples from Outcrop 69 (6231 RS 24, 25 and 99) show typical nephrite texture of fibrous mats of fine-grained tremolite with individual crystals about 0.01 to 0.04mm long. Coarser, isolated tremolite prisms are to 1mm. Apatite is a prominent accessory as rounded grains to 0.4mm. Opaques and staining by reddish-brown, translucent and opaque iron oxides are abundant; up to 5% in RS99.

Portions of Outcrop 69 are foliated. The northern limit of Outcrop 69 just north of the backhoe pit is moderately foliated with an interpreted D_3 schistosity. Jade in the main quarry within D_4 shear zones or close to joints is in places foliated (S_4 fracture cleavage and schistosity) with a microscopic but still indistinct subparallel alignment of fibrous tremolite.

Outcrops 68, 70 and 71 have not been examined in detail. All tend to be coarser grained and grade to semi-nephrite. Outcrop 70 contains a D_4 foliation and may be elongate along a D_4 joint direction. Outcrops 68 and 70 may be located on or immediately adjacent to the same set of closely-spaced D_4 joints and fractures which control jade formation at Outcrop 69.

OUTCROP 76

REFER Figure 48 (Plan 89-182)

Mining and Tenement History

Outcrop 76 was first pegged by D.R. Bartell and registered as MC 692 on 8 September 1975 but cancelled on 28 January 1976. The outcrop was repegged immediately by B. Stadler and on 2 February 1976 registered as MC 734, which was converted to ML 4534 on 4 August 1976 and transferred to Nephrite Australia Pty Ltd on 19 December 1978.

During mining by Stadler/Nephrite Australia Pty Ltd in 1976-1978, 149t of dominantly black jade was recovered (Olliver, 1984). The outcrop had a reputation for high-quality black jade but was considered mined out and the lease was cancelled on 3 November 1980. High-quality black was subsequently obtained from Outcrop 69.

Geological Mapping

Nichol (1974a) described Outcrop 76 as an 8 x 5m pod associated with dolomitic marble and calc-silicate. Sample P1374/74, described as dark grey with rare white spots, is unlikely to be representative of the better quality black.

Outcrop 76 was included in the trial mining program in 1976, prior to mining by Stadler/Nephrite Australia Pty Ltd (Scott et al, 1978). One sample (P1695/76) was selected adjacent to a shot hole to examine the effects of blasting, and the outcrop was slot mined by blasting and backhoe. Very hard, tough nephrite with a very weakly-developed foliation was examined by SEM (Scott et al, 1978, Plates 12 and 13; Barnes et al, 1980, Plate 1). Various carvings were crafted at the O'Halloran Hill College of Further Education; all were of black jade and are held in the Departmental collection. Items carved include a wombat (John Rance), platypus (Joy Grant-Williams), piping shrike (Irene Craven) and ring (Marita Catt) (Scott et al, 1978, Plates 8-10).

The quarry was mapped by the authors assisted by Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata in April 1987 as Outcrop 76 had been the second-largest producer of high-quality black jade. Results are included as Figure 48.

Site Geology

Unfortunately, no nephrite remains exposed at Outcrop 76 though the controls to nephrite formation are still apparent. Key features are similar to Outcrop 69; intrusion of pegmatite and metasomatism (hybrid pegmatite) followed by additional metasomatism along D_4 fractures. Precursors to jade may be either dolomitic marble or massive diopside, in contact with gneissic amphibolite.

Stratigraphy

Outcrop 76 is located on the same stratigraphic horizon as Outcrops 55 and 69, for which more facing and stratigraphic data are available. Available data suggests the sequence of units at Outcrop 76 may be part of Cook Gap Schist or dolomitic facies of Upper or Lower Middleback Jaspilite.

Although the sequence consistently dips westwards and there is no direct evidence for facing, stratigraphic correlations of the sequence along strike at Outcrop 55 tend to suggest facing is eastwards.

Structure

S_1/S_2 gneissic layering strikes consistently NNE with steep westerly dips, generally greater than 70^o (Figure 48). The pattern is somewhat misleading as D_3 folding and mylonitisation is strongly developed - more so than in most of the other outcrops mapped. All units, but particularly some pegmatite, form augen-shaped lenses within an enclosing mylonitic D_3/S_3 schistosity. D_3 folds vary from open to tight and partly mylonitic. S_3 orientation is subparallel with S_1/S_2 and exhibits a similar range in orientations (Figure 48). The more open folds plunge NE with shallow fold axes plunging $10\text{-}30^o$ towards 020^oM.

D_4 structures show considerable variety and sense of displacement, consisting of joint planes, shear zones with a schistosity or cleavage and an ?early-D_4 pegmatite. Three orthogonal joint sets are present (Figure 48) but the dominant set, typical of the jade province, strikes about 100^oM and dips $70\text{-}80^o$N (Plate 12). D_4 shear zones, with associated metasomatic alteration and development of foliation in retrogressive assemblages, are common and were paramount in controlling jade formation. S_4 schistosity in chlorite schist and semi-nephrite exhibits greater variation than synchronous D_4 joints and would reflect in part sigmoidal patterns related to shearing - as demonstrated at other jade outcrops such as Outcrops 36 and 52.

The sense of displacement along D_4 structures varies, showing that D_4 was not a single-phase event. Larger scale displacement of dolomitic marble along SE-trending D_4 fractures and shears indicates sinistral displacement. This is consistent with observed displacement across interpreted early-D_4 pegmatite veins but opposite to the dextral displacement indicated by tremolite fibres in a ?late-stage D_4 fracture. The late-stage fractures with dextral movement are low-angle joints with similar ESE strike but shallow dips of $8\text{-}10^o$SW.

The apparent relative timing for D_4 was:

1. Pegmatite emplacement.
2. The main jointing/shearing/schistosity event with sinistral displacement.
3. Minor low-angle jointing with dextral displacement.

Hybrid Pegmatite

Hybrid pegmatite crops out extensively on the northern face of the quarry, and also occurs within narrow pegmatite dyke(s) in the southern quarry face. Pegmatite emplacement has apparently caused extensive alteration and retrogression of dolomitic marble, massive diopside and gneissic amphibolite. As in some other jade outcrops, particularly Outcrop 69 for example, this alteration is important - either as a precursor to nephrite formation during D_4 jointing/shearing/metasomatism or because nephrite forms directly at the time of pegmatite emplacement and metasomatism.

Quarry outcrops indicate that the ESE trending pegmatite veins were emplaced after development of the S_3 mylonitic schistosity. One outcrop adjacent to the backhoe pit contains hybrid pegmatite as an augen in S_{3m} but this is interpreted as superimposed metasomatism during D_4 shearing which is intense at that locality (Figure 48). The sense of displacement across pegmatite veins is the same as D_4 joints and shear zones. Late-stage N-S and E-W, planar D_4 joints crosscut the pegmatite dyke and are lined with chlorite. The pegmatite is intruded as an early-D_4 phase, probably earlier than the main phase of jointing, shearing, metasomatism and schistosity development.

The hybrid pegmatite is coarse grained with a primary assemblage of quartz and pink K-feldspar. Slight alteration produced pink clinozoisite which replaced feldspar. Metasomatism is usually extensive but of two mutually-exclusive forms.

1. Mobile silica has produced an assemblage of coarse-grained feldspar (residual) and very fine-grained chlorite. This is identical with metasomatism at Outcrop 69.

2. Reactive feldspar has produced an assemblage of coarse-grained quartz (residual) and fine-grained epidote but with the pegmatitic texture preserved (Plate 32). This style also contains bands of radiating actinolite.

Nephrite

Very little direct data are available on the black nephrite as the outcrop was essentially mined out by 1978. Black jade from the trial mining program is very fine grained and with only a weakly developed or incipient foliation which is presumably the S_4 schistosity (Scott et al, 1978, Plates 12 and 13; Barnes et al, 1980, Plate 1).

The backhoe pit (and presumably the nephrite) were along strike of dolomitic marble and massive diopside. Either lithology, or their retrogressed equivalents, may have hosted the nephrite and available data can not distinguish the alternatives. High (presumed) iron content of the black jade would have been sourced from concurrent retrogression of immediately adjacent gneissic amphibolite - now mostly chlorite and epidote.

Although previously considered mined out, and no nephrite remains exposed, the authors believe more nephrite may yet be found at Outcrop 76. The favoured zone for jade formation would be controlled by the intersection of steep D_4 shears with steep layering of dolomitic marble/diopside. Average orientations indicate that this plunges at about 75^o towards 335^oM i.e. below the quarry floor.

Jade may possibly occur along the contact of hybrid pegmatite with massive diopside. Limited exposure prevents measurement of this contact at the main hybrid pegmatite outcrop on the northern side of the quarry, and two measurements of the hybrid pegmatite dyke on the southern quarry face may not be representative of the main area.

OUTCROP 107

REFER Figure 49 (Plan 88-430)

Mining and Tenement History

Outcrop 107 is within ML 4415 which also contains Outcrop 15. Tenement history is outlined in the OUTCROP 15 section.

Outcrop 107 was first mined in about 1974 by Centamin under an option agreement with Australian (Nephrite) Jade Mines Pty Ltd. Production data are not recorded in Olliver (1984) but H. Carmody (1987, pers. comm.) reports that about 25 tonnes of nephrite, including fine-grained black nephrite, was carted away. Mining apparently consisted of bulldozing the abundant surface float and stockpiling the nephrite boulders 30-40m east of the outcrop. The deepest pit (Pit 5) was apparently only 0.5m deep and presumably was only the base of several large outcropping boulders.

The original outcrop locality was difficult to find because of the extensive surface scrapings, but the largest outcrop or most abundant float was probably in the vicinity of Pit 5. However, inspection of the stockpile and bulldozed area 30-40m E of the pits, suggests that jade may crop out in that area also. Mining by Cowell Jade Pty Ltd on 20 March 1985 attempted to locate more fine-grained black nephrite; four backhoe pits were dug, the deepest of which is 2.5m. All four are towards the northern limit (uphill area) of where the jade boulder float was bulldozed. Nephrite was only found in Pit 2 from which 6 tonnes were mined. Nephrite is still exposed in the northeastern wall of the pit.

Geological Mapping

Despite the fact that initial mining probably took place in 1974, the outcrop is not listed by Nichol (1974a), Scott et al. (1978) or Barnes et al. (1980). Olliver (1984) plotted Outcrop 107 but production was not recorded. Initial mapping was a pace and compass survey by Flint and R.S. Robertson (Senior Geologist, SADME) during mining in March 1985. A detailed stadia survey was carried out by the authors and M.W. Flintoft (Field Assistant, SADME) as well as Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata on 3 April 1987. Results of both mapping programs are compiled in this report.

Site Geology

The deposit is located within basal units of Warrow Quartzite. The sequence at Outcrop 107 consists of:
Biotite + quartz schist/gneiss (upper)
Dolomitic marble
Banded calc-silicate (basal)

All three broad units are intruded by syn-Kimban pegmatite. Nephrite lenses crop out along the eastern (upper) contact of the marble.

Nephrite

Nephrite apparently formed in discontinuous lenses over a distance of 38m from Pit 2 to where nephrite crops out on the track. Only the jade cropping out on the track was included in the reserve calculations of Barnes et al (1986), with no allowance for additional jade as exposed in Pit 2 or which may exist below Pit 5.

Nephrite cropping out on the track has a dark red, weathering skin typical of all of the jade for Outcrop 107. Grain size is variable, and tends to be coarse. Translucency is low and some boulders contain a tremolitic schistosity which has been interpreted as S_3. Nephrite colour is mostly dark green but grades to dark grey green.

No nephrite is exposed in Pit 5. Only small boulders of nephrite float remain, although this pit area was the main source of boulder float and ?outcrop which was bulldozed by Centamin in 1974.

Nephrite boulders are exposed at a depth of less than 1m in the northeast corner of Pit 2 although there was no surface outcrop prior to the backhoe mining in March 1985. A small pod of nephrite, 5-6cm long is also evident on the western wall of the pit. About 6 tonnes of nephrite boulders were mined from this pit during March 1985; the largest boulder weighed about 500kg. The remaining boulders consist of massive nephrite and nephritic tremolite grading from fine to coarse grained. Colour is dark green grading to green black. One boulder contains epidote porphyroblasts. All boulders are rimmed by pale green, massive, opaque tremolite and coated by secondary carbonate minerals, including magnesite. A tremolite and nephrite schistosity interpreted as S_3 strikes 031^{o}M and dips 36^{o}W. Two joint sets are also developed within nephrite. One set is vertical, and strikes 115^{o}M, a typical S_4 joint orientation. The other set strikes 022^{o}M and dips 46^{o}E, giving the impression that the nephrite lens dips easterly but a steep westerly dip (parallel to lithological layering) is more likely.

Banded Calc-silicate

Banded calc-silicate is apparently the lowest of the three units exposed. Typically, it contains a range of lithologies but is characterised by a well-developed banding from millimetres to metres thick. Alternating rock types are:

- coarse-grained, quartz + biotite gneiss
- pale-brown cherty quartzite
- calc-silicate bands containing abundant dark green amphibole, probably after diopside.

Cherty quartzite bands, commonly with laminae as thin as 1mm, alternating with massive tremolite bands several centimetres thick are diagnostic and characteristic of this unit. In addition, quartz + biotite gneiss tends to be quartz rich. The contact of the calc-silicate unit with overlying dolomitic marble is a thin zone of massive, coarse-grained tremolite which is considered prospective for nephrite.

Dolomitic Marble

The overlying dolomitic marble unit consists dominantly of dolomitic marble but contains lesser amounts of banded calc-silicate and quartz + sericite schist. This unit hosts nephrite lenses along its eastern (upper stratigraphically) contact.

The dolomitic marble is typically medium to coarse-grained averaging 1-2mm, grey, with disseminated pyrite, tremolite and serpentinised olivine. Tremolite and chlorite are locally abundant and form bands 1-15cm thick where carbonate is absent (Pits 1 and 4). Tremolite bands are light green and coarse grained whereas massive chlorite bands are dark, green black.

Biotite Schist

The upper unit consists of a quartz + biotite schist grading to gneiss as well as abundant pegmatite segregations or veins. The S_1/S_2 schistosity and gneissosity are strongly developed.

Structure

The geological setting suggests that the deposit is on the western flank of a major D_2 isoclinal synform and that the sequence probably faces to the east. Lithological layering and the combined (parallel) S_1/S_2 schistosity and gneissosity strikes NNE (averaging about 15^oMN) and dips steeply to the west (Figure 49).

The broad scatter of several layering readings suggests refolding during D_3.

At least three D_4 joint sets are present:

- one vertical set striking 110^oMN
- a nearly orthogonal set striking 5^oMN
- and a lower angle set dipping moderately to the SE.

The nephrite and nephritic tremolite apparently contain the ?S_3 schistosity as well as D_4 joints.

OUTCROP 114

REFER Figure 50 (Plan 89-184)

Mining and Tenement History

Outcrop 114 is within ML 4217 and the full tenement details are outlined in the section 'OUTCROP 24'. The lease is currently held by the Gemstone Corporation of Australia Ltd.

The locality was designated Outcrop 114 by the authors in 1987 although it had been worked previously, possibly as early as 1972/1973 when the tenement was held by Jade (Australia) Pty Ltd. Historical production details are not recorded in Olliver (1984) and are based on discussions with H. Carmody. The outcrop was bulldozed, using a District Council of Franklin Harbor bulldozer in about 1972/1973. From the pod of banded calc-silicate and jade remaining, most of the bulldozing was in softer rocks surrounding the lens and would have been largely unsuccessful though nephrite and semi-nephrite boulders were recovered by the authors in 1987.

The locality has been predominantly regarded as a source of ornamental green marble. In 1980, about 3t were hand picked for Cowell Jade Pty Ltd and consisted of dark green to medium green marble, including beautiful mottled green, which was considered attractive and easy to work. An additional 2t of fine-grained, green marble with a uniform colour were mined by backhoe by Cowell Jade Pty Ltd in March 1987.

Gemstone Corporation mined the jade outcrop in December 1987 searching for jade with a very light tone but failed to find any.

Geological Mapping

Outcrop 114 was EDM surveyed in March 1987 by the authors and Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata. At that time, the workings consisted of a shallow pit, 20 x 10m and 1.5m deep, with a central knoll 1.5m high of banded calc-silicate containing jade. These were relicts from bulldozing by Jade (Australia) Pty Ltd. Further mining by the Gemstone Corporation in December 1987 has not been mapped.

Site Geology

Although the quantity of nephrite recovered by mining has been small, numerous small pods crop out and illustrate well both:

- jade formation within SE-trending D_4 fractures
- the effects of N-S trending D_4 shears.

D_4 fractures and jade formation clearly postdate all other structures, including refolded D_2 and D_3 folds.

All outcrops have been designated as Outcrop 114 (114A to 114G), though some of the mapped outcrops may correspond with Outcrops 20 and 23 of Nichol (1974a, 1977). Outcrop 23 was described as a 15 x 3m lens and hence should be north of and outside the mapped area of OUTCROP 114.

Stratigraphy

Direct information of stratigraphic facing at Outcrop 114 is lacking but by analogy with equivalents nearby and along strike at Outcrops 24 and 32-36, stratigraphic facing is assumed to be eastwards. However, isoclinal D_2 folds are present and facing will, at least locally, be reversed.

The sequence at Outcrop 114 consists of dolomitic marble grading eastwards to interbedded banded calc-silicate gneiss, chloritised biotite schist and minor flaggy quartzite. Except for dolomitic marble, outcrop is poor and rubbly. All lithologies are considered part of the banded calc-silicate gneiss unit at the base of Warrow Quartzite.

Structure

The regional trend is for lithological layering and gneissosity (undifferentiated S_1 and S_2) to strike about 025°M and dip steeply westwards. Both have been folded into a series of N-plunging, close to tight S-vergence folds. The folds are probably a combination of D_3 reactivated tight to isoclinal D_2 folds. All of the folds on the geological plan (Figure 50) have been labelled as D_3. Stereographic projection plots of S_1/S_2 show a broad scatter of points and reflect additional scattering caused by refolding during D_4. S_3 structures strike about 015°M and dip steeply westwards and as expected are broadly parallel to the regional S_1/S_2 orientation and similar to D_2 axial planes. The only observed F_3 fold plunges 63° towards 335°M.

D_4 structures which are pronounced and obviously control jade distribution at Outcrop 114 are of two types:

- SE-trending fractures, shears and dissolution planes which are typical and found at most jade outcrops,
- a partly interpreted N-S D_4 shear which truncates and offsets dolomitic marble.

The N-S shear forms part of the Ulbana Shear as mapped by Parker (1981, 1983a and b) and as mapped at Outcrop 116. The sense of displacement is apparently dextral (eastside southwards) as indicated by:

- offset of the dolomitic marble horizon by about 80-100m, and
- apparent refolding of the D_3 fold.

The D_3 fold adjacent to Station 1 has apparently been rotated and made more open with the NE-end of the axial plane displaced southwards. The continuation of the dolomitic marble in that sheared out D_3 fold is found southwards in the vicinity of Outcrop 24.

Two D_4 foliations are present and both have been labelled S_4 in Figure 50. The dominant set trends SE, about 130°M, dips steeply NE and are generally parallel to or at a low angle to the fracture planes. Those D_4 fractures represent very narrow zones of high strain and the shear foliation developed (S-surface) tends to be parallel to the fracture (C-surface).

The second set of D_4 foliations is not as well developed but consists of a N-S, steeply west dipping foliation in tremolitic and chloritic rocks. The relative timing and relationships between the two D_4 foliations have not been established. However at Outcrop 116, the N-S phase (S_5) was generally superimposed on the SE-NW phase (S_4).

The tectonic sketch (Figure 50) implies pegmatite emplacement during and/or after D_4 but this is simply a consequence of the way in which the tectonic sketch has been drawn.

Nephrite

Nephrite and semi-nephrite from the pit at Outcrop 114 is mostly evident in dump samples and from scattered boulders. At least part of the nephrite formed as thin bands within banded calc-silicate gneiss with nephrite grading to tremolite schists in probable retrograded diopside bands often only 2-5cm thick. The nephrite is pale coloured and grey to grey-green with both a light tone and low value of chroma. The best of the dump samples is very fine-grained nephrite with a Munsell colour of 5G 4/3 to 4/4.

Tremolite rocks in the pit are deeply weathered, pale green to dark green and vary from massive to schistose (N-S S_4 schistosity). Semi-nephrite in the dump (6230 RS421) consists predominantly of fine fibrous tremolite in nephritic intergrowths as well as in whorls and a contorted texture defining a weak foliation. Larger fibrous aggregates are to 0.5mm and several tremolite prisms are to 0.3mm long. Minor epidote (1%) form subidiomorphic crystals and aggregates to 0.8mm across, sometimes as radiating aggregates. Opaques and translucent iron oxides typically line foliation lamellae and fractures.

Pod 114A wholly within dolomitic marble is not obviously related to a D_4 structure and may be similar to very small nephrite and semi-nephrite occurrences between Outcrops 114F and 114G. The small pod of less than 1m consists of massive tremolite and nephrite which is fine-grained, pale green and coated with opaque tremolite. Pod 114B is very similar but is within a D_4 fracture and consists of a core or augen of massive nephrite within an enclosing tremolite schist. Pod 114C is again similar, with massive nephrite as an augen-shaped body within tremolite schist in the D_4 fracture. The outcrop being 3 x 2m is however larger.

Pod 114D is apparently wholly within banded calc-silicate gneiss and at only 10 x 5cm, probably represents a former diopside or dolomitic marble band. The pod consists of semi-nephrite and tends to be coarse grained. One of the larger lenses, 114E is about 3 x 2m with boulders to 0.9m long. The nephrite varies from massive to foliated but in places is of excellent quality being fine grained, bright pale green and translucent.

Pod 114F is the largest at 4 x 1m but quality varies from massive nephrite to schistose semi-nephrite. SE-trending D_4 foliation is present. The more massive samples are medium green but with fractures and a tendency to be somewhat coarse grained. Strongly foliated semi-nephrite is pale green but again somewhat coarse grained. Metasomatism extends away from the D_4 fracture along strike of the dolomitic marble, and the tremolite-rich zones contain the D_4 foliation. The nephrite and semi-nephrite contain inclusions of pyrite and possibly phlogopite.

Pod 114G is 2 x 0.5m, elongate in the D_4 foliation but at a 20^o angle to adjacent D_4 dissolution planes and joints. The outcrop consists only of foliated, opaque and pale green semi-nephrite. The 15-20m wide dolomitic marble between Outcrops 114F and 114G contains numerous small pods of tremolite, which have not been mapped individually but indicate metasomatism during D_4 was widespread and not just restricted to the very narrow zones of high strain.

Dolomitic Marble

Colour variations are typically between:

- greyish greens from Munsell 10GY 5/2 to 5G 5/2, and
- moderate to dark yellow greens of 10GY 6/4 to 10GY 4/4.

OUTCROP 115 AND WHITE MARBLE PROSPECT

REFER Figure 51 (Plan 88-431)
Log DDH CWM1 Figure 52 (Plan 88-432)

Mining and Tenement History

The white to grey, dolomitic marble was first pegged for ornamental marble, nephrite, epidote and tremolite-actinolite by E.M.G. Swain and registered as MC 4966 on 24 May 1966. No jade outcrops were identified and the claim was cancelled on 27 January 1967 (Olliver, 1984).

However, Harry Schiller had located a small pod of nephrite/semi-nephrite at the northern end of exposed dolomitic marble and the area was repegged by Swain's company, Australian (Nephrite) Jade Mines Pty Ltd. MC 193 was registered on 26 June 1973 and converted to ML 4338 on 10 December 1973.

From June 1973 to July 1979, Centamin N.L. had an indenture agreement with Australian (Nephrite) Jade Pty Ltd to explore, mine, extract and market jade from MC 193/ML 4338. The indenture was cancelled on 4 July 1979 and the lease transferred to Cowell Jade Pty Ltd on 21 November 1979. ML 4338 is current and held by Gemstone Corporation of Australia Ltd.

There has been no production of nephrite or ornamental marble from MC 4966, MC 193 or ML 4338.

Geological Mapping

Under the indenture agreement, Centamin (1973) briefly mapped MC 193/ML 4338 including the jade outcrop. However, the jade outcrop was not recognised by Nichol (1974a), Scott et al. (1978) or Barnes et al. (1980).

In 1979, the Cowell Jade Province was investigated as a potential source of grey green dolomitic marble. During reconnaissance geological mapping by D.A. Young (SADME), a deposit of fine-grained, white dolomitic marble was identified in ML 4338. This was tested with an air-track drill in December 1979 during jade quarrying by D. Linke for Cowell Jade Pty Ltd. Three holes penetrated 1-2m of solid marble beneath which the marble was found to be strongly weathered to soft nodular powder for at least 6m. Drill sites are shown on Figure 51. Drilling was abandoned and the site was not developed.

During subsequent investigations in 1983, a 40.30m diamond drill hole (CWM1) was drilled to more adequately test the site. The area was mapped and surveyed by D.A. Young and A.J. Smith, and mapping data are included as Figure 51. Drill core was logged by D.J. Flint and D.A. Young (Figure 52).

Petrography of sillimanite gneiss in 1987 was by Sumitra Atmanwinata.

Site Geology

From west to east, the sequence within ML 4338 consists of:

- banded calc-silicate gneiss, mica and quartz + mica schist with minor sillimanite gneiss
- dolomitic marble
- sillimanite gneiss with minor quartzite
- granodiorite gneiss of Archaean Miltalie Gneiss.

Foliated granodiorite gneiss and layered granodiorite gneiss along the eastern limit of the mapped area are interpreted as Archaean Miltalie Gneiss. The remainder of the mapped area is interpreted as the basal banded calc-silicate gneiss unit of Warrow Quartzite. Schist units are more quartzose west of the dolomitic marble. Regionally they grade westwards to quartz schists and quartzites suggesting the sequence is basal Warrow Quartzite which faces westwards. The contact of banded calc-silicate gneiss and Miltalie Gneiss is, at least in part, mylonitic.

The structural setting is uncomplicated. All units strike at about 020^{o}M and dip 70-80^o westwards. D_2 folds were not observed but may cause minor repetitions within banded calc-silicate gneiss. However, D_3 folds are abundant particularly in banded calc-silicate gneiss west of dolomitic marble. Folds are open to tight but without new axial planar fabrics. Axial planes strike 010^{o}M, dip steeply east and have fold axes plunging 50-60^o towards 015^{o}M. Fold vergences are consistently Z-shaped. As elsewhere in the jade province, D_3 folds are abundant in quartz-rich banded gneiss but very rare or absent in dolomitic marble highlighting the different mechanical response. Retrograded sillimanite gneiss in places contains a sericitic schistosity which is probably a D_3 mylonitic schistosity.

Retrograde Sillimanite Gneiss

Sillimanite gneiss crops out both east and west of dolomitic marble but is most abundant between the dolomitic marble and Archaean granodiorite gneiss. Retrogression is extensive and very little of the original sillimanite remains (6231 RS 207). The assemblage now consists of fine muscovite/sericite (60%), chloritoid (20%) and sillimanite (10%) with minor chlorite. Muscovite/sericite forms very fine-grained, felted aggregates containing subidiomorphic chloritoid porphyroblasts up to 2mm across. Sillimanite forms contorted fibrous aggregates. Outcrops contains an S_2 schistosity with tight, D_3 kink folds, but a schistosity is not developed within retrogressive products in 6231 RS 207. A sericitic schistosity is developed in retrograded sillimanite gneiss intersected in hole

CWM1. Retrogression is thus interpreted as syn- to late- D_3.

White Dolomitic Marble

Diamond drill hole CWM1 tested white to very light grey and fine-grained dolomitic marble which cropped out along the western (hanging wall) contact of dolomitic marble. The target was intersected in CWM1 9-10m below the surface and consisted of dolomitic marble:

- uniform and fine grain size with an average less than 1mm
- uniform pale colour of white to very light grey (Munsell N8.5)
- inclusions of chlorite, serpentine and tremolite were absent.

However, the zone was only about 2m thick and core was weathered, calcreted and rubbly. The largest intact piece of core was only 9cm long. In outcrop, along strike, dolomitic marble is light grey (N7 to N8).

Deeper intersections of dolomitic marble reveal:

- coarser grain size of 1-4mm,
- more grey colour, averaging light grey (N6.5 to N8),
- and more abundant inclusions either as compositional banding (S_1/S_2) or disseminated aggregates.

Full details of the colour variations are recorded in the drill log (Figure 52) but include:

- serpentine; light olive 10Y 5/4 and yellowish grey 5Y 7/2
- chlorite; dusky yellowish green 10GY 3/2, moderately yellow green 10GY 5/4 and green 5G 5/3
- tremolite; greyish green 10GY 5/2.

The deeper intersections are more typical of dolomitic marble throughout the Cowell Jade Province.

The geological mapping and diamond drilling have downgraded the potential for fine-grained, white dolomitic marble in ML 4338 by showing this occurrence to be restricted, thin, fractured and deeply weathered.

Nephrite

Outcrop 115 consists of semi-nephrite grading to nephrite in a small outcrop of about 0.55x0.46m.

Several boulders crop out in the creek bank. The semi-nephrite is pale green but poorly translucent. Texture is typically nephritic with fine fibrous aggregates with an average grain size of 0.02-0.04mm (6231 RS 120). However, coarser tremolite prisms and needles to 1.5mm are also present and recognisable in hand specimens. These coarse euhedral prisms and needles are late stage and apparently crystallised after formation of the nephritic fine fibrous aggregates.

A relict domainal structure is also present, indicating a pre-nephrite phase of dolomite or diopside. Boulders of float include tremolitic marble suggesting the pre-nephrite phase is more likely to be dolomite.

Fibrous aggregates tend to be aligned forming a D_4 foliation which strikes at 122°M and dips 80°SW. Veins of fibrous tremolite are also present, as observed in other jade outcrops such as Outcrop 15 and 35 for example, and are also interpreted as (late-stage) D_4 structures. Fibre lengths across the vein are up to 5mm.

Dolomitic marble within ML4338 is very similar to other dolomitic marble within the Cowell Jade Province yet jade outcrops are scarce. The reasons are not clear but several observations are relevant within the mapped area of ML 4338:

- hybrid pegmatite is rare
- metasomatic alteration zones of chlorite, tremolite, talc, epidote and clinozoisite are also rare
- D_4 fracturing is not as intense as in other parts of the Cowell Jade Province.

The most significant fracture coincides with Outcrop 115 where dolomitic marble is offset across the fracture, but has not been mapped in detail (Figure 50).

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT.BK.NO. 89/51

COWELL JADE PROVINCE: DETAILED GEOLOGICAL MAPPING AND DIAMOND DRILLING OF JADE AND ORNAMENTAL MARBLE OUTCROPS, 1982-1987.

VOLUME 3

GEOLOGICAL SURVEY

by

D.J. FLINT

and

E.A. DUBOWSKI

SENIOR GEOLOGISTS
MINERAL RESOURCES BRANCH

JUNE 1991

DME 85/88

E00237

VOLUME 3

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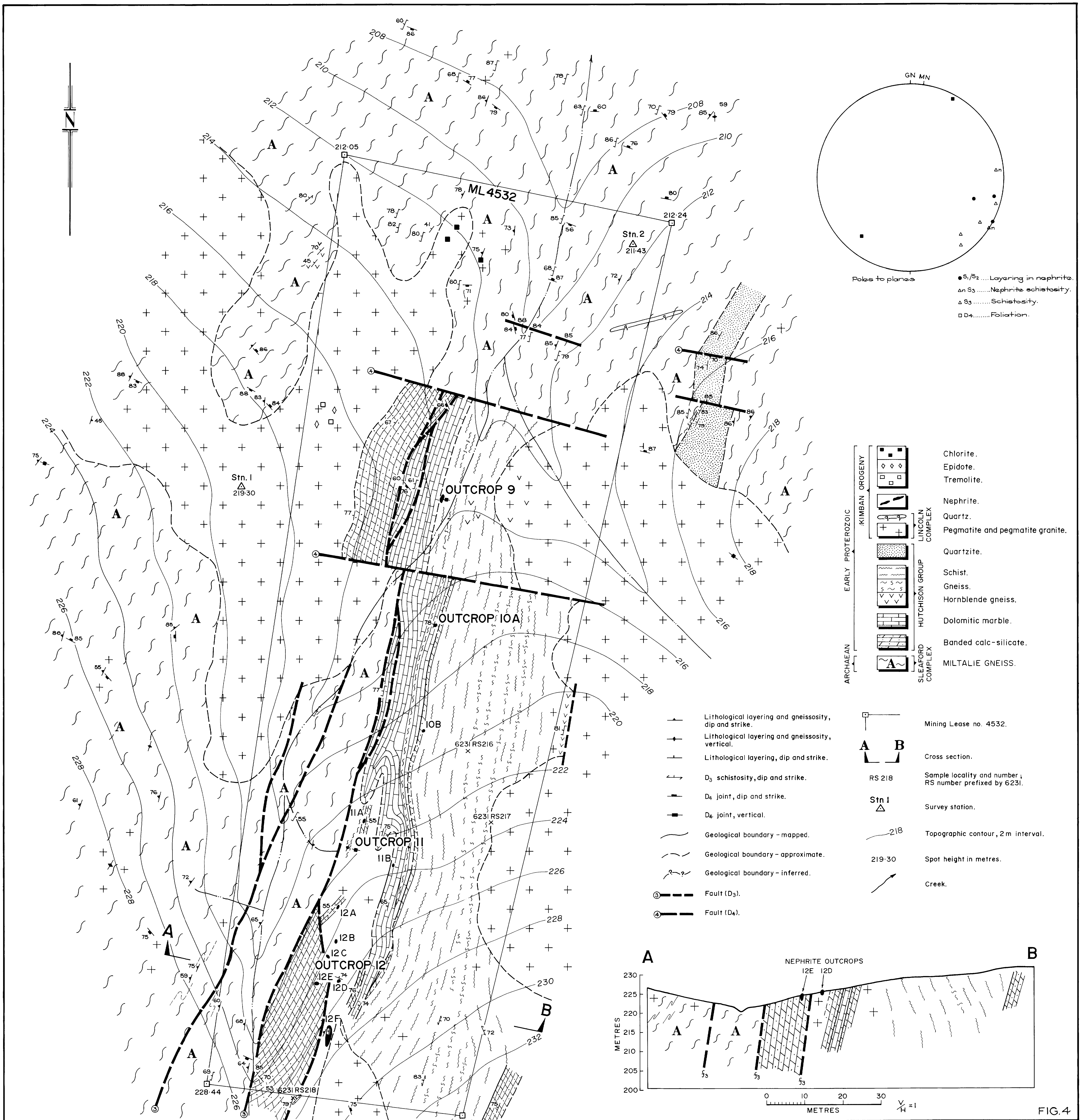


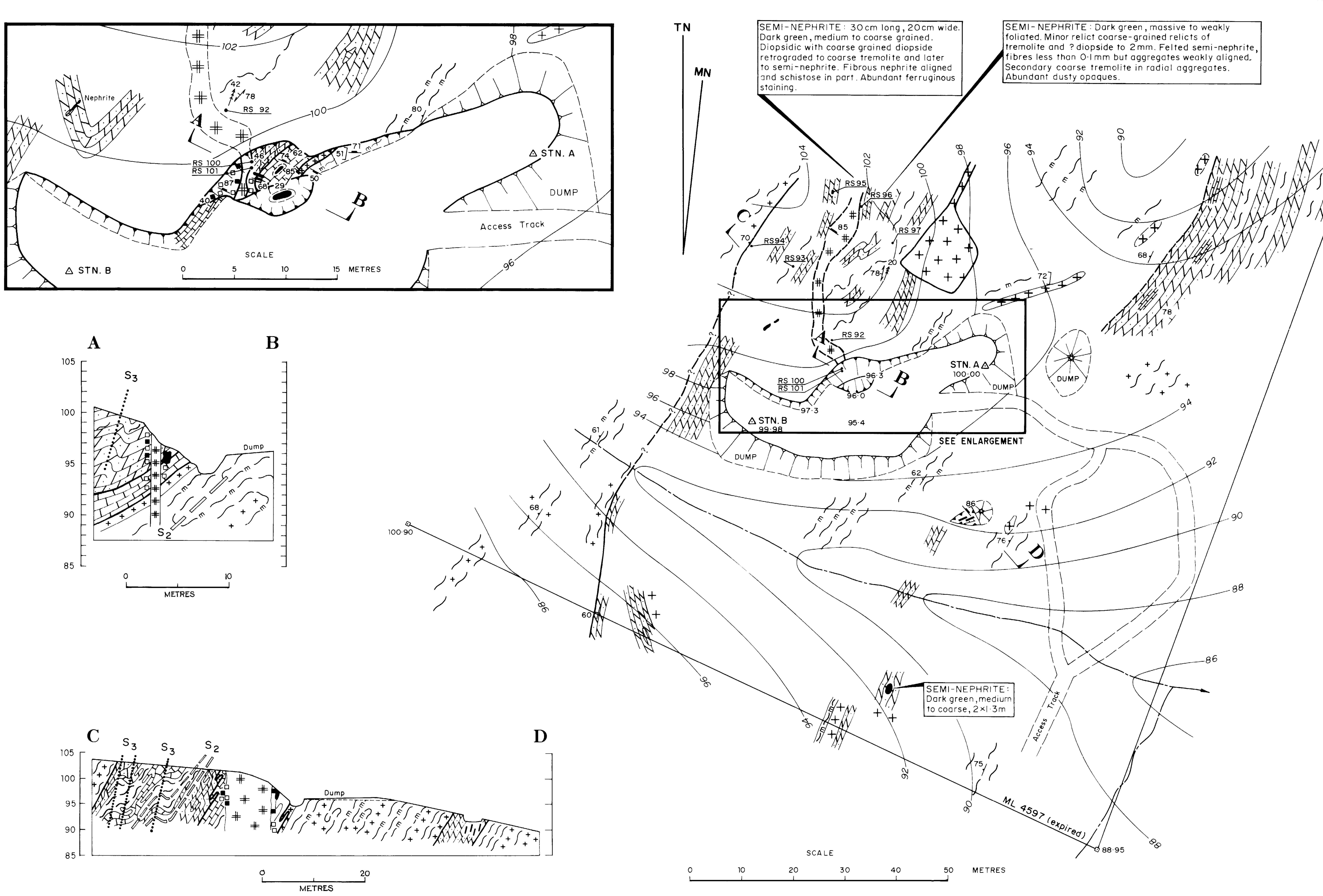
Datum = A.H.D. (approx), S.F.B. 815.

FIG. 4

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 9-12
GEOLOGICAL MAP

COMPILED E.A. Dubowski	C D O 4-7-91 DATE
DRAWN J.W.	SCALE 1:500
DATE	PLAN NUMBER
CHECKED	88-422



SEMI-NEPHRITE: 30 cm long, 20 cm wide. Dark green, medium to coarse grained. Diopsidic with coarse grained diopside retrograded to coarse tremolite and later to semi-nephrite. Fibrous nephrite aligned and schistose in part. Abundant ferruginous staining.

SEMI-NEPHRITE: Dark green, massive to weakly foliated. Minor relict coarse-grained relicts of tremolite and ? diopside to 2 mm. Felted semi-nephrite, fibres less than 0·1 mm but aggregates weakly aligned. Secondary coarse tremolite in radial aggregates. Abundant dusty opaques.

SEMI-NEPHRITE: Dark green, medium to coarse, 2×1·3m

60	Lithological layering; dip and strike
75	Gneissosity (undifferentiated S_1/S_2); dip and strike
34	Gneissosity – S_2; dip and strike
78	Axial plane of D_3 fold; dip and strike
42	F_3 fold axis; plunge and trend
71	Joint; dip and strike
35	Joint, vertical
S_2	Trace of D_2 axial plane
S_3	Trace of D_3 axial plane
	Geological boundary:
	mapped
	approximate
—?——?—	inferred

	Quarry face with scree
	Dump
	Track
ML 4597	Mining Lease No. 4597 (Expired)
A B	Cross section
RS 92	Sample locality and number, prefixed by 6231
STN. A △	Survey Station
98	Topographic contour, contour interval 2 m
95·4	Spot height in metres

LEGEND

EARLY PROTEROZOIC — KIMBAN OROGENY — LINCOLN COMPLEX — MINBRIE GNEISS — HUTCHISON GROUP — WARROW QUARTZITE (basal Banded Calc-Silicate Gneiss)

CHLORITE: dark green to greenish black. Most abundant along margin of leucogranite vein. Massive and schistose varieties.

TREMOLITE: massive, coarse-grained light green tremolite along the margin of altered leucogranite. Similar composition and texture to jade but much coarser grained.

NEPHRITE and SEMI-NEPHRITE: medium green to greenish black, fine-grained but variable with small bands of coarser grained tremolite, brown to reddish brown weathering skin. Mostly massive but with weakly developed cleavage/schistosity – probably S_3 and/or S_4. Inclusions are opaques, diopside and chlorite (RS 95 and 96)

NEPHRITE and SEMI-NEPHRITE: as above but interpreted position of mined out lens. Shape and size not known.

LEUCOGRANITE: extensively altered in proximity of marble and jade. Coarse grained plagioclase is dominant whereas quartz is minor. Major secondary phases are white to pale yellow epidote (10 - 15 %) and actinolite - tremolite (5 - 8 %) forming massive crystals and fibrous wispy aggregates (RS 100 and 101).

PEGMATITE: quartz and feldspar.

APLITE and GRANITE: as sills; grades into migmatite gneiss.

MIGMATITE GNEISS: banded quartzofeldspathic gneiss with foliated biotite-rich bands alternating with leucocratic quartz + feldspar segregations. Leucocratic zones dominant. Banding from centimetres to metres thick.

CALC - SILICATE: siliceous calc-silicate with only subordinate diopside, tremolite, actinolite and chlorite. Grades into interbands of plagioclase + chlorite gneiss and granodiorite gneiss containing up to 15% chlorite and 20% sericite (RS92-94 and 97).

DOLOMITIC MARBLE: grey and coarse-grained with an average grain size of 2-3 mm. Dark brown on weathered surfaces. Bedded with bands and disseminations of diopside, tremolite, chlorite and yellow serpentinised olivine. Grades into calc-silicate.

MICACEOUS GNEISS: grading to mica schist; biotite rich and with abundant sills and bands of aplite and granite. Blackish when fresh but weathers reddish brown. S_2 gneissosity / schistosity across compositional banding in quarry face.

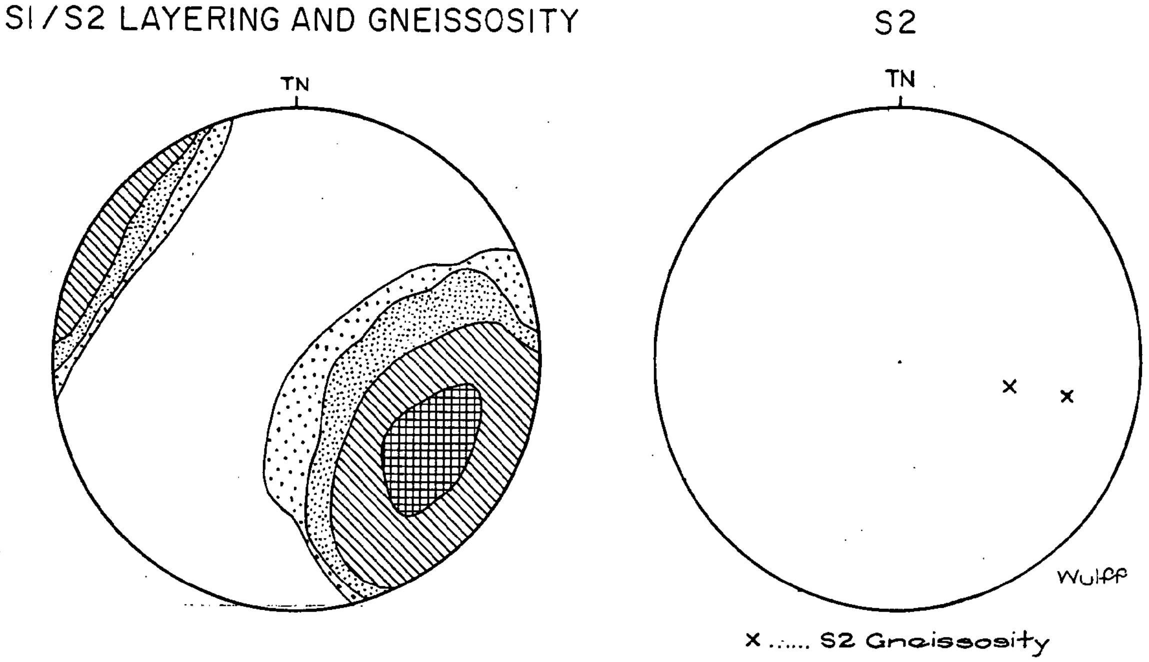
Surveying by A. J. Smith; SFB 680
Assumed datum of 100 metres at Station A
Geological mapping by D. J. Flint and E. A. Dubowski

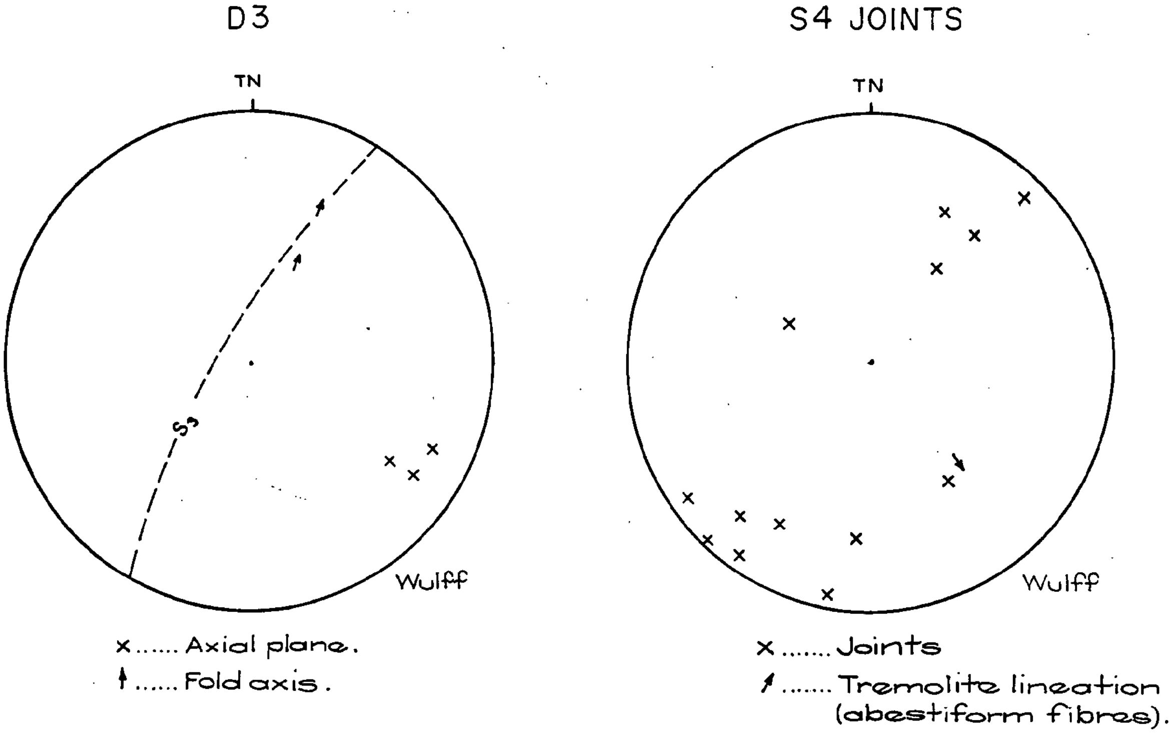
FIG.5

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 14
GEOLOGICAL MAP

COMPILED D. F.	1·3·88 DATE
DRAWN M. B.	SCALE As shown
DATE Oct '85	PLAN NUMBER
CHECKED	88-82





Contours at 0·5, 1, 2, 4% per 1% area; equal area projection

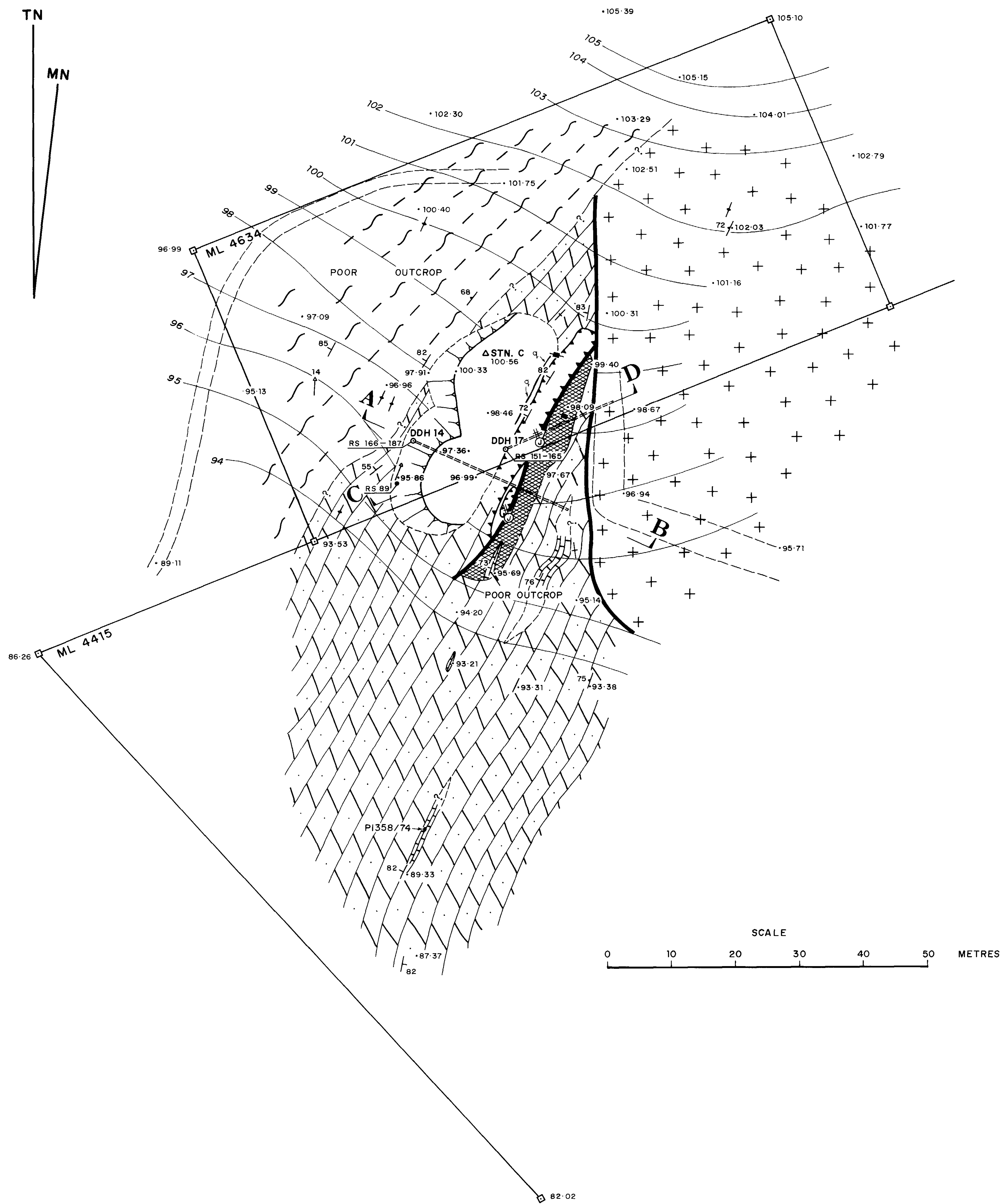
FIG. 6

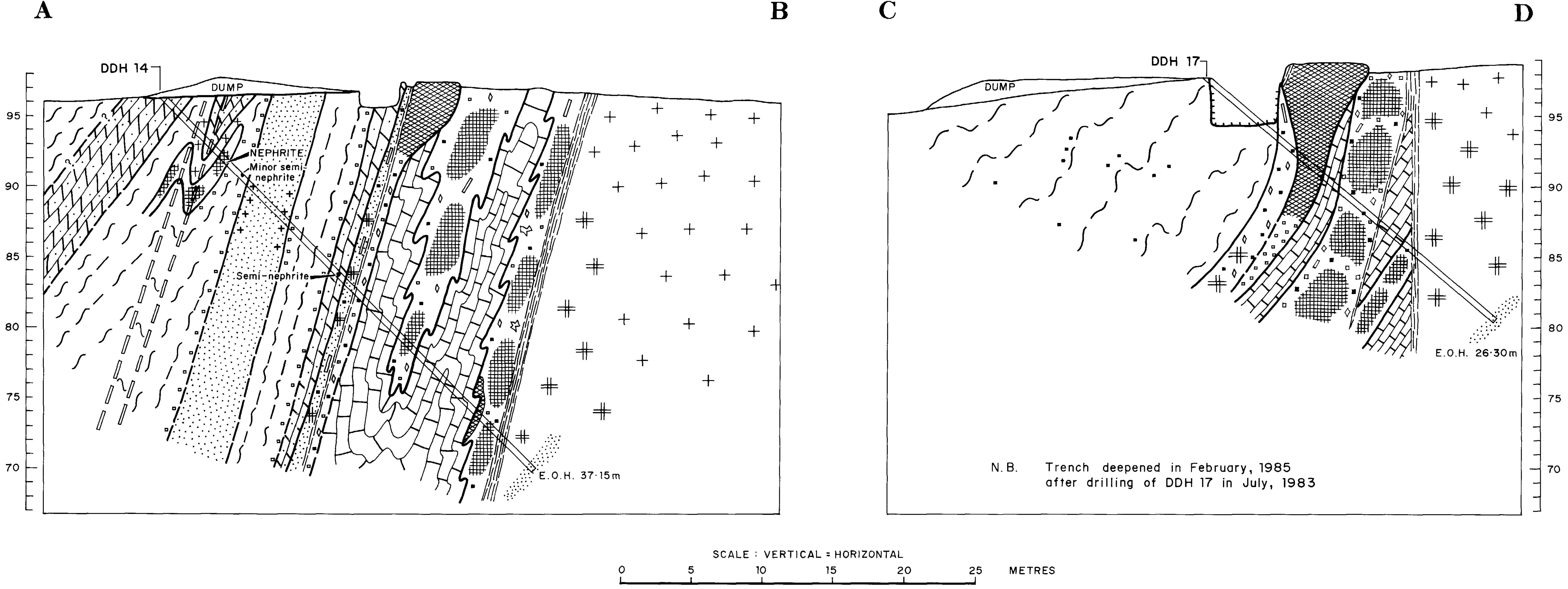
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 14
STEREOGRAPHIC PROJECTIONS

COMPILED D.J. Flint	CDO	DATE 4.7.91
DRAWN J.W.	SCALE	
DATE 6-9-88	PLAN NUMBER S20213	
CHECKED		

3917





N.B. Trench deepened in February, 1985
after drilling of DDH 17 in July, 1983

LEGEND

BRECCIA + MYLONITE : angular fragments, typically diopside within very fine grained schistose matrix, retrogressed assemblages include zoisite, scolecite? and near granite margin, plagioclase; zone probably indicates calc-silicate – granite contact is a fault.

JADE + NEPHRITIC TREMOLITE : in outcrop, bold and massive, varying in colour, texture and quality. Colour varies from medium grey-green to more common dark green and black. Banding is a result of concentration of either porphyryblasts of chlorite, actinolite or coarser tremolite, and often defines ptygmatic folds. Rinds are often found on boulders; some development of leopard skin texture (RS 182). Foliation is formed by preferred orientation of tremolite or nephrite.

TREMOLITE : pale green to dark green, predominantly massive, medium to coarse grained, in sheaves and clusters. Foliation due to parallel alignment of fibres; tremolite on faulted contact of Outcrop 15 reaches 10-15 cm in length. Is found as bands and veins in gneiss and calc-silicates. Pale, fine grained tremolite grades to dark green nephrite (RS 68).

CHLORITE : massive, dark green; forms as alteration masses in proximity to jade or as retrogressed assemblages in gneisses and granitic rocks, disseminated sphere forms as porphyryblasts.

EPIDOTE + CLINOZOISITE : highly variable in colour, pale-yellow, yellow-green, green and pink associated, as discrete grains, with diopside, and tremolite in highly retrogressed zones, or as compositional bands within calc-silicates.

DIOPSIDE : white to off-white, coarse-grained, found in retrogressed zones, often altering to tremolite and nephritic tremolite (RS 166, 167). Does not outcrop.

ALPITE + GRANITE : as sills, dykes and leucocratic segregations in quartzite and migmatite gneiss.

ALTERED INTRUSIVE : contaminated, coarse-grained, light to dark grey granitic rock with off-white and pink K-feldspars. Biotite forms as stringers, defines relict gneissic banding. Contaminated and altered products include epidote and chlorite/sericite (RS 186).

DOLOMITIC MARBLE : massive to compositionally banded, fine to coarse-grained, colour varies from off-white to grey, yellow, yellowish-green to green; green colour related to serpentinization and chloritization, patchy inclusions of diopside, tremolite, nephrite, epidote and clinozoisite.

CALC-SILICATE : compositionally banded, siliceous, green to dark green, tremolite and epidote rich rocks, locally grading to nephritic tremolite. Gradational into gneiss, particularly when calc-silicate is quartz rich and contains chloritized biotite.

QUARTZITE : massive, fine grained, grey to pale-pinkish red, sericitic, with poorly developed schistosity; minor development of leucocratic segregations.

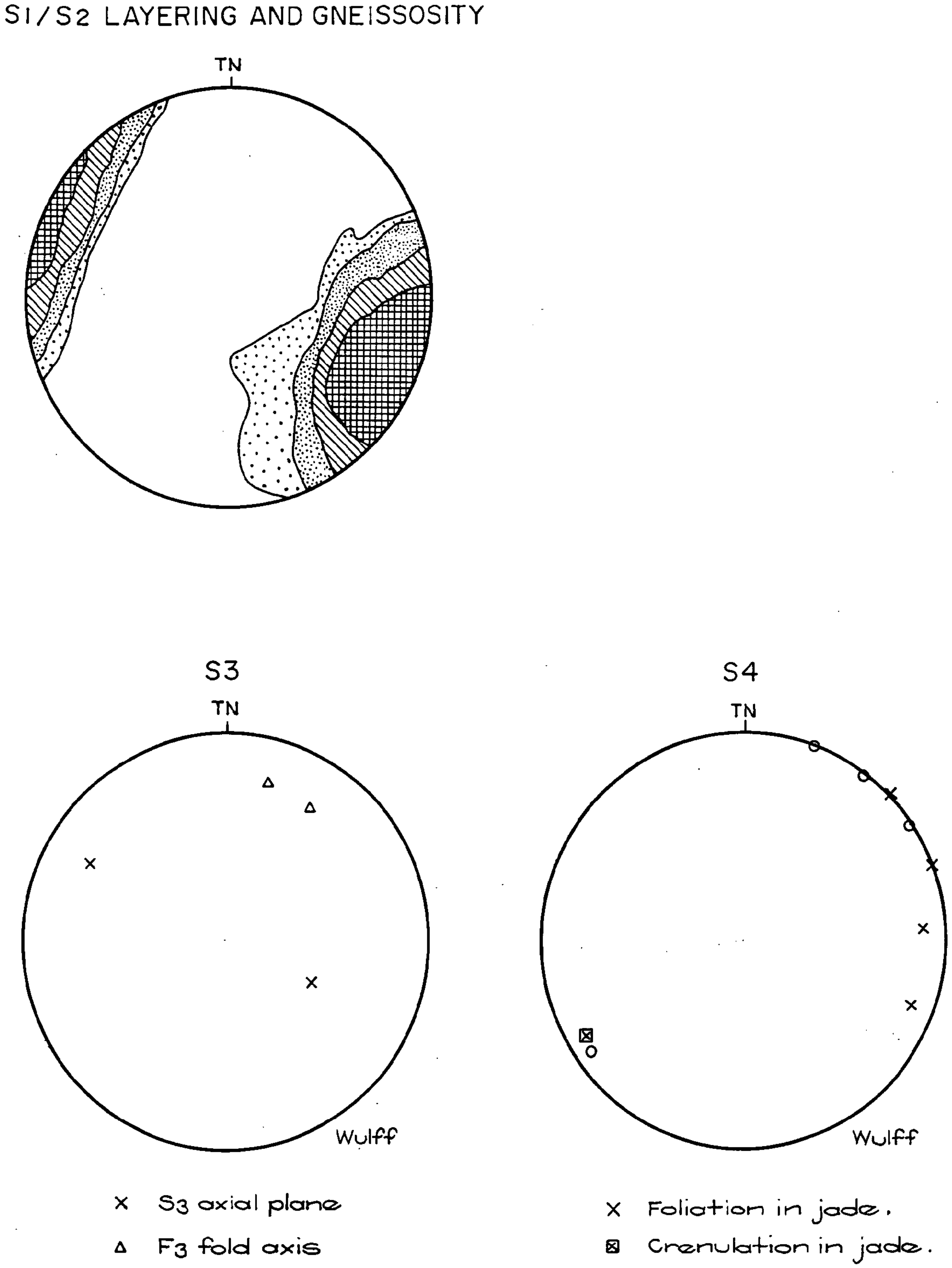
BANDED GNEISS : massive to well banded quartzofeldspathic gneiss, with foliated biotite-rich bands and leucocratic segregations; biotite commonly chloritized and feldspars sericitised. Thin bands and veins contain tremolite/actinolite.

GNEISS : as above, but poorly banded, locally migmatitic.

———	Geological boundary; observed
– – – –	Geological boundary; approximate
—?——?—	Geological boundary; inferred
━━━	Fault and mylonite (plan only)
83	Compositional banding; strike and dip
	Compositional banding; strike and vertical dip
—	Compositional banding; strike (dip not measured)
72	Gneissic foliation; strike and dip, undifferentiated S_1 and S_2
	Gneissic foliation; strike and vertical dip
73	Joint; strike and dip
	Joint, strike and vertical dip
→ 14	Fold axis; plunge and trend, age unknown
▭▭▭▭	Axial plane; S_2 or S_3
	Jade foliation
ML 4634	Mineral Lease No. 4634
△ STN. C	Survey Station
• 95·71	Spot height
—100—	Topographic contour
RS 89	Sample locality and number, prefixed by 6231
DDH 17	Diamond drillhole (inclined) with plan projection and sample numbers
	Trench
	Dump
═══	Track
A B	Cross section

Geology by E.A. Dubowski, M. Sahl and D.J. Flint
Stadia Survey by P.P. Crettenden and A.J. Smith
(SFB 680 + 682)
Assumed Datum, 100 metres at STN. A (located on dump and since removed)

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED D. F.	*WC* 1 · 3 · 88 C.D.O. DATE
COWELL JADE	DRAWN M. B.	SCALE 1 : 500
GEOLOGICAL MAP – ML 4634 and 4415 OUTCROP 15, CROSS SECTIONS A–B, C–D	DATE Dec '85 CHECKED	PLAN NUMBER 88-83



Contours at 0·5, 1, 2, 4% per 1% area ; equal area projection.

FIG.8

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 15
STEREOGRAPHIC PROJECTION

COMPILED E.A.Dubowski	C D O	4-7-91 DATE
DRAWN J.W.	SCALE	
DATE 6-9-88	PLAN NUMBER	
CHECKED	S20214	

3917

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

MINERAL RESOURCES BRANCH

HOLE No. DDH 14
PAGE 1 of 2

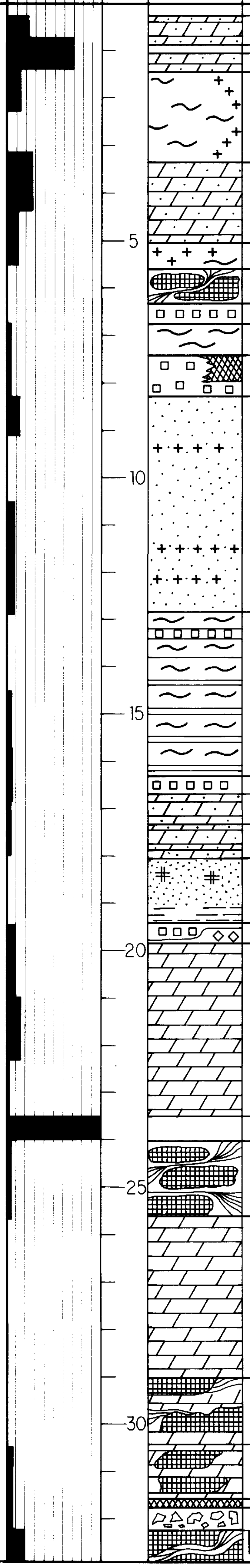
PROJECT COWELL JADE
OUTCROP 15
LOCATION 6231
HUNDRED MINBRIE SECTION 116

ELEVATION
INCLINATION 45°
AZIMUTH 108°m
DEPTH 37·15m
DATUM

DRILLER D.E. White
COMMENCED 17·5·83
COMPLETED 25·5·83
LOGGED D. Flint, E. Dubowski

UNIT / STATE No. 611/83
DOCKET NUMBER 355/75
PLAN REFERENCE 83 – 40 & 88-83
DRAWING No.

CORE SIZE | CORE LOSS (%) 0 50 100 | DEPTH (m) | GRAPHIC LOG



LITHOLOGICAL DESCRIPTION

ALLUVIUM – no core

CALC-SILICATE: Massive to poorly banded; tremolite-rich; average grain size about 1mm.

CALC-SILICATE: Fine-grained, siliceous, green calc-silicate with leucocratic segregations.

GNEISS: sericitic gneiss with abundant coarse-grained quartz and feldspar veining. Minor bands of calc-silicate which exhibit thin laminations. Traces of tremolite/actinolite in leucocratic veins.

CALC-SILICATE: Banded green to dark green siliceous calc-silicate. 2-4mm, dark grey, siliceous bands alternate with dark green to green black bands of biotite and tremolite/actinolite. Close to tight fold with no new axial planar minerals at 4·15m. Primary diopside apparently absent – possibly present at 4·9 - 5·0m.

APLITE: Weakly banded with gneiss relicts. Late stage brittle fracturing with dark green-black chlorite lining fractures.

DIOPSIDIC CALC-SILICATE: Mostly medium grained but v.coarse grained diopside at 6·1 - 6·25m. Banded and in places weakly mylonitised. Retrogressed with dark green chlorite & tremolite aggregates + pink clinozoisite retrogression of diopside at 6·24m (RS167) chlorite lines fractures within diopside. Trace nephrite.

TREMOLITE: Massive, weak compositional banding. Colour banding (green, green bl. & grey) from grain size variations. In places, nephritic.

GNEISS: Quartz & feldspar ± sericite. Dark grey and compositionally banded with leucocratic segregations. Bands up to 10mm thick.

TREMOLITE: Grades to nephritic tremolite as at 7·69 m (RS169). Mostly massive. Colour mostly pale green but locally darker, fine grained & nephritic. In places banded with diopside, epidote, zoisite & quartz.

SERICITIC QUARTZITE: Grey quartzite with spotty and disseminated sericite but which is not well aligned and does not define a schistosity. Rock distinctly massive with essentially no banding or gneissosity and contrasts with Banded Gneiss below. Contains white leucocratic segregations.

BANDED GNEISS: Distinct, well banded gneiss with pink and grey bands 5-40mm thick. Grey to grey-black contains aligned chloritised biotite. Pink coarser-grained bands contain abundant K-feldspar.

Tremolite band at 13·16 - 13·32m with minor banded quartzitic calc-silicate on lower margin. Dark green, massive, coarse-grained and with only diffuse compositional banding within the tremolite. Minor oxidised pyrite.

TREMOLITE: Poorly banded, mostly med. green, probably after diopside, contains yellow-green epidote infilling fractures.

CALC-SILICATE: Banded and siliceous. Grades from well-banded quartzite, quartzitic calc-silicate and massive tremolite.

CALC-SILICATE: Tremolite-rich; banded. Retrogressive assemblage with pronounced mineralogical zoning of tremolite & epidote group minerals. Perhaps locally nephritic in narrow foliated schistose zones.

QUARTZITE: Grey foliated sericitic quartzite with abundant coarse-grained leucocratic segregations containing minor small aggregates of chlorite and tremolite. Chlorite in stringers parallel to sericitic schistosity and lining cross-fractures.

CALC-SILICATE: Mixed with bands of yellow-green epidote/zoisite & pale green tremolite in radiating clusters.

DOLOMITIC MARBLE: Varies from massive to compositionally banded. Recrystallised & retrogressed with chloritisation of phlogopite and serpentinisation of olivine. Green colour caused by both serpentine and chlorite. Colour varies markedly from off-white, grey, uniform pale green to irregularly mottled in pale yellow-green, green and reddish-brown. Medium grained, averaging around 1mm.

NO CORE

DIOPSIDE: Massive, off-white diopside with diffuse compositional banding.' Irregularly fractured and partly retrogressed with fractures and veins containing nephrite, chlorite, minor epidote and carbonate.

DOLOMITIC MARBLE: Very similar to marble zone above, including variously coloured and irregular mottling. Most abundant colours are ① off-white to grey with yellow spotting of serpentinised olivine (RS 176) and ② irregular banding and mottling of pale green and white (RS 177).
Locally sheared, white and probably consists of schistose fine-grained calcite & tremolite.

DIOPSIDE with DOLOMITIC MARBLE bands: Mostly massive, off-white, very coarse-grained diopside with typical fracturing & granulation with fractures lined with tremolite & dk. green chlorite. Diopside bands alternate with med.-grained, off white to grey to pale green, dolomitic marble with tremolite.

DOLOMITIC MARBLE: but with minor DIOPSIDE bands: Mixed off-white, grey & pale green marble without yellow-green serpentinised olivine. Grey, fine-grained bands consist of tremolite & calcite. In lower portion banded green & white marble grades into underlying jade.

JADE and NEPHRITIC TREMOLITE: Medium green, fine-grained and weakly translucent. Forms a very distinctive leopard skin texture with white, fine-grained ?chondrodite – see RS 182.

BRECCIA: Very fine-grained, white diopside clasts set in a pale grey-green, fine grained, diopsidic matrix.

PETROGRAPHIC SAMPLE / ASSAY SAMPLE

PETROGRAPHIC SAMPLE 6231 RS No.	Depth (m)	ASSAY SAMPLE from	RS No	to
166	5·89	5·75	166	5·94
167	6·24	6·10	167	6·30
168	6·59	6·39	168	6·62
169	7·69	7·39	169	7·99
170	14·87	14·82	170	15·00
171	17·48	17·45	171	17·62
172	17·74	17·62	172	17·75
173	22·20	22·16	173	22·32
174	23·15	23·12	174	23·28
175	24·23	24·15	175	24·32
176	26·96	26·74	176	27·00
177	27·36	27·22	177	27·50
178	29·29	29·27	178	29·36
179	31·18	31·00	179	31·26
180	31·40	31·26	180	31·49
181, 182	31·66, 31·70	31·55	181	31·65
		31·65	182	31·75
183	31·88	31·82	183	31·94

STRUCTURES

- Gneissic banding and leucocratic veining at 90° to core axis.
- sericitic gneissosity at 75° to core axis.
- Close fold with no axial planar recrystallisation. Axial plane at 70° to core axis.
- Compositional banding, rich in retrogressive products, at 75° to core axis.
- Diffuse compositional banding. " " " " " " to core axis.
- Gneissic compositional banding (S_1) at 55° to core axis.
- Compositional banding (?retrogressive) at 60° " " "
- " " (S_0/S_1) at 30° " " "
- S_0/S_1 gneissic banding at 60° to core axis.
- " " " " 60° " " "
- " " " " 55° " " "
- " " " " 65° " " "
- " " " " 60° " " "
- " " " " 50° " " "
- Compositional banding, probably S_0/S_1, at 60° to core axis.
- " " " " " 50° " " "
- " " " " " 60° " " "
- Gneissic banding in calc-silicate at 55° to core axis.
- Mylonitic sericitic foliation at 50° to core axis.
- " " " " 50° " " "
- " " " " 45° " " "
- " " " " 35° " " " ; distinctly across earlier layering
- Compositional banding, not necessarily S_0/S_1, at 55° to core axis.
- " " " " " " 50° " " "
- " " " " " " 50° " " "
- " " " " " " 50° " " "
- " " " " " " 55° " " "
- Compositional banding, probably S_1, at 55° to core axis.
- " " " " " 50° " " "
- " " " " " 65° " " "
- Compositional banding at 55° to core axis; prob. retrogressive banding
- " " " 50° " " " ; probably $S_0 S_1$
- " " " 70° " " " ; partly mylonitic.
- " " " 55° " " " ; probably S_0/S_1
- Retrogressive compositional banding at 70° to core axis.
- " " " " 80° " " "
- Compositional banding, perhaps S_0/S_1 at 70° " " "
- " " " " 70° " " "
- Tremolite schistosity in nephrite, probably S_4, at 75° to core axis.

FIG. 9

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 15
LOG OF DIAMOND DRILLHOLE 14

COMPILED D.F.
DRAWN M. B.
DATE Oct '85
CHECKED
1·3·88
SCALE As shown
PLAN NUMBER 88-77

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

MINERAL RESOURCES BRANCH

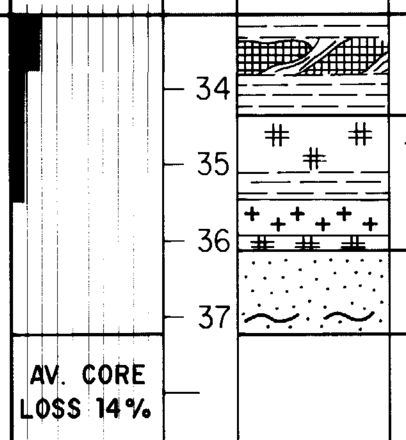
HOLE No. DDH 14 (cont.)
Page 2 of 2

PROJECT COWELL JADE
OUTCROP 15
LOCATION 6231
HUNDRED MINBRIE SECTION 116

ELEVATION
INCLINATION 45°
AZIMUTH 108° m
DEPTH 37·15m
DATUM

DRILLER D.E. White
COMMENCED 17·5·83
COMPLETED 25·5·83
LOGGED D. Flint, E. Dubowski

UNIT / STATE No. 611 / 83
DOCKET NUMBER 355 / 75
PLAN REFERENCE 83 – 40 & 88-83
DRAWING No.



CORE SIZE	CORE LOSS (%) 0 50 100	DEPTH (m)	GRAPHIC LOG	LITHOLOGICAL DESCRIPTION	DEPTH (m)	GRAPHIC LOG	PETROGRAPHIC SAMPLE RS No.	PETROGRAPHIC SAMPLE Depth	ASSAY SAMPLE RS No. from	ASSAY SAMPLE RS No.	ASSAY SAMPLE RS No. to	STRUCTURES
				DIOPSIDE : Mostly massive, fine-grained, pale greenish grey and brownish grey diopside or ? zoisite. Irregularly fractured and chloritised. Alteration includes dark green, fine gr. tremolite bands up to 50 mm wide. Foliated mylonitic & altered in lower sections with stringers containing pink clinozoisite.			184	33·20	33·0	184	33·25	Mylonitic foliation, Sm, at 60° to core axis.
		34			34		185	34·04	34·00	185	34·15	" " " " 50° " " "
		35 36		*ALTERED GRANITE : Highly altered and dominantly a dark greenish grey to greyish black. Often mylonitised (RS 186) with quartz, microcline and plagioclase relicts forming elongate stringers in a foliated matrix containing biotite, two forms of chlorite and epidote. Massive, intact pinky-red K-feldspar and quartz vein from 35·56 – 36·07 m.*	35 36		186	35·30	35·26	186	35·36	
		37		*QUARTZITE : Pale pinkish-red, fine-grained quartzite with minor sericite defining a poorly-developed gneissosity. Brittle fractured with cross-cutting veins of epidote.*	37		187	36·51	36·42	187	36·54	
	AV. CORE LOSS 14%			*END OF HOLE 37·15 m.*								

COMMENTS.

1. *Significantly more Diopside and Dolomitic Marble are present in the drill core than was anticipated from outcrops.*
2. *Mylonitisation leads to additional retrogression of all phases but particularly of diopside.*
3. *Pre-drilling prediction of location of jade lens in drill core corresponds to 20-24 m.*
4. *Unlike DDH 15 & 16, an S_4 tremolite or chloritic schistosity is largely absent. Only exception is in the band of jade and nephritic tremolite at 31·8 m.*
5. *Note unusual Mg-rich phases within nephrite – see petrography of RS 182.*

FIG. 10

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED D.F.	WR 1·3·88 C.D.O. DATE
COWELL JADE	DRAWN M. B.	SCALE As shown
OUTCROP 15 LOG OF DIAMOND DRILLHOLE 14	DATE Oct '85 CHECKED	PLAN NUMBER 88 - 78

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

MINERAL RESOURCES BRANCH

HOLE No. DDH 17

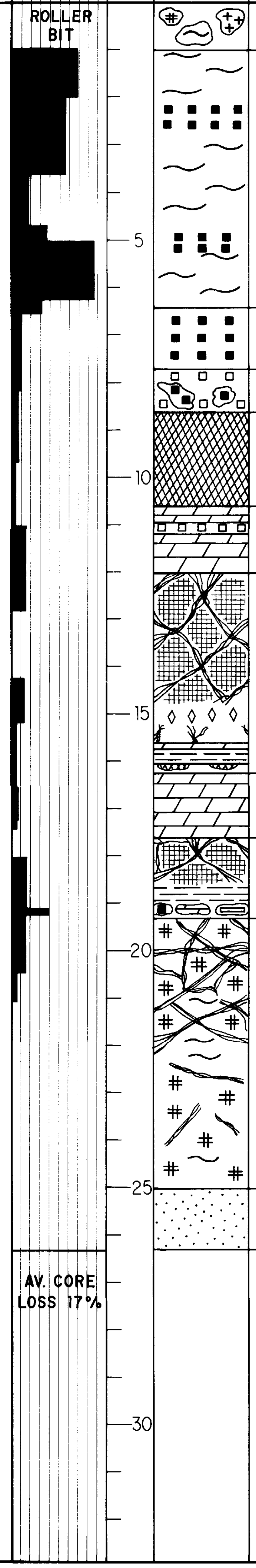
PROJECT COWELL JADE
OUTCROP 15
LOCATION 6231
HUNDRED MINBRIE SECTION 116

ELEVATION 40° DATUM
INCLINATION 40°
AZIMUTH 060°m
DEPTH 26·3m

DRILLER D. E. White
COMMENCED 2·7·83
COMPLETED 12·7·83
LOGGED D. Flint

UNIT / STATE No. 601/84
DOCKET NUMBER 355/75
PLAN REFERENCE 83-40 & 88-83
DRAWING No.

CORE SIZE | CORE LOSS (%) 0 50 100 | DEPTH (m) | GRAPHIC LOG | LITHOLOGICAL DESCRIPTION | DEPTH (m) | GRAPHIC LOG | PETROGRAPHIC SAMPLE | ASSAY SAMPLE | STRUCTURES



ALLUVIUM:

GNEISS: Quartz & feldspar + biotite gneiss with abundant bands of chlorite ± tremolite parallel to gneissic banding. Core fragmented and weathered with poor core recovery.
Dark green massive chloritic bands at 2·2 - 2·75m (with tremolite)
3·35 - 4·0 "
4·65 - 4·75 "
4·80 - 5·0 "

CHLORITE: Massive, fine to medium grained, dark green, chlorite rock with 1-2% light fawn, disseminated porphyroblasts of sphene to 1mm across.

TREMOLITE & CHLORITE: Massive tremolite at the top with clusters of radial tremolite to 3mm across. At the base, consists of fine-grained dark green chloritic and chloritised amphibole aggregates and bands which are fragmented and enclosed in weakly-schistose p.green trem. matrix.

JADE & NEPHRITIC TREMOLITE: Varies from medium grey-green to dark green. Porphyroblasts of 1-2mm are abundant, ranging up to 20% and consisting of cummingtonite?, anthophyllite?, chlorite & chloritised amphibole. Porphyroblasts concentrated in bands 3-8mm which define ptygmatic folds. Lower 20-30cm consists of nephritic tremolite.

DOLOMITIC MARBLE: Mostly a banded & mottled mid-green and grey dolomitic marble. Grey and fine-grained near jade contact; coarse-grained tremolite from 10·83 - 11·10m. Mauve epidote or clinozoisite from 11·63 - 11·72 m.

DIOPSIDE: Partially-retrogressed, massive, coarse-grained diopside rocks with white diopside crystals to 15mm. Dark green bands of retrogression are to 10-15mm thick and consist of tremolite, chlorite, epidote and dolomite. Diopside abundance > 90%. Epidote-rich retrogressive band at 14·8 - 15·2 m.
Brittle fracturing of diopside present with long deformation bands less than 0·5m wide containing granulated diopside, fine-grained calcite and dolomite, yellowish epidote and ? serpentine.
Mylonitised at 15·75 - 16·05m with retrogression to white nephritic tremolite schist with relict augen of diopside and dark-green chlorite.

DOLOMITIC MARBLE: Predominantly fine-grained, mid-green marble but also includes banded green and grey marble, as well as pseudo-breccia texture with green (chloritic/serpentiferous) dolomitic marble clasts in a fine-grained dolomite-rich matrix.

DIOPSIDE: Massive at the top but brecciated and veined, with retrogressive bands consisting dominantly of tremolite & chlorite. Middle zone 'speckled' with retrogressive assemblages of tremolite and epidote; tremolite dark green, translucent and appears 'nephritic' but is too coarse gr. Retrogressive assemblages mylonitised and fragmented at the base.

GRANITE: White to off-white microcline-rich intrusive with ~ 70% feldspar; primary grain size 2-3mm. Early phase contamination and alteration produced about 20% yellow-green epidote. Late stage fracturing and alteration, particularly in upper section, produced dark green chlorite and minute acicular ? actinolite.
Relict quartz & feldspar + biotite gneissic banding at:
21·3 m.
22·0 — 22·4 m.
22·9 m.
24·3 — 24·8 m.

QUARTZITE: Fine-grained and massive with disseminated sericite 'spots' < 1mm across. Gradational into unit above.

26·3m. END OF HOLE.

COMMENTS.
1. Jade of surface outcrop intersected at 8·62 - 10·65 m.
2. Diopside and marble more abundant in drill core than suggested by outcrop.
3. Mylonite zones are essentially tremolite schist from retrograded diopside.
4. Quartzite is interpreted as possible Warrow Quartzite.

PETROGRAPHIC SAMPLE

Depth	RS No.
151	6·72
152	7·86
153	8·34
154	8·69
155	9·05
156	10·52
157	10·69
158	12·25
159	14·61
160	15·89
161	16·07
162	17·68
163	18·20
164	18·95
165	20·05

ASSAY SAMPLE
RS No.
from to

STRUCTURES

- S1/S2 gneissic banding at 42° to core axis.
- S1/S2 gneissic banding at 45° to core axis.
- " " " " 32° " " "
- S1/S2? gneissic banding at 40° to core axis.
- " " " " 40° " " "
- " " " " 42° " " "
- Sm mylonitic foliation at 65° " " "
- S1/S2 banding at 42° to core axis.

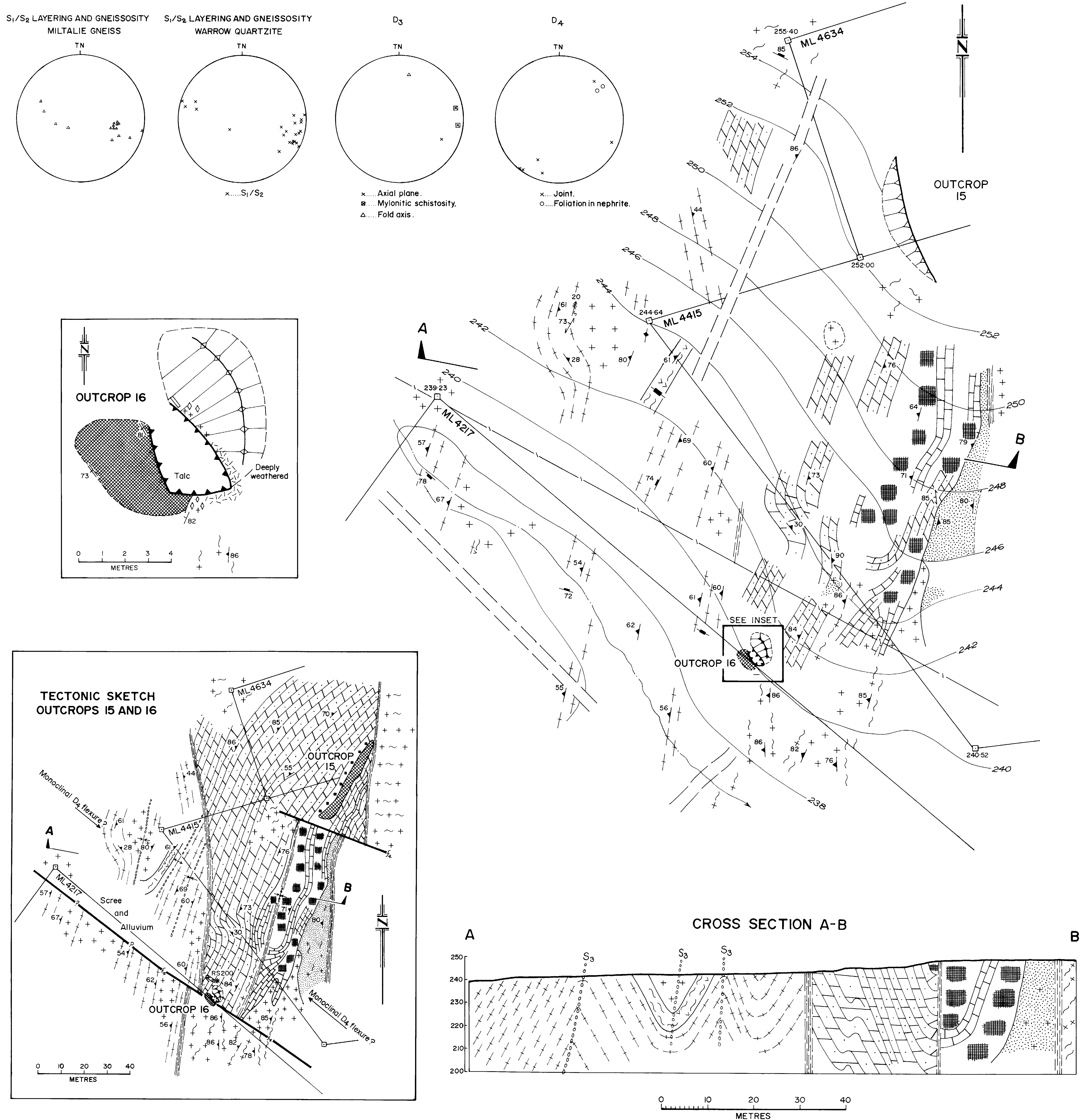
FIG. 11

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 15
LOG OF DIAMOND DRILLHOLE 17

COMPILED D.F.
WC 1·3·88 DATE
DRAWN M. B.
SCALE As shown
DATE Oct '85
CHECKED
PLAN NUMBER 88-81

3917



▩	NEPHRITE AND SEMI-NEPHRITE.
◇	CLINOZOISITE: As alteration product of feldspar in pegmatites; exposed in backhoe pit at outcrop 16.
▤	MYLONITE: Probably syn-D_3.
+	PEGMATITE.
+ ~	MIGMATITE.
⋯	QUARTZITE: Grades from massive, flaggy to locally gneissic and migmatitic.
▦	DIOPSIDE: Massive, coarse grained, off-white. Often as mono-minerallic rock but partially retrogressed to tremolite and chlorite.
▭	DOLOMITIC MARBLE.
▱	BANDED CALC-SILICATE GNEISS: Often quartz-rich with epidotic quartzite bands. Grades to quartzofeldspar gneiss, in part migmatitic. Calc-silicate bands of diopside, hornblende and retrogressive equivalents are minor but diagnostic.
v ~	HORNBLENDE GNEISS.
+	PEGMATITE: Not differentiated from Kimban Orogeny pegmatite.
+−	GRANODIORITE GNEISS: Grey to pink, thinly banded but uniform. Possible equivalent to Plug Range.

EARLY PROTEROZOIC
KIMBAN OROGENY
LINCOLN COMPLEX
WARROW QUARTZITE
Basal Banded Calc-silicate Gneiss
ARCHAEAN
MILTALIE GNEISS

Geological boundary – mapped.
Geological boundary – approximate.
Geological boundary – inferred.
Fault (D_4) – mapped. f4
Fault (D_4) – inferred. ? f4
74 Gneissic layering S_1/S_2; dip and strike.
73 D_3 axial plane; strike and dip.
S ⟶ 20 D_3 fold axis; plunge and trend with vergence.
D_3 fold hinge (synformal).
80 D_4 joint; dip and strike.
80 D_4 foliation; dip and strike.
Mineral Lease.
△ 243·06 Survey station with spot height.
250 Topographic contour; 2m interval.
✳ RS200 Sample locality and number; prefixed by 6231 (see TECTONIC SKETCH)
Backhoe pit.
Dump.
Creek.
A B Cross Section.

Theodolite and EDM survey by P.P. Crettenden, A.J. Smith and M.W. Flintoft; SFB 680, 682 & 815.
Geology by D.J. Flint, E.A. Dubowski, W. Simandjuntak, A. Sulaeman and S. Atmanwinata.
Datum - approximate AHD, 252·00 m at S-SW corner post ML 4634.
NOTE: Only one lease peg for ML 4217 was surveyed. Lease orientation is as shown on SADME Plans 76-263 and 76-264.

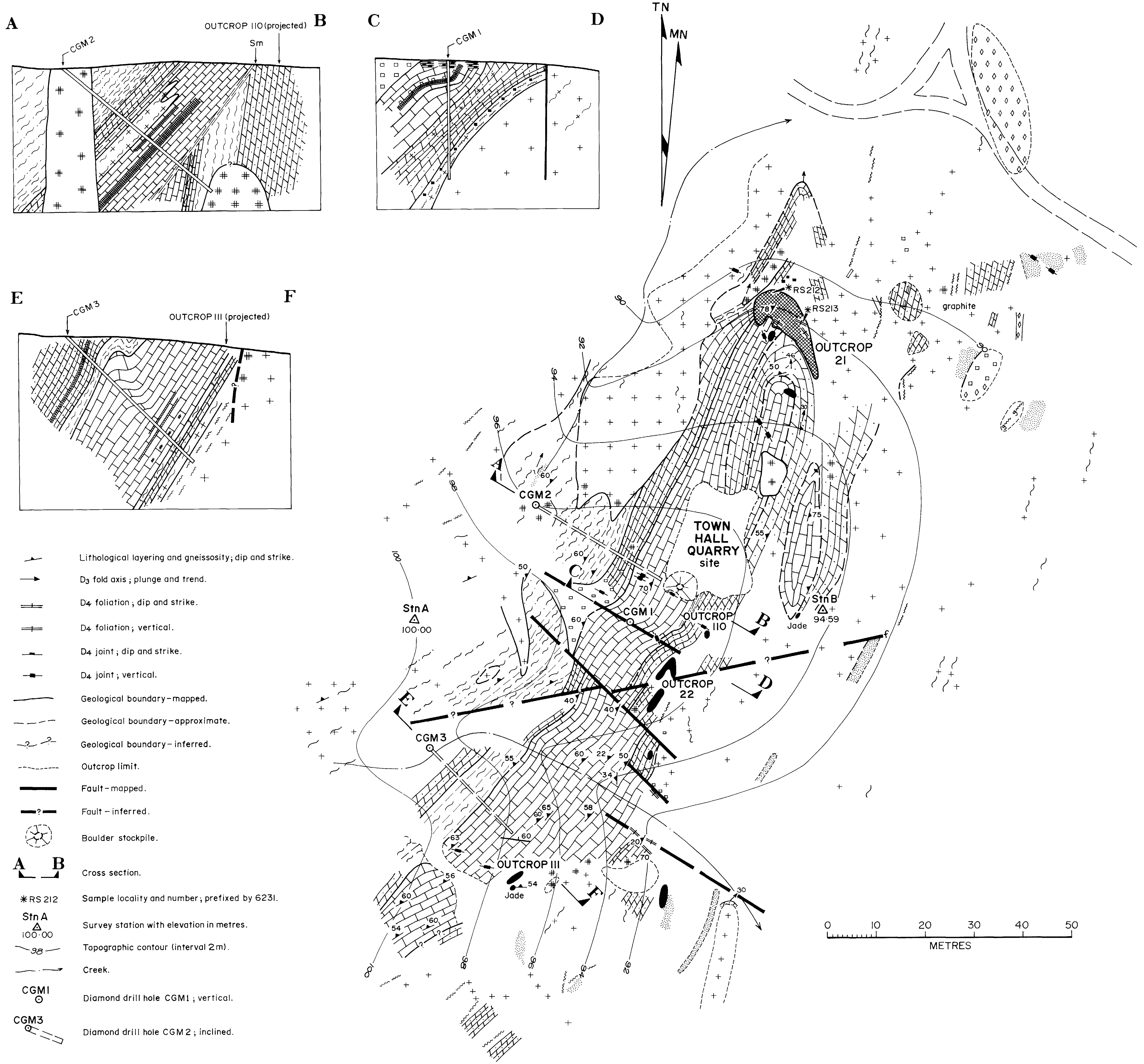
FIG. 12

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

COWELL JADE
OUTCROP 16

GEOLOGICAL PLAN AND STEREOGRAPHIC PROJECTIONS

	COMPILED D.J. Flint	DRN J.W.	SCALE 1:500	PLAN NUMBER
DIRECTOR GENERAL		CKD	DATE May '89	89-271



Lithological layering and gneissosity; dip and strike.

D3 fold axis; plunge and trend.

D4 foliation; dip and strike.

D4 foliation; vertical.

D4 joint; dip and strike.

D4 joint; vertical.

Geological boundary-mapped.

Geological boundary-approximate.

Geological boundary-inferred.

Outcrop limit.

Fault-mapped.

Fault-inferred.

Boulder stockpile.

A B Cross section.

✳RS 212 Sample locality and number; prefixed by 6231.

Stn A △ 100·00 Survey station with elevation in metres.

98 Topographic contour (interval 2 m).

Creek.

CGM1 Diamond drill hole CGM1; vertical.

CGM3 Diamond drill hole CGM 2; inclined.

QUATERNARY

CALCRETE : Cross Section and drill logs only. Fragmentary calcrete rubble with minor white, secondary magnesite.

EARLY PROTEROZOIC

KIMBAN OROGENY

CHLORITE : Massive to weakly schistose, fine grained and very dark green. When coarse grained, grades to biotite schist and gneiss. Limonite stains fractures. Banding absent but contains minor feldspar or clinozoisite.

EPIDOTE : Massive, fine grained, dusky yellow green with veins of feldspar or clinozoisite / zoisite.

NEPHRITE and SEMI-NEPHRITE : Massive to foliated with a D_4 schistosity. Relict compositional S_1/S_2 banding in Outcrop 21. Predominantly dark green and with low translucency. Tendancy to be coarse grained and with coarser tremolite prisms occasionally present. Contains relicts of diopside.

MYLONITE

LINCOLN COMPLEX

HYBRID PEGMATITE : Variable texture and grain size depending upon degree of alteration. When fine grained, tends to be comprised of grey quartz and green epidote. When coarse; feldspar is abundant but variably altered to clinozoisite/zoisite which is moderate orange pink, reddish brown or reddish orange. Late-stage fractures lined with tremolite.

GRANITE and PEGMATITE : Grade to leucocratic segregations of migmatite gneiss.

MIGMATITE GNEISS : Inhomogeneous and varying from gneissic granite to layered, migmatite gneiss. Often contains biotite-rich aggregates to 50 mm across, but dominated by coarse-grained quartz and feldspar.

GNEISSIC GRANITE : Grey, homogenous, ? granodiorite, poorly-defined biotitic foliation and with gneissic xenoliths. CGM2 only.

WARROW QUARTZITE

QUARTZITE : Massive, fine grained, in places flaggy and sericitic.

QUARTZ-RICH GNEISS : Fine-grained, poorly-developed gneissic banding, feldspathic and partly altered to clinozoisite / zoisite but migmatitic segregations minor. Grades to quartzite.

?basal Banded Calc-Silicate Gneiss

BANDED GNEISS : Distinctly banded / layered with quartzitic, gneissic and migmatitic bands. Epidote infills fracture. Gradational to quartz-rich gneiss and banded calc-silicate gneiss.

BIOTITE GNEISS : Coarse grained, biotite-rich with only thin (<6 mm) leucocratic bands. Strongly kinked / crenulated during D_3.

BIOTITE SCHIST and CHLORITE SCHIST : Dark green when chloritised but biotite bronze coloured. Leucocratic segregations or bands minor and are fine grained. Grades to biotite gneiss.

GRAPHITE SCHIST : Graphite + quartz schist; grades into quartzite.

BANDED CALC-SILICATE GNEISS : Banded gneiss with bands of quartzite, quartz + biotite gneiss, migmatite gneiss and massive diopside / tremolite. Epidote staining common. Occasional but minor dolomitic marble.

DIOPSIDE : Massive, very coarse grained (often >5mm), off-white to light grey. Invariably fractured and brecciated with fractures lined by dark green to dusky yellow green chlorite or tremolite. Partially retrogressed to NEPHRITE. (CGM 2 and 3).

DOLOMITIC MARBLE : Dominantly coarse grained (2-5mm), light to dark grey, and partly banded. Colour not uniform with irregular mottled colours as well as banding. Dolomitic marble from medium light grey to medium dark grey (N7-N3) and greyish green (10GY5/2) but with serpentinised olive aggregates (eg light olive 10Y5/4, greenish yellow 10Y7/6, dusky yellow green 10GY 3/2, etc), antigorite (eg greyish orange 10YR 7/4 and dark yellowish orange 10YR 6/6) and tremolite. Dark brown weathered surfaces and dolomitic marble is pyritic.

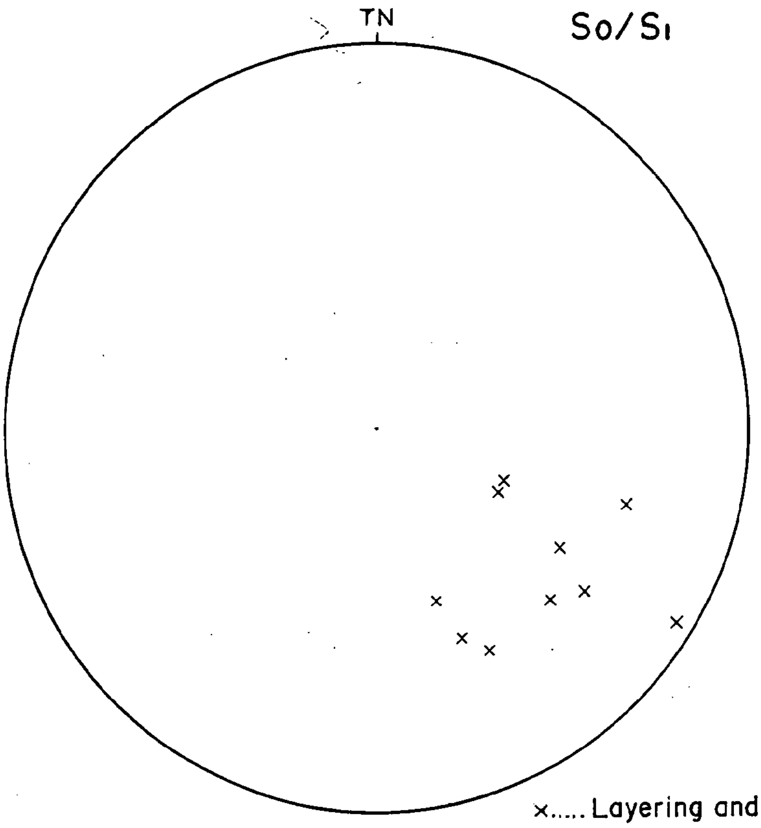
SILLIMANITE GNEISS : Podded sillimanite gneiss but extensively retrograded. Augen-shaped pods of grey sillimanite / sericite to 15 x 3 mm are elongate in a biotite or phlogopite S_2 gneissosity / schistosity.

Geological mapping and compilation by D. J. Flint and D. A. Young.
Stadia survey by A. J. Smith; S.F.B. 196.
Arbitrary datum of 100m at Station A.

FIG. 13

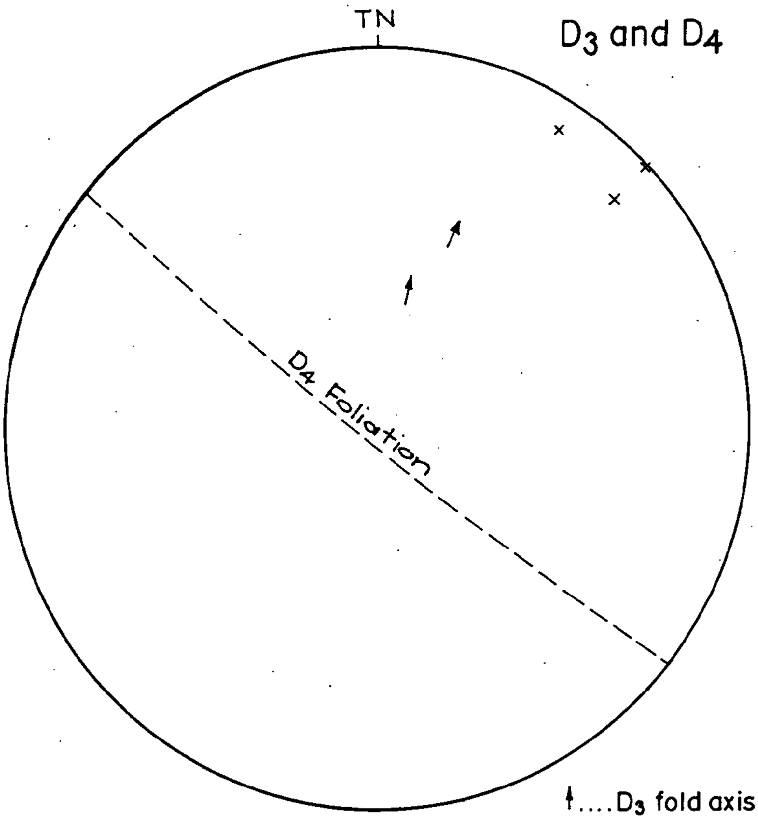
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED D.J. Flint	4·7·91 C.D.O. DATE
COWELL JADE	DRAWN J.W	SCALE 1:500
OUTCROPS 21, 22, 110, 111 AND GREEN MARBLE PROSPECT	DATE	PLAN NUMBER
GEOLOGICAL MAP	CHECKED	88-423

39/7



S_0/S_1

×..... Layering and gneissosity



D_3 and D_4

↑.... D_3 fold axis

×.... D_4 foliation

Wulff nets

FIG.14

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 21, 22, 110, 111
AND GREEN MARBLE PROSPECT

STEREOGRAPHIC PROJECTIONS

COMPILED D. Flint
DRAWN J.W.
DATE 6-9-88
CHECKED
C.D.O. DATE 4.7.91
SCALE
PLAN NUMBER S20215

3917

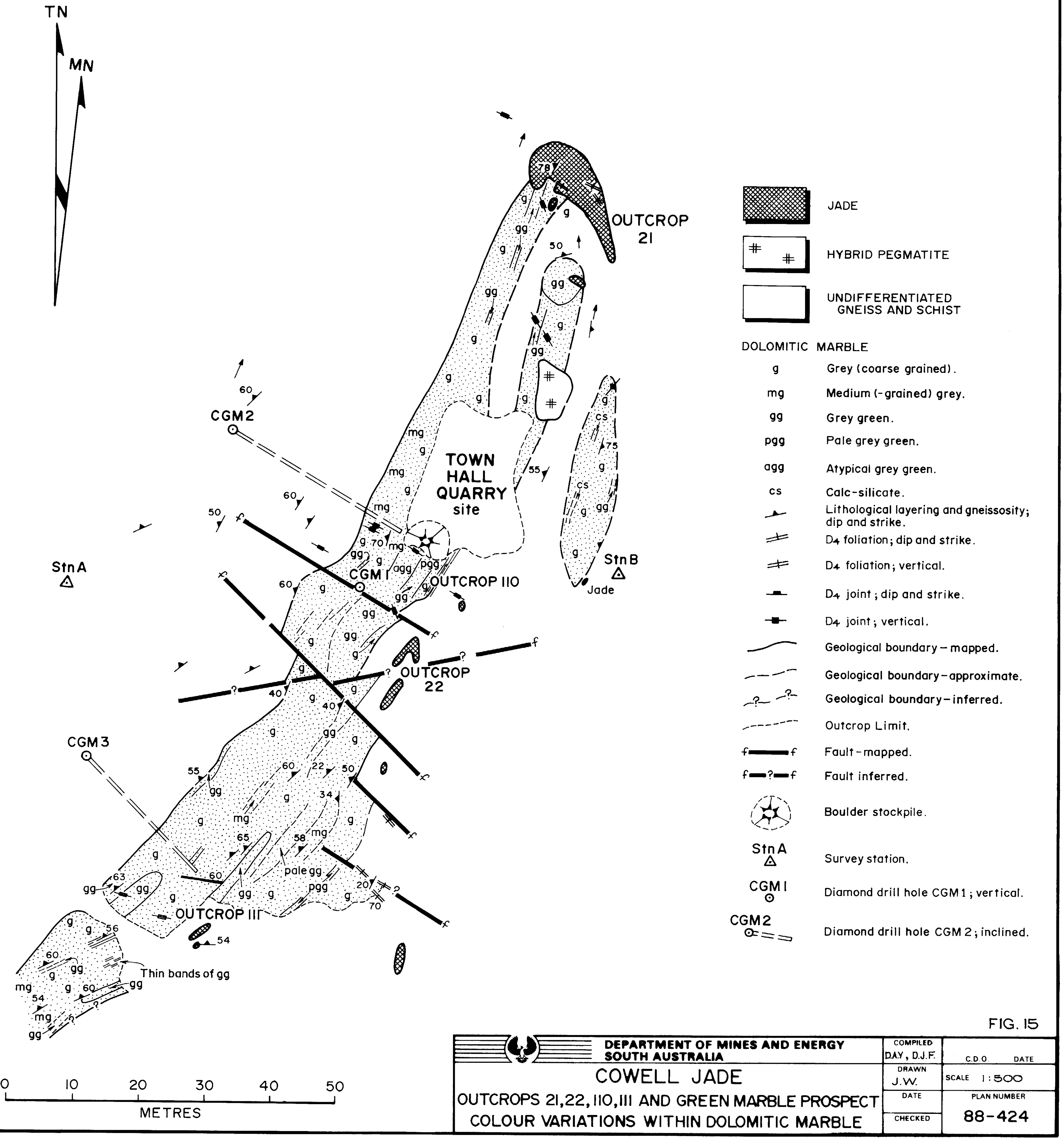


FIG. 15

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

OUTCROPS 21, 22, 110, 111 AND GREEN MARBLE PROSPECT

COLOUR VARIATIONS WITHIN DOLOMITIC MARBLE

COMPILED DAY, D.J.F.	C.D.O. DATE
DRAWN J.W.	SCALE 1:500
DATE	PLAN NUMBER
CHECKED	88-424

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

NON – METALLIC RESOURCES DIVISION

HOLE No CGM 1

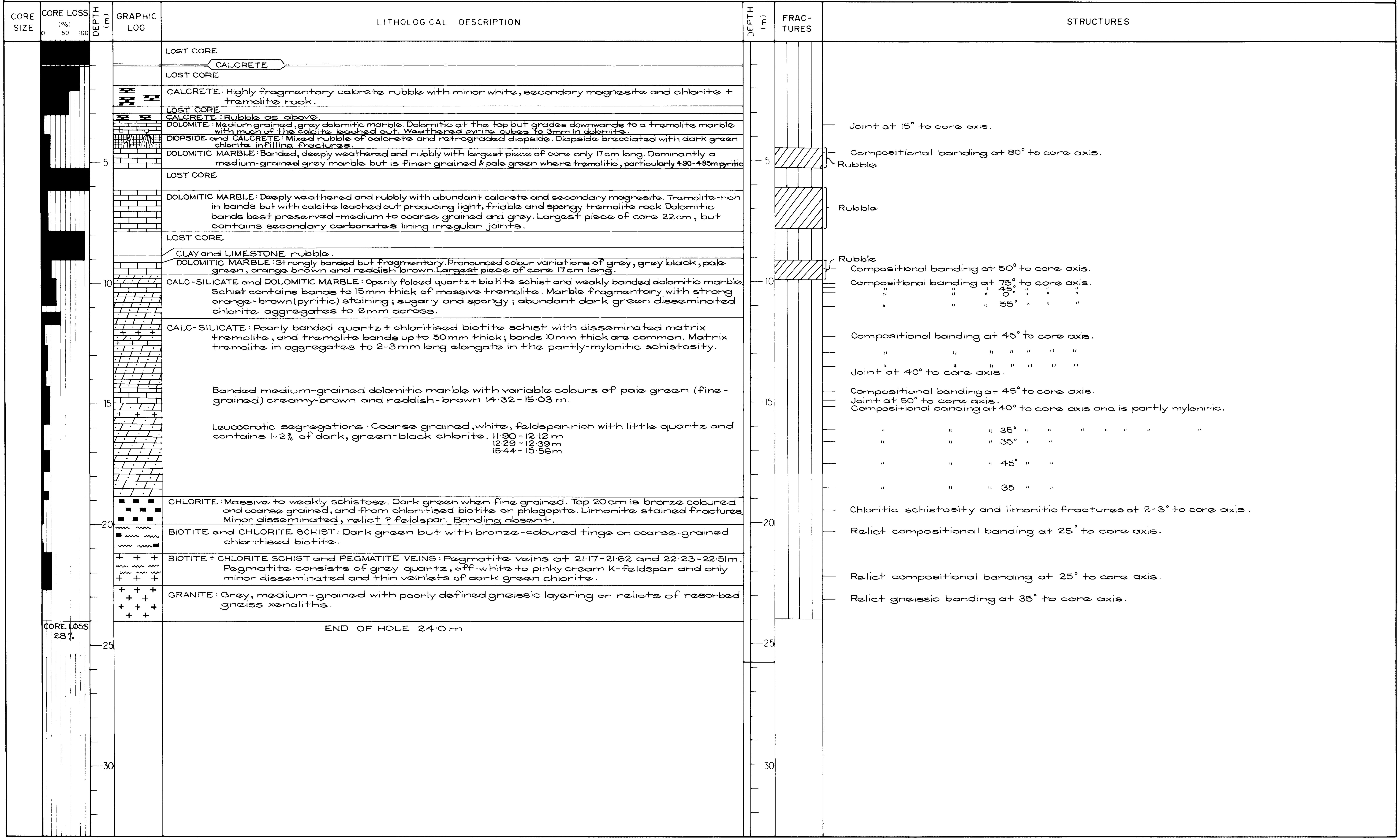
PROJECT COWELL MARBLE
LOCATION 6231
HUNDRED MINBRIE SECTION 123

ELEVATION
INCLINATION 90°
AZIMUTH –
DEPTH 24·00 m

DATUM

DRILLER D.E.WHITE
COMMENCED 27-4-83
COMPLETED 3-5-83
LOGGED D.J.FLINT

UNIT / STATE No 609/83
DOCKET NUMBER 306/82
PLAN REFERENCE 88-423
DRAWING No



LOST CORE

CALCRETE

LOST CORE

CALCRETE: Highly fragmentary calcrete rubble with minor white, secondary magnesite and chlorite + tremolite rock.

LOST CORE

CALCRETE: Rubble as above.

DOLOMITE: Medium grained, grey dolomitic marble. Dolomitic at the top but grades downwards to a tremolite marble with much of the calcite leached out. Weathered pyrite cubes to 3mm in dolomite.

DIOPSIDE and CALCRETE: Mixed rubble of calcrete and retrograded diopside. Diopside brecciated with dark green chlorite infilling fractures.

DOLOMITIC MARBLE: Banded, deeply weathered and rubbly with largest piece of core only 17 cm long. Dominantly a medium-grained grey marble but is finer grained & pale green where tremolitic, particularly 4·90-4·95m pyritic

LOST CORE

DOLOMITIC MARBLE: Deeply weathered and rubbly with abundant calcrete and secondary magnesite. Tremolite-rich in bands but with calcite leached out producing light, friable and spongy tremolite rock. Dolomitic bands best preserved – medium to coarse grained and grey. Largest piece of core 22 cm, but contains secondary carbonates lining irregular joints.

LOST CORE

CLAY and LIMESTONE rubble.

DOLOMITIC MARBLE: Strongly banded but fragmentary. Pronounced colour variations of grey, grey black, pale green, orange brown and reddish brown. Largest piece of core 17 cm long.

CALC-SILICATE and DOLOMITIC MARBLE: Openly folded quartz + biotite schist and weakly banded dolomitic marble. Schist contains bands to 15mm thick of massive tremolite. Marble fragmentary with strong orange-brown (pyritic) staining; sugary and spongy; abundant dark green disseminated chlorite aggregates to 2mm across.

CALC-SILICATE: Poorly banded quartz + chloritised biotite schist with disseminated matrix tremolite, and tremolite bands up to 50 mm thick; bands 10mm thick are common. Matrix tremolite in aggregates to 2-3 mm long elongate in the partly-mylonitic schistosity.

Banded medium-grained dolomitic marble with variable colours of pale green (fine-grained) creamy-brown and reddish-brown 14·32 - 15·03 m.

Leucocratic segregations: Coarse grained, white, feldspar-rich with little quartz and contains 1-2% of dark, green-black chlorite. 11·90 - 12·12 m
12·29 - 12·39 m
15·44 - 15·56 m

CHLORITE: Massive to weakly schistose. Dark green when fine grained. Top 20 cm is bronze coloured and coarse grained, and from chloritised biotite or phlogopite. Limonite stained fractures. Minor disseminated, relict ? feldspar. Banding absent.

BIOTITE and CHLORITE SCHIST: Dark green but with bronze-coloured tinge on coarse-grained chloritised biotite.

BIOTITE + CHLORITE SCHIST and PEGMATITE VEINS: Pegmatite veins at 21·17 - 21·62 and 22·23 - 22·51 m. Pegmatite consists of grey quartz, off-white to pinky cream K-feldspar and only minor disseminated and thin veinlets of dark green chlorite.

GRANITE: Grey, medium-grained with poorly defined gneissic layering or relicts of resorbed gneiss xenoliths.

END OF HOLE 24·0 m

Joint at 15° to core axis.
Compositional banding at 80° to core axis.
Rubble
Rubble
Rubble
Compositional banding at 50° to core axis.
Compositional banding at 75° to core axis.
" " " 45° " " "
" " " 0° " " "
" " " 55° " " "
Compositional banding at 45° to core axis.
" " " " " " "
" " " " " " "
Joint at 40° to core axis.
Compositional banding at 45° to core axis.
Joint at 50° to core axis.
Compositional banding at 40° to core axis and is partly mylonitic.
" " " 35° " " " " " " "
" " " 35° " "
" " " 45° " "
" " " 35 " "
Chloritic schistosity and limonitic fractures at 2-3° to core axis.
Relict compositional banding at 25° to core axis.
Relict compositional banding at 25° to core axis.
Relict gneissic banding at 35° to core axis.

FIG. 16

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
LOG OF DIAMOND DRILL HOLE CGM 1

D.F.
UR 1·3·88

PLAN NUMBER
88-425

3917

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

NON – METALLIC RESOURCES DIVISION

HOLE No. CGM 2

PROJECT COWELL MARBLE
LOCATION 6231
HUNDRED **MINBRIE** SECTION 123

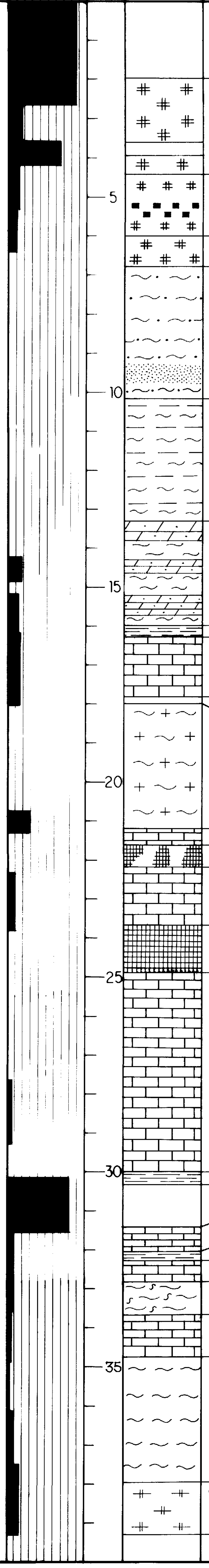
ELEVATION
INCLINATION 40°
AZIMUTH 115 MN
DEPTH 39·30m

DATUM

DRILLER D.E. WHITE
COMMENCED 4-5-83
COMPLETED 13-5-83
LOGGED D.J. FLINT

UNIT / STATE No. 610/83
DOCKET NUMBER 306/82
PLAN REFERENCE 88-423
DRAWING No.

CORE SIZE | CORE LOSS (%) 0 50 100 | DEPTH (m) | GRAPHIC LOG



LITHOLOGICAL DESCRIPTION

LOST CORE

HYBRID GRANITE: Variable grain size and texture depending on degree of alteration. Varies from fine grained and grey-green where quartz and epidote dominate to zones containing very coarse-grained pink K-feldspar. Pink clinozoisite probably partially replaces K-feldspar: colour is mostly moderate orange pink (10 R 7/4) with darker grains moderate reddish brown (10 R 6/6). Core fragmentary; deeply weathered and clay-rich at 3·91 – 4·20 m.

HYBRID GRANITE: Fine grained and dominated by grey quartz and green epidote; coarse-grained feldspar only minor with no pink clinozoisite. Core again highly fragmentary, particularly chloritic band from 5·10 – 5·55 m.

HYBRID GRANITE: Again, dominant feature is bright orange pink or reddish orange clinozoisite (about 10 R 6/4 or 10 R 6/5) replacing feldspar. Fine grained. Irregular, thin <1mm fractures lined with tremolite.

QUARTZ RICH GNEISS: Fine grained, quartz-rich gneiss with only a poorly-developed gneissic banding. Overall, gneiss is partly altered and contains minor pinkish clinozoisite after feldspar at 9·19 – 9·28 m. Leucocratic segregations minor.

Foliated, sericitic quartzite at 9·21 ~ 9·75 m.

BANDED GNEISS: Distinctly banded and with more abundant feldspar than above unit. Quartz and biotite rich and hence a grey-black colour but with a pale green tinge because of epidote infilling irregular fractures and in bands parallel with the gneissic banding.

Distinct large K-feldspar 20 mm long at 12·67 m.

Most abundant epidote at 12·95 – 13·10 m.

BANDED CALC-SILICATE GNEISS: Distinctly banded from:-

(1) Quartz + biotite gneiss bands which are dark grey with a pronounced biotitic gneissosity enclosing minor feldspar-rich augen.

(2) Pale green massive tremolite bands up to 10 cm thick. Disseminated minor epidote.

MYLONITE: Mylonitised calc-silicate of above

DOLOMITIC MARBLE: Fine to medium grained but banded and with highly varying colour. Dominant and largest bands consist of grey (N5-N4) with moderate greenish-yellow (10 Y 7/4) spots or serpentised chlorite; minor yellowish grey (5Y 7/3) and pale green (5G 7/1). Other bands are brown and grey with dominantly greyish orange (10 YR 6/4) with lighter varients 10 YR 8/4 on a grey (N7) background.

LOST CORE and RUBBLE + CLAY: Deeply weathered contact of marble; poor recovery.

MIGMATITE GNEISS: Granitic and possibly intrusive but is inhomogeneous and with diffuse, relict gneissic banding. Strongly recrystallised and probably migmatitic. Variably mixed grey quartz, white K-feldspar with disseminated fine-grained biotite, and biotite-rich aggregates to 50 mm across.

Minor pink clinozoisite after feldspar at 19·45 and 20·90 m.

DOLOMITIC MARBLE: Diffuse banding to 10 mm thick with uneven mottled colours of pale green, greyish orange and grey

DIOPSIDE: Retrograded banded diopside with chloritised biotite or ? phlogopite aggregates.

DOLOMITIC MARBLE: Fragmentary with high variability of colour, texture and composition; calcite abundant. Main zones are tremolite + calcite marble with dendrite. Staining on fractures. Colour predominantly greyish green 10 GY 5/2 and 6/2 with darker bands to 10 GY 4/2 and dusky yellowish green 10 GY 3/2, mixed with lesser pale green 5G 7/2 and grey N7. Includes secondary calcite veins to 30 mm wide.

DIOPSIDE: Extensively fractured with thin hairline cracks lined by dark green chlorite. Numerous aggregates of dark yellowish green chlorite after ? phlogopite. Small bleb of **NEPHRITE** 25 × 5 mm within diopside at 24·8 m.

DOLOMITIC MARBLE: Marble less fragmentary with core lengths to 62 cm. Banded with broad colour zones but colour not uniform; irregularly mottled colours as well as diffuse finer bandings. Broader bands are:-

24·8 – 26·0: Dominantly greyish green 10 GY 5/2 with medium light grey N6 – N5.
26·0 – 27·0: Mixed grey (dominantly N6, some N5 – N4) with moderate greenish yellow 10Y 7/4 to light olive 10Y 5/4.
27·0 – 28·0: Dominantly light grey N6-N7 with orange-brown zones of greyish orange 10 YR 7/4 to darker and more saturated dark yellowish orange 10 YR 6/6.
28·0 – 28·6: Dominantly medium dark grey N4-N3 with lesser spots of serpentine of light olive 10Y 5/4 and 6/4 with minor dark greenish yellow 10Y 7/6.
28·6 – 30·0: Light grey N6 – N7 with strong yellow hues of moderate greenish yellow 10Y 7/4 & 8/4 and greyish orange 10 YR 8/4

MYLONITISED MARBLE with thin calc-silicate bands.

LOST CORE and CLAY.

DOLOMITIC MARBLE: Banded but more distinctly, is spotted with spots and bands ranging in colour from medium grey, dark green, reddish brown and yellow brown. Deeply weathered and rubbly. Dominantly grey.

? MYLONITISED DIOPSIDE: Very fine grained. Off-white stringers 25mm × 2mm in a very fine grained light grey matrix.

DOLOMITIC MARBLE: Spotting, as above. Dominantly medium grey of N4-N5 but ranging N3 - N7, with spotting of light brown 5YR 5/6 ? antigorite and dusky yellowish green 10GY 3/2 chlorite ranging to paler yellowish green 10GY 7/2

SILLIMANITE GNEISS: Abundant grey aggregates of 15 × 3mm elongate in a biotite schistosity; probable retrograde sillimanite but now very fine-grained sericite. Not banded.

DOLOMITIC MARBLE: Colour banding with additional colour variations across compositional banding. Colours range from light grey N7-N6, light brown 5YR 5/6, pale yellowish orange 10YR 8/6 and 7/6 and greyish yellow green 5GY 7/2. Mostly weathered, rubbly or fractured.

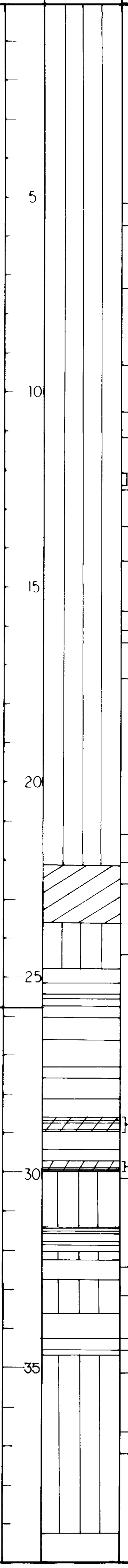
BIOTITE GNEISS: with thin, fine grained leucocratic zones up to only 6 mm thick. Strongly crenulated, mylonitised and grading to calc-silicate with tremolite bands at 37·0 – 37·42 m.

Crenulating and mylonitic phase appears to be same – D3 ?.

GNEISSIC GRANITE: Very coarse grained with a poorly-defined biotitic foliation, and with relict gneiss xenoliths or bands. Highly fragmented rubbly core.

END OF HOLE 39·30 m

DEPTH (m) | FRACTURES



STRUCTURES

Close-spaced jointing parallel to core axis.
Gneissosity at 65° to core axis.
Gneissosity at 75° to core axis.
Gneissosity at 85° to core axis.
Gneissosity at 80° to core axis.
D4 joint parallel with core axis.
Gneissosity at 75° to core axis.
Gneissic banding at 85° to core axis.
Gneissic banding at 80° to core axis.
Gneissic banding at 75° to core axis.
Mylonitic schistosity at 85° to core axis.
Compositional banding at 85° to core axis.
Compositional banding at 80° to core axis.
Compositional banding at 90° to core axis.
Compositional banding at 90° to core axis.
Joint at 45° to core axis
Fragmentary; largest piece of core 27 cm long only.
Fine-grained diopside bands at 75° to core axis
Fracture/joint at 80° to core axis.
" " " " " " "
" " " " " " "
" " " 30° " " "
" " " 65° " " "
" " " 35° " " "
" " " 25° " " "
" " " 35° " " "
" " " 80° " " "
Rubble.
Fracture/joint at 70° to core axis.
Rubble.
Relict calc-silicate compositional banding at 55° to core axis.
Fracture/joints at 50° and 30° to core axis.
Fracture/joints at 50° to core axis.
Compositional banding at 60° to core axis.
Biotite schistosity at 60° to core axis.
Fracture parallel to compositional banding and at 65° to core axis.
Thin closed joint at 20° to core axis; core intact.
Gneissic banding at 60° to core axis.
Gneissic banding at 40° to core axis.
D3 crenulations and mylonitic schistosity at 45° to core axis.

NOTE: 1. **Nephritic** segregations in dolomitic marble at 16·75 – 16·95 m. Nephrite is dusky yellowish green, around 10 GY 3/3, weakly translucent and has an unaltered core of off-white diopside or Fe-free epidote or zoisite. Nephritic zone is 15 cm long and 2 cm wide. Surrounding marble is tremolitic, fine-grained and pale green ie. 5G 8/1 and 8/2 with darker variants to 10 GY 5/1.

2. Thin band, 4 mm thick of impure **nephrite** at 17·00 m. Again, contains diopside or epidote/zoisite.

3. **Nephrite** segregation as retrogression of diopside at 24·8 m. Nephrite dusky yellowish green 10 GY 3/2 and 25 × 5 mm.

FIG. 17

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

LOG OF DIAMOND DRILL HOLE CGM 2

COMPILED D. Flint	4.7.91 C.D.O. DATE
DRAWN J.W.	SCALE
DATE	PLAN NUMBER 88-426
CHECKED	

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

NON – METALLIC RESOURCES DIVISION

HOLE No. CGM 3

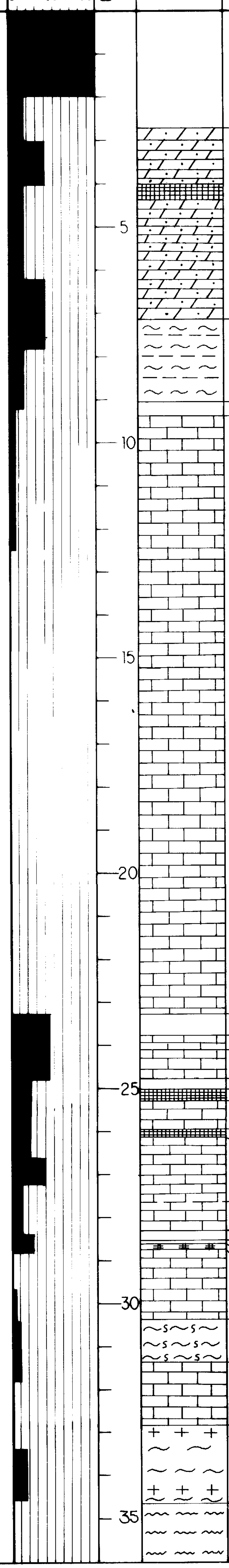
PROJECT COWELL MARBLE
LOCATION 6231
HUNDRED MINBRIE SECTION 123

ELEVATION
DATUM
INCLINATION 45°
AZIMUTH 131° MN
DEPTH 36·00m

DRILLER D. E. WHITE
COMMENCED 14-6-83
COMPLETED 23-6-83
LOGGED D.J. FLINT

UNIT / STATE No. 614/83
DOCKET NUMBER 306/82
PLAN REFERENCE
DRAWING No. 88-423

CORE SIZE | CORE LOSS (%) | DEPTH (m) | GRAPHIC LOG | LITHOLOGICAL DESCRIPTION | DEPTH (m) | FRACTURES | STRUCTURES



LITHOLOGICAL DESCRIPTION

LOST CORE : 0-2·0m Roller bit used.

BANDED CALC-SILICATE : Poor core recovery with rubbly core and several clay zones. Mostly banded calc-silicate with quartz-rich and tremolite-rich bands. Massive diopside band at 4·0 -4·3m, which is partly retrogressed to **NEPHRITE**

BANDED GNEISS : Thinly banded and quartz rich, but overall is quartz + biotite + feldspar with dark grey-black colour. White leucocratic bands minor. Open folds in gneissosity at 8·3-8·8m. Deeply weathered zones with clay (after calc-silicates) at 7·27-7·37m, 8·72-9·0m, 9·06-9·29m.

LOST CORE.

DOLOMITIC MARBLE : Banding with variable colouring due to banding as well as irregular mottling and yellow-green spotting from disseminated serpentine, chlorite and tremolite aggregates. Overall, dominant colour is medium light grey N6 but ranging from N7 to N4, with varying percentages of light olive 10Y 5/4 and dusky yellow green 5GY 5/2 serpentine-rich areas. whereas chloritic zones are greyish olive green 5GY 3/2 and dusky yellowish green 10GY 3/2. Paler shades are 10Y 6/3 and 10Y 7/3.

Moderate yellowish green 10GY 5/3 bands are fine grained but rare; at :- 11·47-11·54 m, 20·83-21·13m, 22·0-22·07m, 22·73-22·81m. Each of those zones are banded and not of uniform colour. Marble is fresh and massive with very few joints.

10·35-10·70m : Mixed colours with pale olive 10Y 6/2 serpentiferous spots dominating over the medium dark grey N4 background. Strongly spotted with only diffuse banding.

10·70-11·03m : Dominated by medium dark grey N4, possibly N3 with serpentine and/or chlorite of moderate yellowish green 10GY 5/3 and greyish green 5G 5/2.

11·45-11·90m : Browner zones within marble are of ? antigorite and are light brown 5YR 5/5

16·68-16·74m : Browner zones within marble are of ? antigorite and are moderate yellowish brown 10YR 5/4.

20·65-22·84 : Banding more diffuse and spotting of chlorite is dominant. Grey background is medium light grey N6, with some N5 and N7 with spots of pale green 5G 6/2. chlorite and carbonate approximately of equal abundance.

LOST CORE

DOLOMITIC MARBLE : Rubbly and deeply weathered.

DOLOMITIC MARBLE : As for large zone above with colour mottling of light grey, brown and yellow green. Jointed and rubbly.

LOST CORE

DIOPSIDE : White, coarse-grained and brecciated with infillings of dusky green chlorite.

DOLOMITIC MARBLE : Medium grained and banded; minor augen-like bands. Dominantly greyish green 10GY 5/2 and dusky yellow green 5GY 5/2, lesser N5-N4 and yellowish brown 10YR 6/4 bands to 35 mm thick.

DIOPSIDE

DOLOMITIC MARBLE : Deeply weathered, rubbly and with calcreted clay zones.

DOLOMITIC MARBLE : Medium grained and banded; Dominantly light grey N7-N6 with yellowish grey 5Y 7/2 and darker yellowish brown 10YR 6/4 and 5Y 5/6 ? antigorite. Green chlorite only very minor.

CLAY and RUBBLE.

CLINOZOISITE : Fine grained, pale pink, diffuse alignment, not banded.

HYBRID GRANITE : Deeply weathered and rubbly but with pale orange-pink clinozoisite after feldspar.

DOLOMITIC MARBLE : Medium grained. Dominantly medium dark grey N4 with pronounced spotting of chlorite of dusky green 5G 4/2 and 4/3. Banding subordinate to spotting. Minor zoisite and phlogopitic bands.

SILLIMANITE GNEISS : Fine grained grey sericite in aggregates to 10mm long elongate in a biotitic or phlogopitic schistosity. Sericite possibly after sillimanite. Identical with sericite gneiss in CGM2 at 33m. White coarse-grained quartz + feldspar segregations 5cm thick at 30·47 and 30·73m.

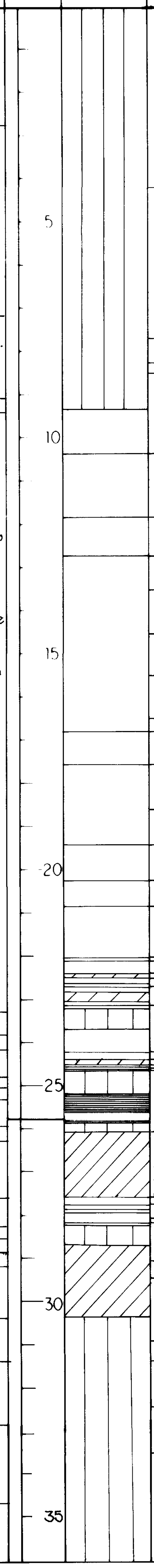
CALC-SILICATE : Mixed calc-silicate unit with bands of widely variation composition ie :-
- impure dolomitic marble (minor).
- banded quartz + biotite rich calc-silicate with pink clinozoisite.
- tremolite and epidote rich bands.

BIOTITE GNEISS : With leucocratic segregations which are probably migmatitic segregations ie at 32·87-33·33m and 34·19-34·68m.

CHLORITE SCHIST : Consists of coarse mica flakes of chloritised biotite or phlogopite. Compositional banding absent but contains 2-3% disseminated white feldspar or colourless zoisite / clinozoisite; these aggregates to only 3mm across.

END OF HOLE 36·0 m

CORE LOSS 18%



STRUCTURES

So compositional banding at 55° to core axis.
Gneissic banding at 80° to core axis.
Gneissic banding at 70° to core axis.
Open D3 folds in gneissosity.
Joint at 30° to core axis.
Joint at 60° to core axis.
Joint at 60° to core axis.
Compositional banding at 90° to core axis.
Compositional banding at 90° to core axis.
Compositional banding at 90° to core axis.
Compositional banding at 85° to core axis.
Joint at 60° to core axis.
Joint at 35° to core axis.
Compositional banding at 85° to core axis.
Joint at 5° to core axis.
Joint at 50° to core axis.
Joint at 40° to core axis.
Joints at 45° to core axis.
Rubble.
Compositional banding at 85° to core axis and two limonitic joints at 65° to core axis.
Rubble.
Calcite and calcrete in open joint at 3° to core axis.
Calcite joints at 60° and 50° to core axis, and compositional banding at 65° to core axis.
Rubble joints.
Close-spaced fractures at 80° to core axis which are parallel with compositional banding.
Rubble.
Joint parallel with core axis as well as a cross-fracture.
Compositional banding at 80° to core axis.
Joint at 45° to core axis.
Compositional banding at 75° to core axis.
Compositional banding at 75° to core axis.
Rubble with numerous fractures - both parallel with and at high angles to the core axis.
Gneissic banding at 90° to core axis.
Compositional banding (primary or secondary ?) at 80° to core axis.
Compositional banding (primary or secondary ?) at 80° to core axis.
Gneissosity at 75° to core axis.

✱ NOTE

1. **Nephrite** band 25 mm thick at 4·2m. Forms from retrogression of diopside; incomplete retrogression produces a speckled appearance of relict, white diopsiode and dusky green nephrite.

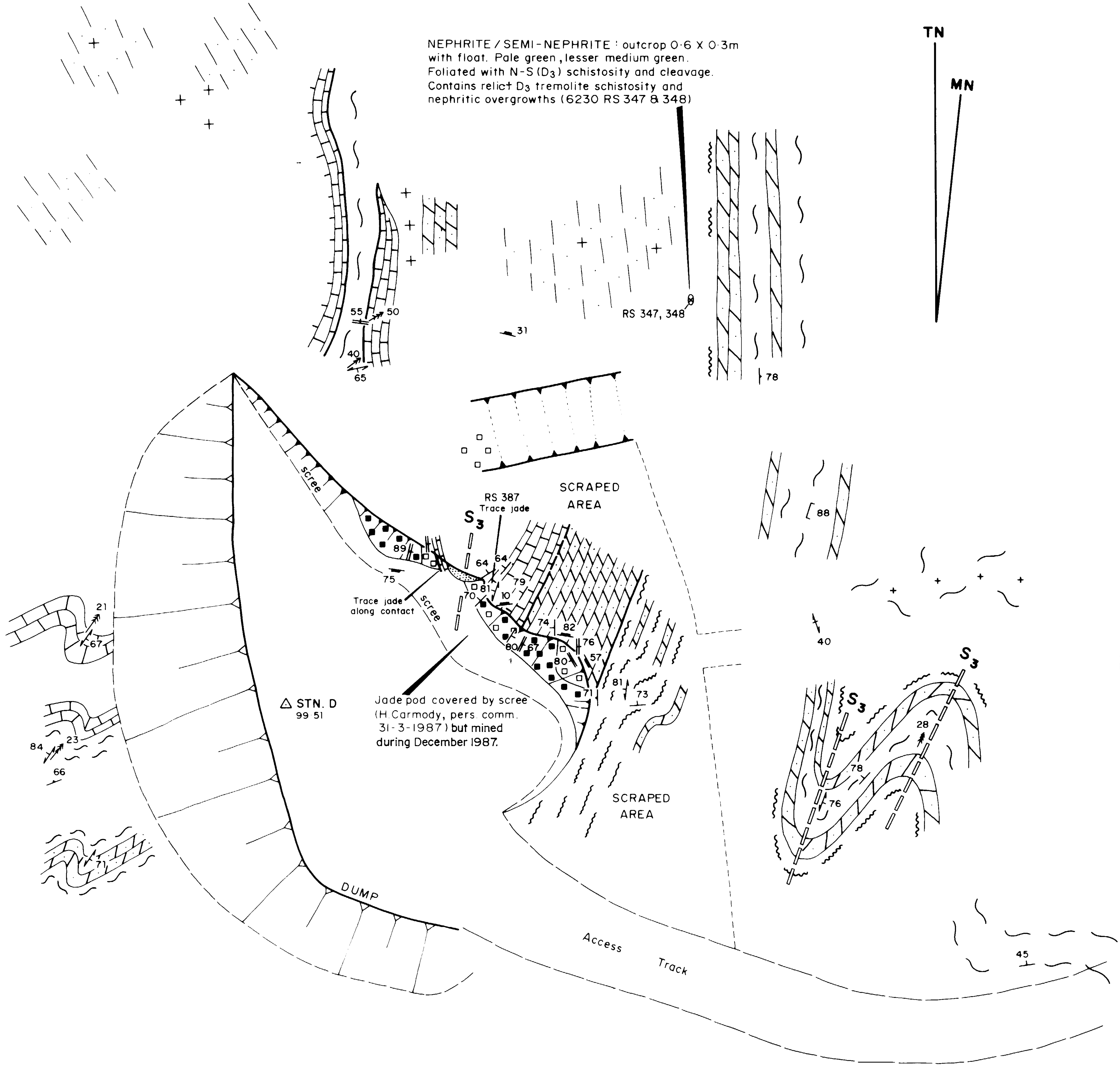
FIG. 18

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

LOG OF DIAMOND DRILL HOLE CGM 3

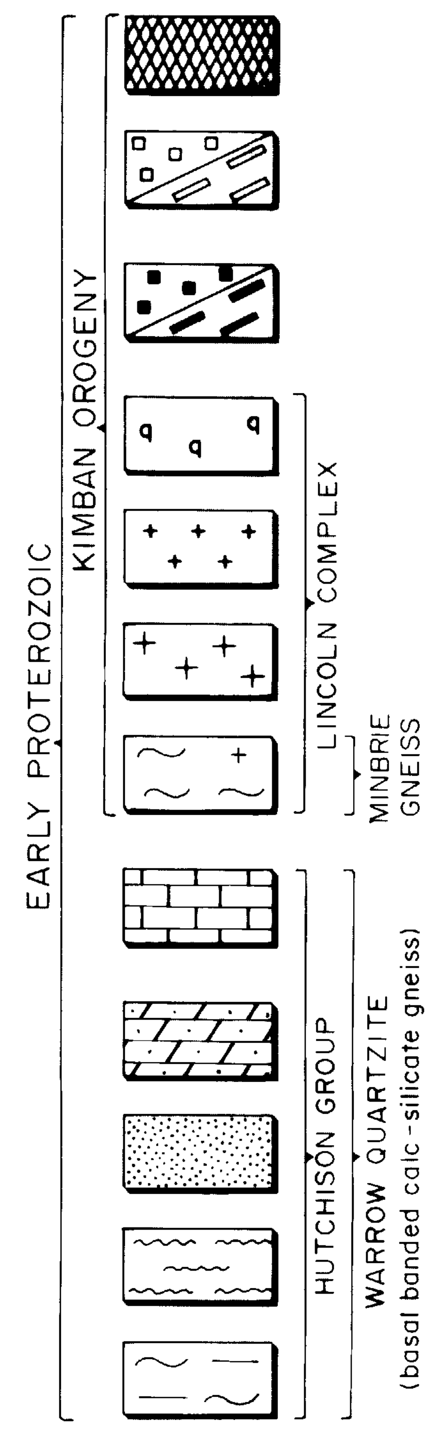
COMPILED D. Flint
C.D.O. B 4·7·91 DATE
DRAWN J.W.
SCALE
DATE 6-9-88
CHECKED
PLAN NUMBER 88-427



NEPHRITE / SEMI-NEPHRITE : outcrop 0·6 X 0·3m with float. Pale green, lesser medium green. Foliated with N-S (D_3) schistosity and cleavage. Contains relict D_3 tremolite schistosity and nephritic overgrowths (6230 RS 347 & 348)

Jade pod covered by scree (H Carmody, pers. comm. 31-3-1987) but mined during December 1987.

LEGEND



NEPHRITE and NEPHRITIC TREMOLITE : variable colour from rare, moderately translucent yellow to yellow green nephrite to more typical opaque or only weakly translucent varieties of dark yellow green, green and grey green.

TREMOLITE : fine-grained, pale green to grey green, milky opaque, massive to weakly foliated tremolite. Grades to coarser grained masses which are either schistose or felted. Finer grained varieties grade into nephritic tremolite and nephrite.

CHLORITE : dark green to greenish black with both massive and schistose varieties. Paler green fine-grained tremolite often present. Forms large alteration masses in proximity to nephrite, occasionally with diffuse ?original compositional banding.

QUARTZ VEIN : white to off-white and massive.

APLITE and GRANITE : as sills, dykes and as segregations in migmatite gneiss into which they grade.

PEGMATITE : massive coarse-grained segregations and intrusions of quartz, feldspar and biotite.

MIGMATITE GNEISS : massive to poorly banded quartzofeldspathic gneiss with foliated biotite-rich bands and massive leucocratic quartz + feldspar segregations. Leucocratic zones dominant.

DOLOMITIC MARBLE : grey and coarse-grained with an average grain size of 2-3 mm. Dark brown on weathered surfaces. Poorly 'bedded' with bands and disseminations of diopside, tremolite, epidote/zoisite, chlorite and yellow serpentinised olivine.

CALC - SILICATE : siliceous and banded calc-silicate with only subordinate diopside, tremolite, actinolite and chlorite. Gradational into gneiss particularly when calc-silicate is quartz-rich and contains chloritised biotite. Selected bands consist entirely of coarse-grained felted masses of tremolite

QUARTZITE : foliated, sericitic, fine-grained, white to very white quartzite.

BIOTITE SCHIST : black, biotite-rich schist grading to biotite gneiss. Leucocratic segregations minor and parallel schistosity.

BANDED GNEISS : similar to above migmatite gneiss but with more pronounced banding and subordinate leucocratic zones. Banding from centimetres to metres thick.

Assumed arbitary datum of 100m at Station A on Outcrop 32.
Theodolite surveying by A.J. Smith ; S.F.B. 681.
Geological mapping by D. J. Flint and E. A. Dubowski.

UNLOCATED PREVIOUS SAMPLING

SAMPLE NO.	REFERENCE	ROCK TYPE
P 1368/74	Nichol (1974)	Nephrite
P 1370/74	Nichol (1974)	Impure nephrite with ?chlorite

Geological boundary; observed

Geological boundary; approximate

Outcrop boundary

80 Compositional banding; dip and strike

78 Gneissosity; undifferentiated S_1 and S_2 gneissosity, dip and strike

88 Gneissosity; S_2, dip and strike

36 Axial plane ; S_3, dip and strike

67 Schistosity in retrogressive zones; S_4, dip and strike

75 Joint; probably produced during D_4

S_3 Trace of D_3 axial plane

21 D_3 fold axis, plunge and trend

△ STN. D Survey station

RS 347 Sample locality and number, prefixed by 6230

Quarry face

Dump

Track

SCALE

0 5 10 15 20 25 METRES

Assumed arbitary datum at Station A on Outcrop 32.
Theodolite surveying by A.J. Smith, SFB 681.
Geological mapping by D.J. Flint and E. A. Dubowski.

FIG. 19

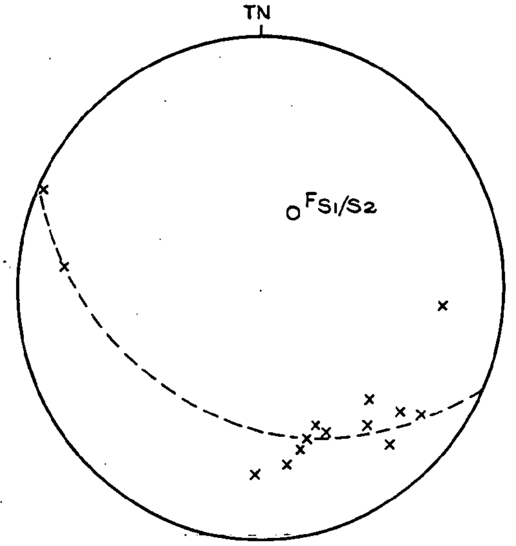
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 24, ML 4217
GEOLOGICAL PLAN

COMPILED	4.7.91 CDO DATE	
DRAWN	SCALE	
DATE	PLAN NUMBER	
CHECKED	88-84	

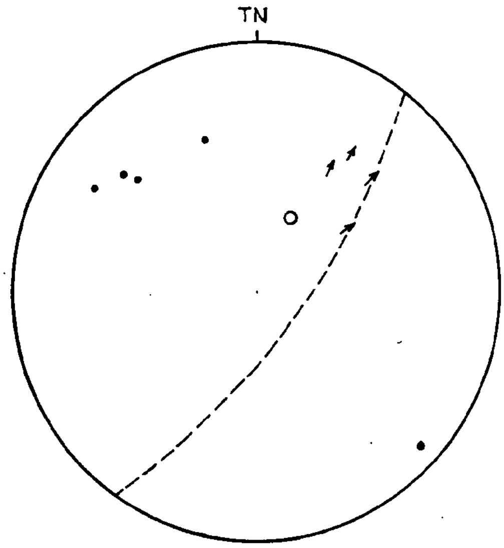
3917

S1/S2



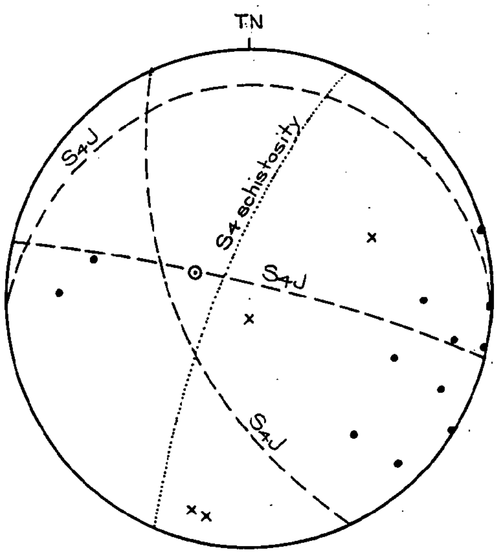
x.....Layering and gneissosity.
o.....Normal to S_1/S_2 great circle distribution.

D3



•...... Axial plane.
↑...... Fold axis.
FS1/S2 o..... Normal to S1/S2 distribution.

D4



x...... Joint.
⊙...... Slick-en-side lineation on S_4 schistosity.
•....... Schistosity.

Wulff nets

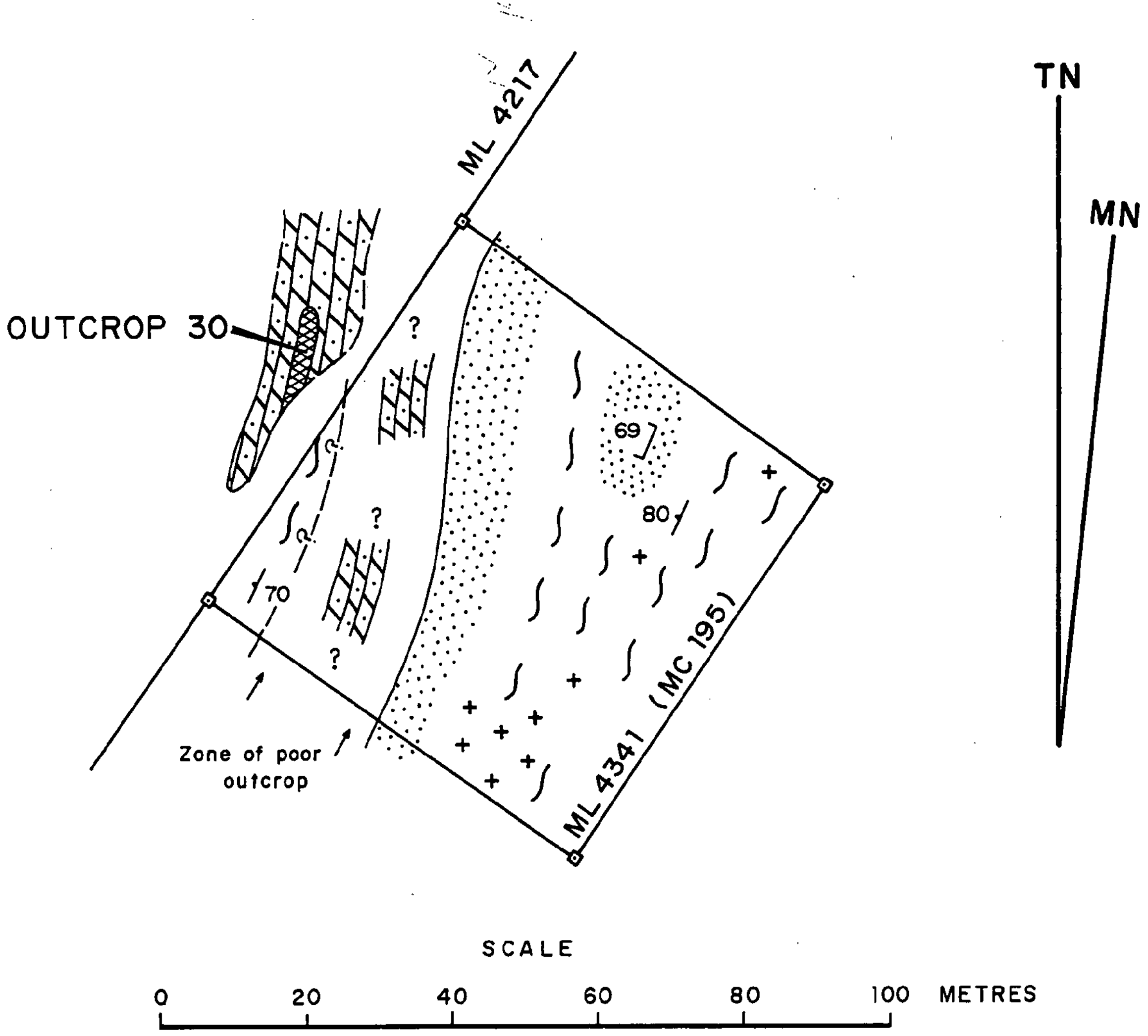
FIG. 20

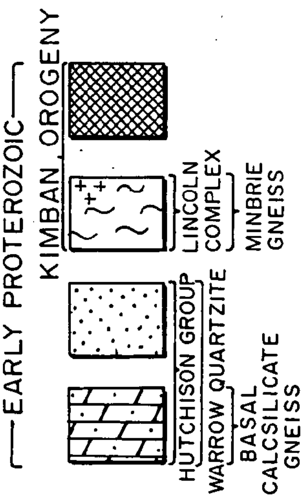
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 24
STEREOGRAPHIC PROJECTIONS

COMPILED D. Flint	CDO 4-7-91 DATE
DRAWN J.W.	SCALE
DATE 6-9-88	PLAN NUMBER S20216
CHECKED	

3917





NEPHRITE and **SEMI-NEPHRITE** : predominantly dark green.

GNEISS and **MIGMATITE** : quartz + feldspar + biotite gneiss with abundant large, coarse grained leucocratic segregations (migmatite). Abundant mesoscopic (? D_2) folds

QUARTZITE : strongly developed planar parting – probably S_2. Probable Warrow Quartzite.

CALC-SILICATE.

———	Geological boundary – observed
–?––?–	– inferred
70	Gneissosity; undifferentiated S_1 and S_2, dip and strike
69	Gneissosity; S_2, dip and strike
ML 4341	Mineral Lease number 4341

Geological mapping by Australian (Nephrite) Jade Mines Pty. Ltd. in September 1973, with additional data by D. J. Flint (SADME), Sept. 1985

FIG. 21

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 30 AND ML 4341
GEOLOGICAL MAP

COMPILED	D. F.
C.D.O.	
DATE	1·3·88
DRAWN	M. B.
SCALE	1 : 1000
DATE	Dec '85
CHECKED	
PLAN NUMBER	S 19838

3917

LEGEND

- Geological boundary and/or limit of outcrop - observed
- Geological boundary and/or limit of outcrop - approximate
- Creek
- ML 4217 Mineral Lease No. 4217, current as at 30-6-85
- (MC 5332) Mineral Claim No. 5332, current during mapping in 1970/71
- 215 Topographic contour, contour interval 5m
- 48 Gneissic foliation, undifferentiated $S_1 + S_2$, strike and dip
- 45 Probable S_4 foliation, strike and dip
- 35 Foliation of unknown age or characteristics, strike and dip

ALLUVIUM

BRECCIA : range of clast types shown. Matrix not recorded but probably predominantly tremolite + chlorite

CHLORITE ± TALC SCHIST : alignment is shown where schistosity orientation known

TREMOLITE ROCK : too coarse to be nephrite. Massive and schistose varieties undifferentiated

NEPHRITE and NEPHRITIC TREMOLITE : largest outcrop contained high quality translucent green nephrite

QUARTZ ?VEIN : white and foliated along its strike length. Interpreted fault zones

LEUCO-GRANITE : highly altered, varies from 'quartz-rich' to 'foliated dolerite'. Most commonly is feldspar + chlorite, massive and with a blotchy or mottled fabric

GRANITE and PEGMATITE

DOLOMITIC MARBLE

MIGMATITE GNEISS : varies from melanocratic schistose rocks (biotite-rich) to leucocratic segregations grading to granite and pegmatite

Based on 30m (100 feet) grid geological mapping by Hopwood (1970) and Hopwood and Coles (1971). Original mapping at 1:600 and with unknown height datum.

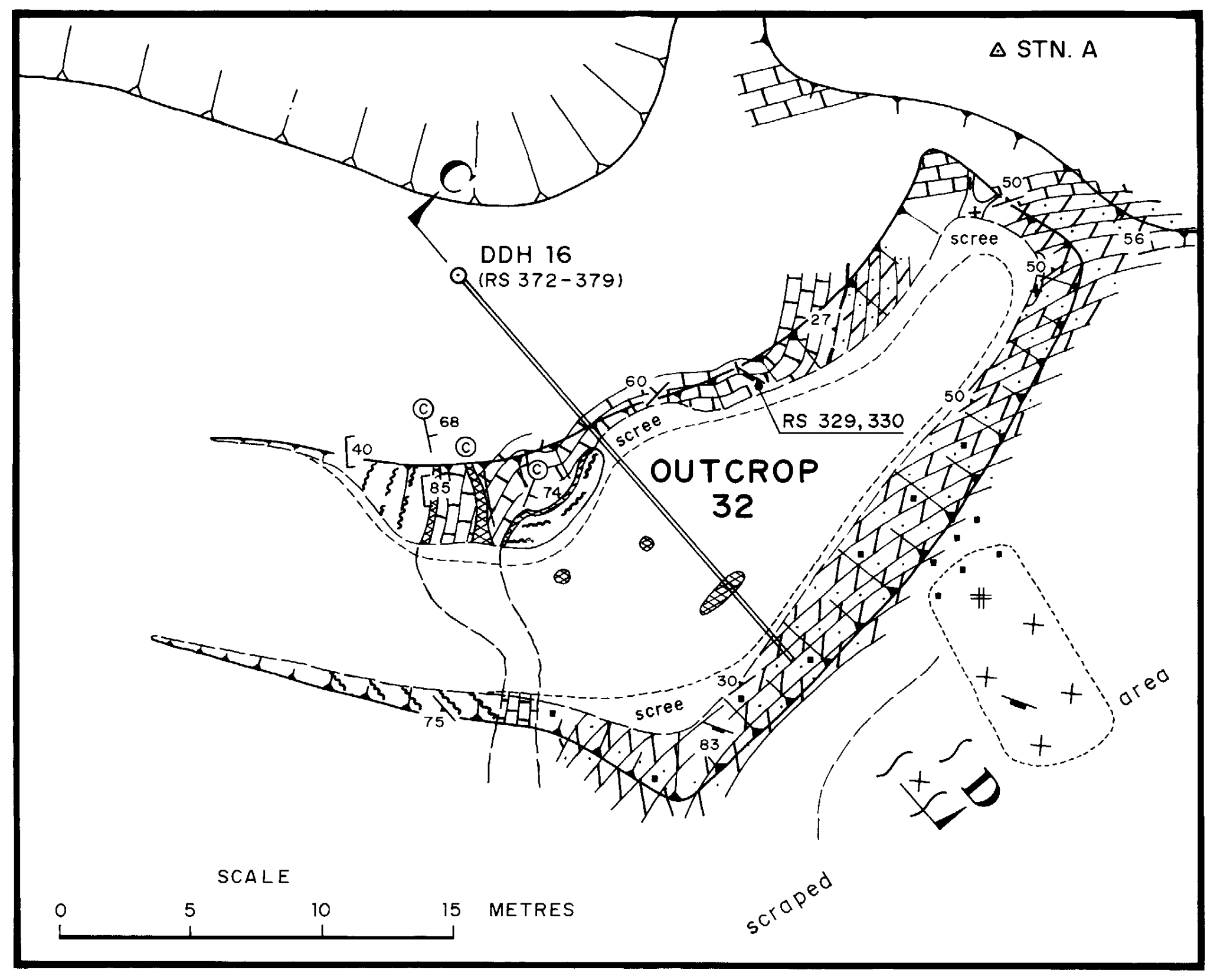
FIG. 22

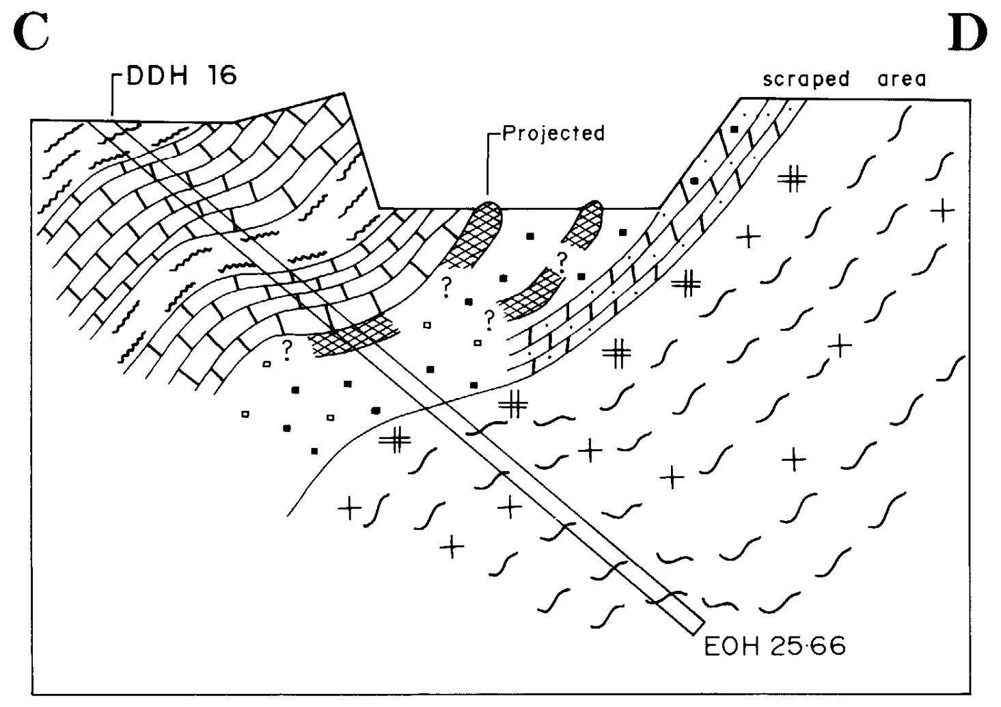
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

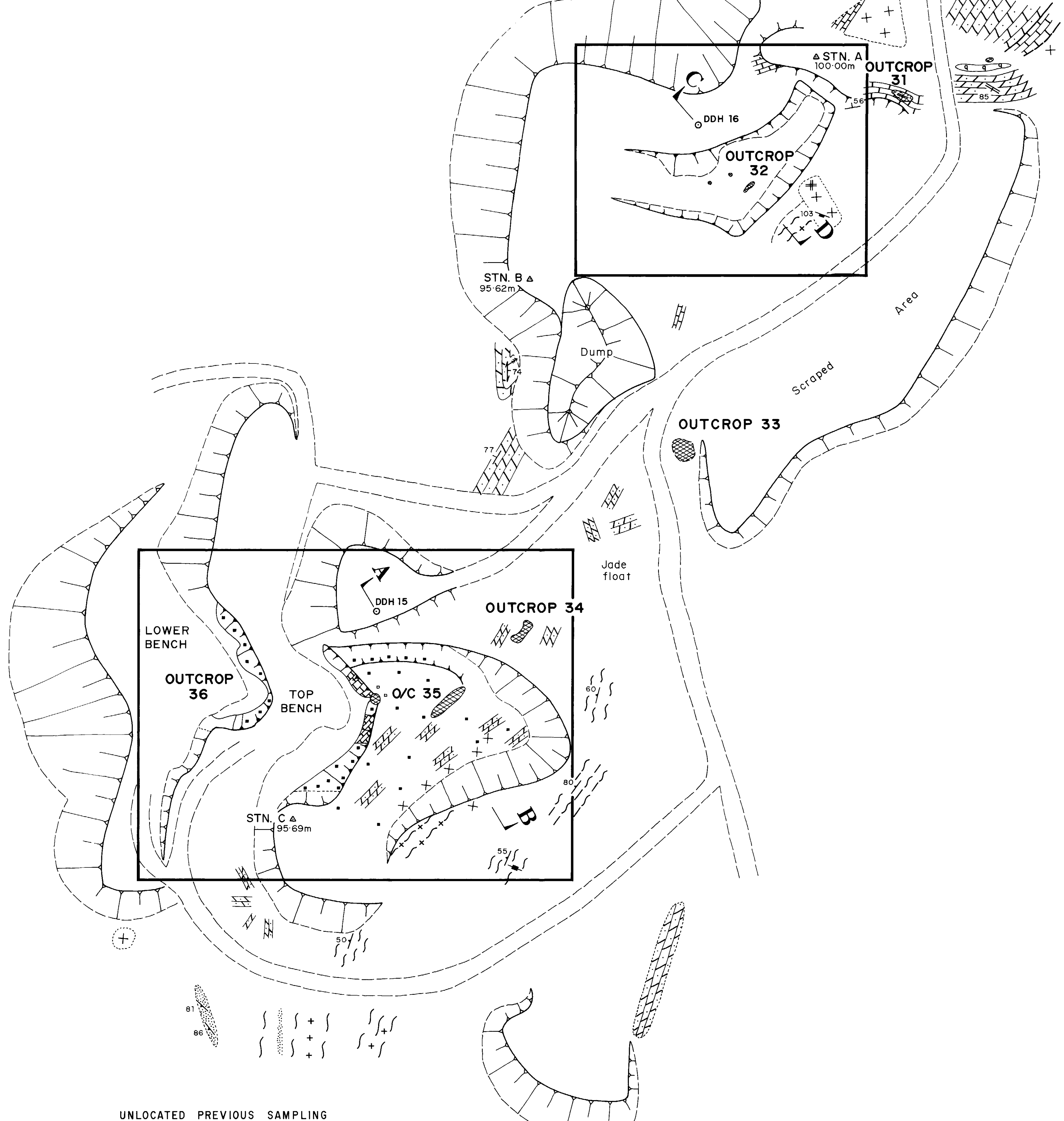
COWELL JADE
OUTCROPS 31-36
PRE-MINING GEOLOGY

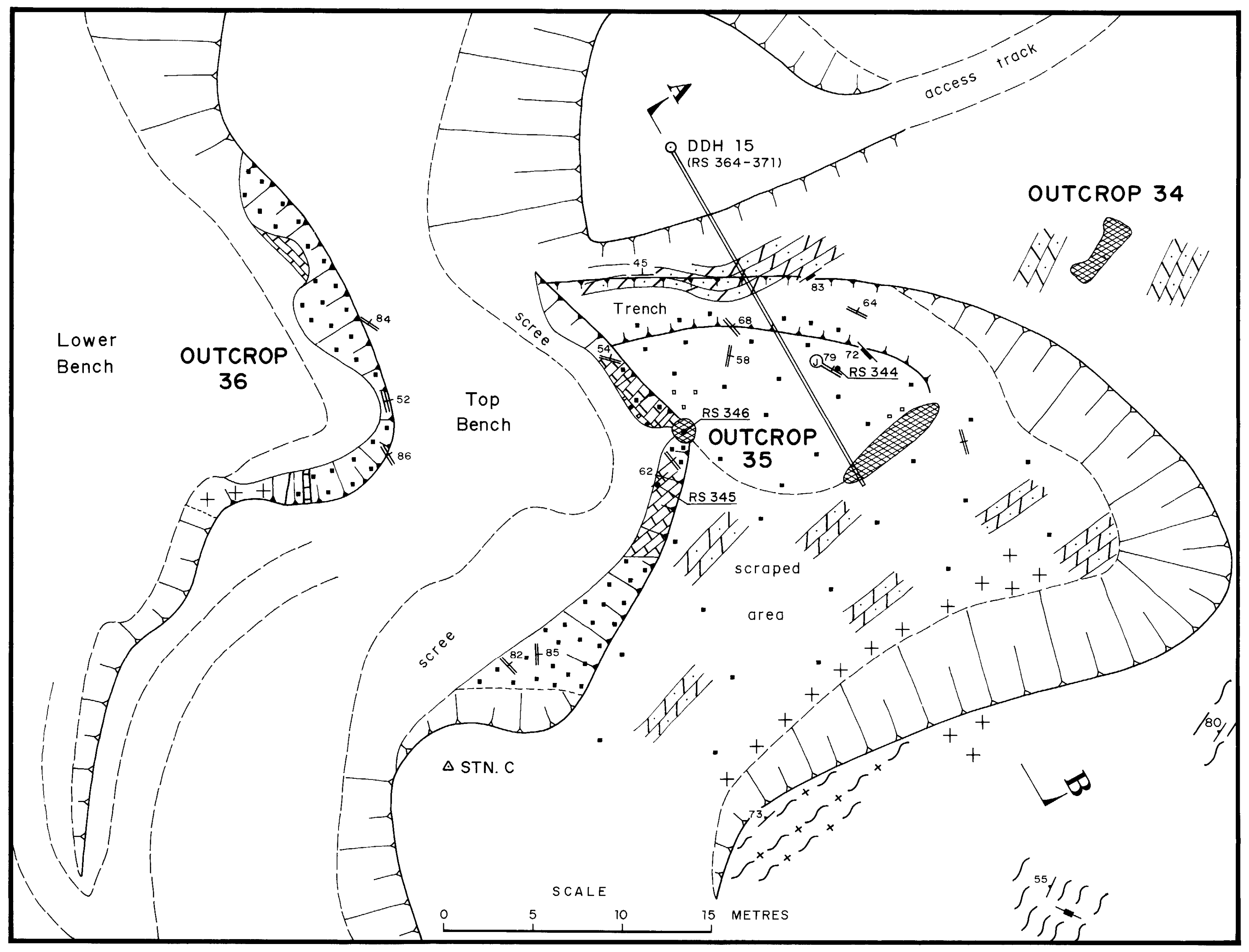
COMPILED D. F.	UR C D O	1-3-88 DATE
DRAWN M. B.	SCALE 1 : 500	
DATE Oct '85	PLAN NUMBER 88-85	
CHECKED		

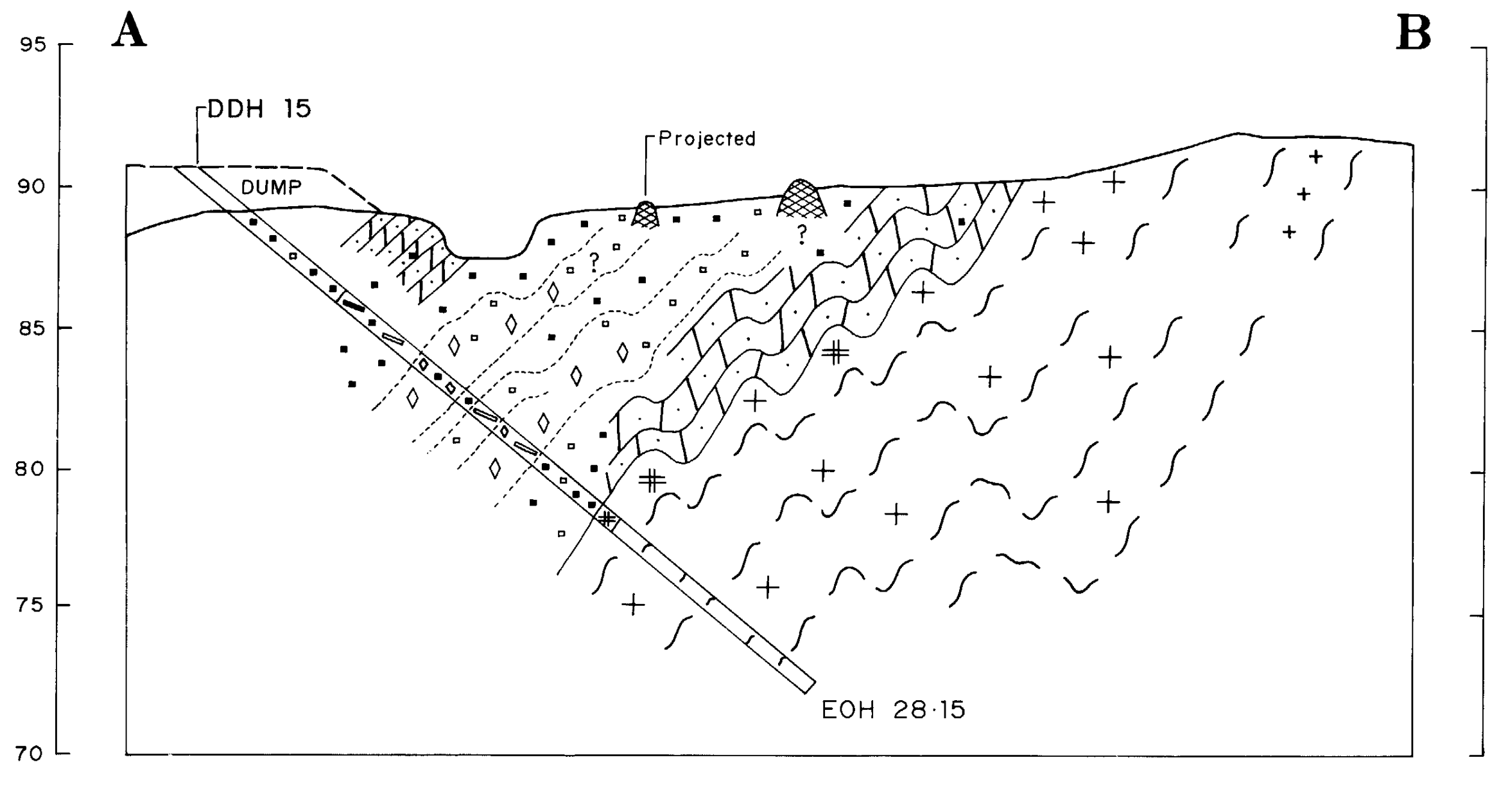
3917











LEGEND

CLINOZOISITE : massive to weakly banded, rarely with clinozoisite augen. Colour highly variable from white, off-white, pale yellow green, tan to brown, pale purple to orange and pink-orange. Phlogopite occasionally present. Schistose varieties minor.

NEPHRITE and NEPHRITIC TREMOLITE : variable quality from rare moderately translucent yellow to yellow green nephrite to more typical opaque or only weakly translucent varieties of dark yellow green, green and grey green. Nephrite of Outcrop 32 contains abundant porphyroblasts of phlogopite.

TREMOLITE : fine-grained, pale green to grey green, milky opaque, massive to weakly foliated tremolite. Grades to coarser grained masses which are either schistose or felted. Finer grained varieties grade into nephritic tremolite and nephrite.

CHLORITE : dark green to greenish black with both massive and schistose varieties. Paler green fine-grained tremolite often present. Forms large alteration masses in proximity to nephrite. Occasionally with diffuse ?original compositional banding containing coarse-grained tremolite, chloritised phlogopite and diopside.

QUARTZ VEIN : white to off-white and massive.

APLITE and GRANITE : as sills, dykes and as segregations in migmatite gneiss into which they grade.

PEGMATITE : massive coarse-grained segregations and intrusions of quartz, feldspar and biotite.

ALTERED INTRUSIVE : altered aplite, granite and pegmatite. Primary phases of milky microcline, clear grey quartz and albite with extensive alteration producing yellow-green epidote. Late stage fractures are lined with chlorite, actinolite and epidote.

DOLOMITIC MARBLE : grey and coarse-grained with an average grain size of 2-3 mm. Dark brown on weathered surfaces. Poorly 'bedded' with bands and disseminations of diopside, tremolite, epidote/zoisite, chlorite and yellow serpentinised olivine.

CALC-SILICATE : siliceous and banded calc-silicate with only subordinate diopside, tremolite, actinolite and chlorite. Gradational into gneiss particulary when calc-silicate is quartz-rich and contains chloritised biotite. Selected bands consist entirely of coarse-grained felted masses of tremolite.

QUARTZITE : foliated, seritic, fine-grained, white to very white quartzite.

BIOTITE SCHIST : black, biotite-rich schist grading to biotite gneiss. Leucocratic segregations minor and parallel schistosity.

MIGMATITE GNEISS : massive to poorly banded quartzofeldspathic gneiss with foliated biotite-rich bands and massive leucocratic quartz + feldspar segregations. Leucocratic zones dominant.

BANDED GNEISS : similar to above migmatite gneiss but with more pronounced banding and subordinate leucocratic zones. Banding from centimetres to metres thick.

Geological boundary; observed

Geological boundary; approximate

Outcrop boundary

56 Compositional banding; dip and strike

55 Gneissosity; undifferentiated S_1 and S_2 gneissosity; dip and strike

40 Gneissosity; S_2, dip and strike

36 Schistosity; S_3, dip and strike

64 Schistosity in retrogressive zones; probably S_4, dip and strike

J 68 Schistosity as above but within nephrite

C 74 Contact of nephrite; strike and dip

56 Joint; probably produced during D_4

S_3 Trace of D_3 axial plane

28 D_3 fold axis; plunge and trend

STN. A Survey Station and height in metres

RS 346 Sample locality and number, prefixed by 6230

DDH 15 Diamond drillhole (inclined), with plan projection and sample numbers

scree Quarry face

Dump

Track

A B Cross section

UNLOCATED PREVIOUS SAMPLING

OUTCROP NO.	SAMPLE NO.	REFERENCE	ROCK TYPE
32	M 1	Jade (Australia) Pty. Ltd.	Nephrite
	M 2	- Env. 2310	Nephrite
	M 3	"	Nephrite
	M 4	"	Nephrite
	P 97/73	Nichol (1974)	Banded calc-silicate
	P 98/73	"	Chlorite + tremolite
	P99/73	"	Nephrite
	P 100/73	"	Nephrite
	P 101/73	"	Tremolite
	P 102/73	"	Dolomitic marble
	P1371/74	"	Nephritic tremolite
33	P1372/74	"	Nephrite with epidote
34	P1360/74	"	Talc + tremolite

Arbitary assumed datum of 100m at Station A

Surveying by A. J. Smith, 1982 (SFB 681)

Geological mapping by D. J. Flint, E. A. Dubowski,
Abdulazziz Ziab and Mohammed Rehaili

SCALE
0 10 20 30 40 50 METRES

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

GEOLOGICAL MAP AND CROSS SECTIONS A-B, C-D
OUTCROPS 31-36, ML 4217 and 4381

D. F.		1·3·88
DRAWN M. B.	SCALE 1:500	
DATE Dec '85	PLAN NUMBER	88-86
CHECKED		

3917

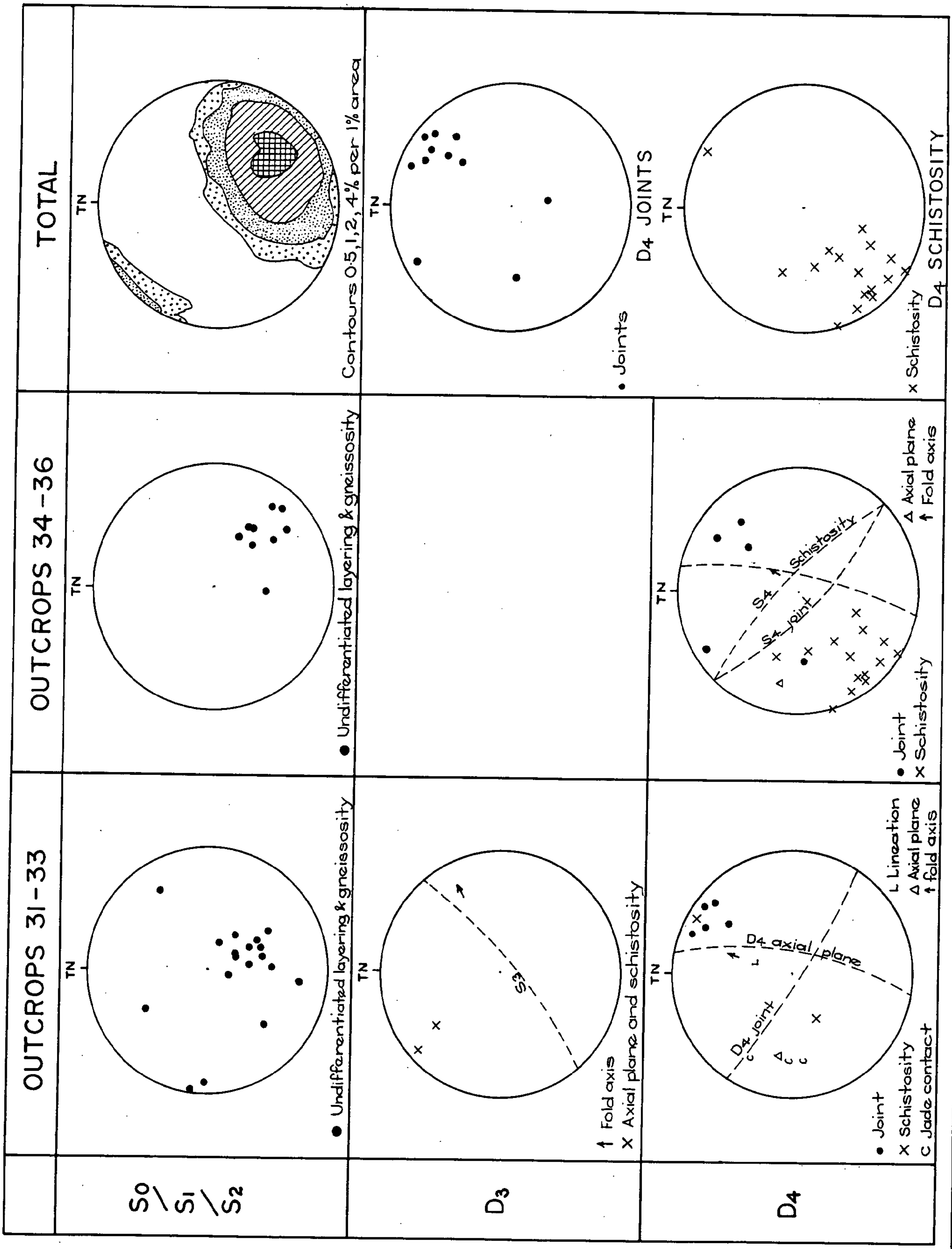


FIG. 24

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 31-36
STEREOGRAPHIC PROJECTIONS

COMPILED D.Flint	C D O	DATE 4-7-91
DRAWN J. Williams	SCALE	
DATE 6-9-88	PLAN NUMBER	
CHECKED	S20217	

3917

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

NON – METALLIC RESOURCES DIVISION

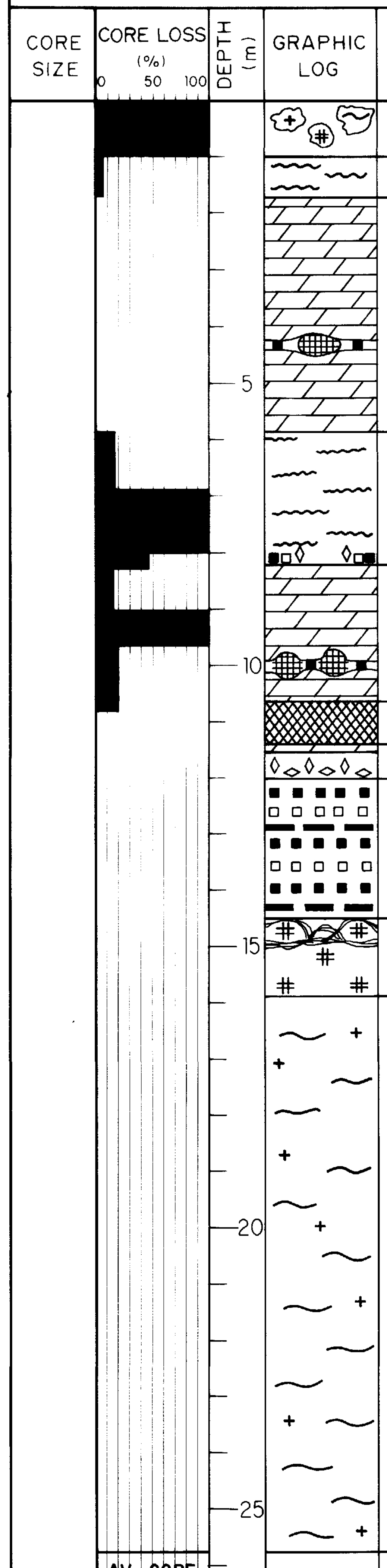
HOLE No. DDH 16

PROJECT COWELL JADE
LOCATION 6230
HUNDRED MINBRIE SECTION 123

ELEVATION
INCLINATION 40°
AZIMUTH 139°
DEPTH 25·66m
DATUM

DRILLER D. E. White
COMMENCED 6·6·83
COMPLETED 10·6·83
LOGGED D. Flint, E. Dubowski

UNIT / STATE No. 613/83
DOCKET NUMBER 355/75
PLAN REFERENCE
DRAWING No.



AV. CORE LOSS 10%

LITHOLOGICAL DESCRIPTION

OVERBURDEN: Roller bit used through alluvium and dump material.

SCHIST: Dark grey to black, quartz + biotite dominant; lesser chlorite and feldspar. Coarse quartz & feldspar segregations & bands present. Fracture & joint surfaces stained with iron oxides.

DOLOMITIC MARBLE: Impure with abundant inclusions of serpentine, tremolite, chlorite, epidote & ? talc. Dominantly medium grained and grey but with irregular banding and mottling of yellow serpentine after olivine, medium green tremolite, dark green chlorite ± talc and yellow-orange-brown iron and manganese staining.
? Possible small aggregate of nephrite 1 cm across at 3·20 m.
5-10 cm thick band of off-white diopside, veined and retrogressed by dark green chlorite and tremolite at 4·3 m.
Microfaults displace primary mineralogical banding. Pink and white calcite infill joints and irregular fractures.

GNEISS: Dark grey and grey-black biotite-rich gneiss with dark grey quartz-rich segregations. Strongly folded with disrupted quartz-rich bands and an axial planar biotite schistosity; quarry mapping suggests D_2 folds.
Chloritised at the base with 2-5 cm bands of massive, retrogressive mid-green tremolite, chlorite and pinkish clinozoisite. Grades downhole into marble.

DOLOMITIC MARBLE: Dominantly grey, fine to medium grained but with abundant light to medium green tremolite bands several centimetres thick, as well as darker green chlorite ± talc aggregates and bands. Chlorite banding parallel to and across primary compositional banding. Fine-gr. off-white to grey ? diopside from 8·90 - 9·05 m. Marble and diopside weathered with iron oxides and with Mn-rich dendrites at 10·2 m.

JADE: Medium green with abundant 0·5 - 1·5 mm porphyroblasts of phlogopite which are up to 25% (vol.) Porphyroblasts show no alignment but are concentrated into diffuse bands 0·5 - 2·0 cm thick.

CLINOZOISITE + PHLOGOPITE SCHIST: A light olive-grey clinozoisite + phlogopite schistosity wraps around small olive augen, 2-5 mm across, of pure clinozoisite.

CHLORITE ± TREMOLITE: Mottled dark green chlorite and lesser paler green tremolite. Mostly massive but chlorite in places defines a schistosity — probably S_4. Minor dark brown chlorite or biotite at 12·10 m and at basal contact, 14·42 m; brownish colour from phlogopite + clinozoisite (RS 378).

MICROCLINE + QUARTZ INTRUSIVE: Extensively veined and altered above 14·88 m with chlorite locally. Mafics essentially absent below 14·88 m, with about 50:50 milky white microcline and clear grey quartz. Late-stage actinolite and epidote in fractures in upper portion (RS 379).

GNEISS: Quartz + feldspar + biotite gneiss with abundant massive, leucocrative quartz + feldspar segregations or veins. Feldspar white and milky. Biotite is blackish, concentrated in trails and bands, and defines the gneissosity.
Minor massive chlorite in aggregates at 17·7 - 17·8 m and 19·27 - 19·34 m.

END OF HOLE 25·66 m.

Comments.

1. Jade intersected at 10·6 - 11·2 m is as predicted prior to drilling and is an extension of jade outcrops in the quarry floor.
2. Jade is also exposed in the quarry wall at the base of Dolomitic Marble but was not intersected at the corresponding position in the drill core i.e., 5·8 m.
3. Nephrite has a dusky yellow green colour but is marked by abundant porphyroblasts, up to 20 - 25% by volume, consisting of phlogopite, epidote and coarse-grained tremolite.

PETROGRAPHIC SAMPLE

Depth	RS No.
10·05	372
10·63	373
10·95	374
11·05	375
11·21	376
11·71	377
12·09	378
14·42	379

ASSAY SAMPLE

from	RS No.	to
10·00	372	10·13
10·56	373	10·66
10·93	374	10·99
11·00	375	11·12
11·14	376	11·28
11·68	377	11·74
12·00	378	12·13
14·35	379	14·52

STRUCTURES

- S_1/S_2 gneiss banding at 30-35° to core axis, joints at 20-30°.
- S_1/S_2 compositional banding in marble at 60° to core axis.
- " " " " " " " " " "
- " " " " " " 55° " " "
- " " " " " " 70° " " "
- Diopside banding at 50° to core axis.
- chlorite lining S_4 fractures parallel to core axis.
- Compositional banding in marble at 50° to core axis.
- " " " " " 60° " " "
- ? Diopside banding at 45° to core axis; chloritic alteration along S_4 fractures at 10 - 30° to core axis.
- Porphyroblast-rich bands at 40° to core axis; dendrite-lined joint at 5° to core axis.
- chlorite and epidote-lined S_4 joints at 10° to core axis.
- S_1/S_2 biotitic gneissosity at 55° to core axis.
- " " " " 50° " " "
- " " " " 30° " " "
- " " " " 55° " " "
- " " " " 55° " " "
- " " " " 40° " " "

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

LOG OF DIAMOND DRILLHOLE 16

COMPILED D.F.
DATE Oct '85
DRAWN M. B.
CHECKED
ur 1·3·88
SCALE
PLAN NUMBER 88-80

3917

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

NON – METALLIC RESOURCES DIVISION

HOLE No. DDH 15

PROJECT COWELL JADE
OUTCROP 35
LOCATION 6230
HUNDRED MINBRIE SECTION 123

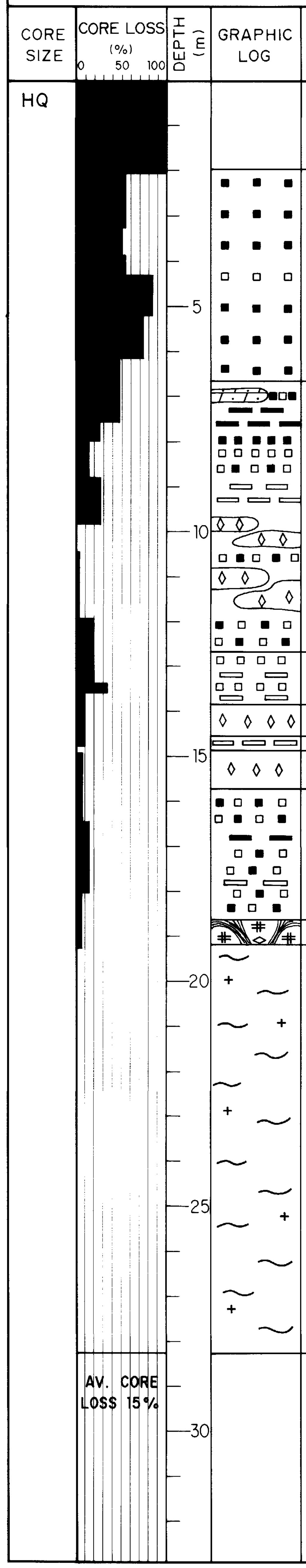
ELEVATION
INCLINATION 40°
AZIMUTH 148° m
DEPTH 28·15 m

DATUM

DRILLER D.E. White
COMMENCED 26·5·83
COMPLETED 4·6·83
LOGGED D. Flint, E. Dubowski

UNIT / STATE No 612 / 83
DOCKET NUMBER 355 / 75
PLAN REFERENCE 88-86
DRAWING No.

CORE SIZE: HQ



LITHOLOGICAL DESCRIPTION

Roller bit through dump.

CHLORITE: Dark green and predominantly massive, occasionally schistose. Mostly fine-grained but ranges up to coarsely micaceous; tremolite minor. Deeply weathered, core fragmentary and with poor core recovery. Quartz fragments coated in chlorite locally concentrated at 3·1m, 4·8m and 6·2m.

TREMOLITE & CHLORITE: Medium green aggregates of radiating tremolite with abundant dark green chlorite. Varies from massive to schistose. Fine-grained varieties also contain appreciable feldspar i.e., RS 365.
Retrogressed calc-silicate and feldspar & chlorite rocks in bands or veins at 6·7 - 7·2 m, 9·75 - 10·30m & 10·9 - 11·8 m. Quartz and feldspar and alteration products form distinct leopard-skin texture at 6·7 - 7·2 m. (RS 364).
Highly fragmented chlorite schist at 8·2 - 8·5 m.
Late stage cross-cutting tremolite schist bands, to 3 cm wide, at 9·14 - 9·58 m and 10·0 - 10·9 m and 11·4 - 11·75 m.

11·85 - 12·65 : - Blotchy appearance with aggregates to 20mm across consisting of dark green, fine-grained chlorite in a matrix of medium green, fine-grained tremolite and minor chlorite. Tremolite is schistose (S_4). Minor relict white spots to 3 mm of diopside or feldspar; heavily altered.

TREMOLITE: Fine-grained, pale green, milky opaque, massive to weakly foliated, - probably S_4 schistosity. Fragmented core; includes fragments of medium green, semi-translucent tremolite — bordering on nephritic tremolite, in irregular veinlets less than 1mm thick. Pale green 10G 6/2.

CLINOZOISITE ROCK: Wavy and lenticular bands of off-white to yellow clinozoisite alternating with a dark grey-green chloritic mylonitic schistosity.

TREMOLITE: Fine-grained, pale green and milky opaque, foliated with S_4 schistosity.

CLINOZOISITE: Off-white to pale yellow-green clinozoisite bands outlining open folds in layering, which alternate with dark grey-green bands of chlorite ± tremolite. Clinozoisite banding and parallel chlorite schistosity predates S_4 joints.

TREMOLITE + CHLORITE: Medium grey-green colour dominant but dark green where chlorite locally abundant. Tremolite often as medium to coarse grained radiating aggregates forming very coarse felted masses. Diffuse ? original compositional banding contains tremolite, phlogopite and diopside.
Cross-cutting schistose bands consist both of chlorite and pale green, milky opaque tremolite aligned in S_4 (RS 370).
18·04 - 18·57m : chlorite matrix invading tremolite, strong development of S_4 chlor. & trem. schistosity.

FELDSPAR INTRUSIVE: Extensively altered in upper portion with f. gr. epidote and chlorite (RS 371).

GNEISS: Banded, quartz & biotite gneissic bands alternating with intrusive or migmatitic, leucocratic quartz & feldspar bands up to 50mm thick.
Leucocratic bands, with pink-orange K-feldspar at 19·26 - 19·39 m, 19·91 - 20·00 m & 21·46 - 21·66 m.
Feldspar blastesis, with microcline porphyroblasts to 5mm across, at 22·18 - 22·26 and 22·60 - 22·79 m.
Chloritised biotite from 25·2 - 25·76 m. Brecciation and with chlorite lining fractures is most abundant from 26·0 - 27·75 m with S_4 jointing - possibly axial planar to folded gneissic banding at 26·78 m.
Leucocratic band, 70mm thick at 27·66 m, contains medium-green tremolite in small aggregates.

END OF HOLE 28·15m.

Comments.

1. *Core from 2·0m to 18·6m consists almost entirely of chlorite, tremolite and clinozoisite/epidote — in that order of abundance. Unusually, both dolomitic marble and diopside are absent.*
2. *Epidotisation of feldspar-rich intrusive predates development of a chlorite & tremolite S_4 schistosity.*
3. *Although massive and schistose tremolite were intersected, neither approach the quality of jade.*

PETROGRAPHIC SAMPLE Depth	PETROGRAPHIC SAMPLE RS No.	ASSAY SAMPLE from	ASSAY SAMPLE RS No.	ASSAY SAMPLE to
7·13	364	7·08	364	7·20
9·80	365	9·76	365	9·89
13·38	366, 367	13·35	367	13·41
14·18	368	14·0	368	14·35
15·61	369	15·51	369	15·62
16·40	370	16·31	370	16·50
18·75	371	18·50	371	18·78

STRUCTURES

- *? Original compositional banding at 75° to core axis.*
- *Clinozoisite banding at about 60° " " "*
- *Schistosity, age unknown, at 70° to core axis.*
- *Tremolite band and schistosity, probably S_4, at 12° to core axis.*
- *Compositional banding at 30° to core axis, S_4 trem. & chlor. schisosity at 20° to core axis.*
- *S_4 tremolite & chlorite schistosity at 20 - 30° to core axis.*
- *Compositional banding at 20 - 30° to core axis; 5mm band of foliated tremolite parallel to core axis.*
- *S_4 trem. & chlor. schistosity at 10 - 15° to core axis.*
- *" " " " " " " " " " ", plus diffuse compositional banding at 70° to core axis.*
- *Wavy, lenticular mylonitic clinozoisite banding at 85 - 90° to core axis.*
- *S_4 Tremolite schistosity at 40° to core axis.*
- *Clinozoisite banding, $S_3 - S_m$?, at 80° to core axis.*
- *Diffuse compositional banding at 75 - 85° to core axis with S_4 tremolite schistosity at 10 - 15° to core axis.*
- *Chlorite-rich S_4 chlor. & trem. schistosity at 40° to core axis.*
- *Mylonitised ? epidote rich S_m schistosity at 80 - 85° to axis*
- *S_1/S_2 gneissosity at 75° to core axis.*
- *" " " 80° " " "*
- *" " " 50° " " "*
- *" " " 52° " " "*
- *" " " 50° " " "*
- *" " " 65° " " "*
- *" " " 50° " " "*
- *Chlorite lining narrow S_4 joints parallel to core axis.*

FIG. 26

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 35
LOG OF DIAMOND DRILLHOLE 15

COMPILED D.F.	UR 1·3·88	C.D.O.	DATE
DRAWN M. B.	SCALE		
DATE Oct '85	PLAN NUMBER 88-79		
CHECKED			

3917

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT.BK.NO. 89/51

COWELL JADE PROVINCE: DETAILED GEOLOGICAL MAPPING AND DIAMOND DRILLING OF JADE AND ORNAMENTAL MARBLE OUTCROPS, 1982-1987.

VOLUME 4

GEOLOGICAL SURVEY

by

D.J. FLINT

and

E.A. DUBOWSKI

SENIOR GEOLOGISTS
MINERAL RESOURCES BRANCH

JUNE 1991

DME 85/88

E00237

VOLUME 4

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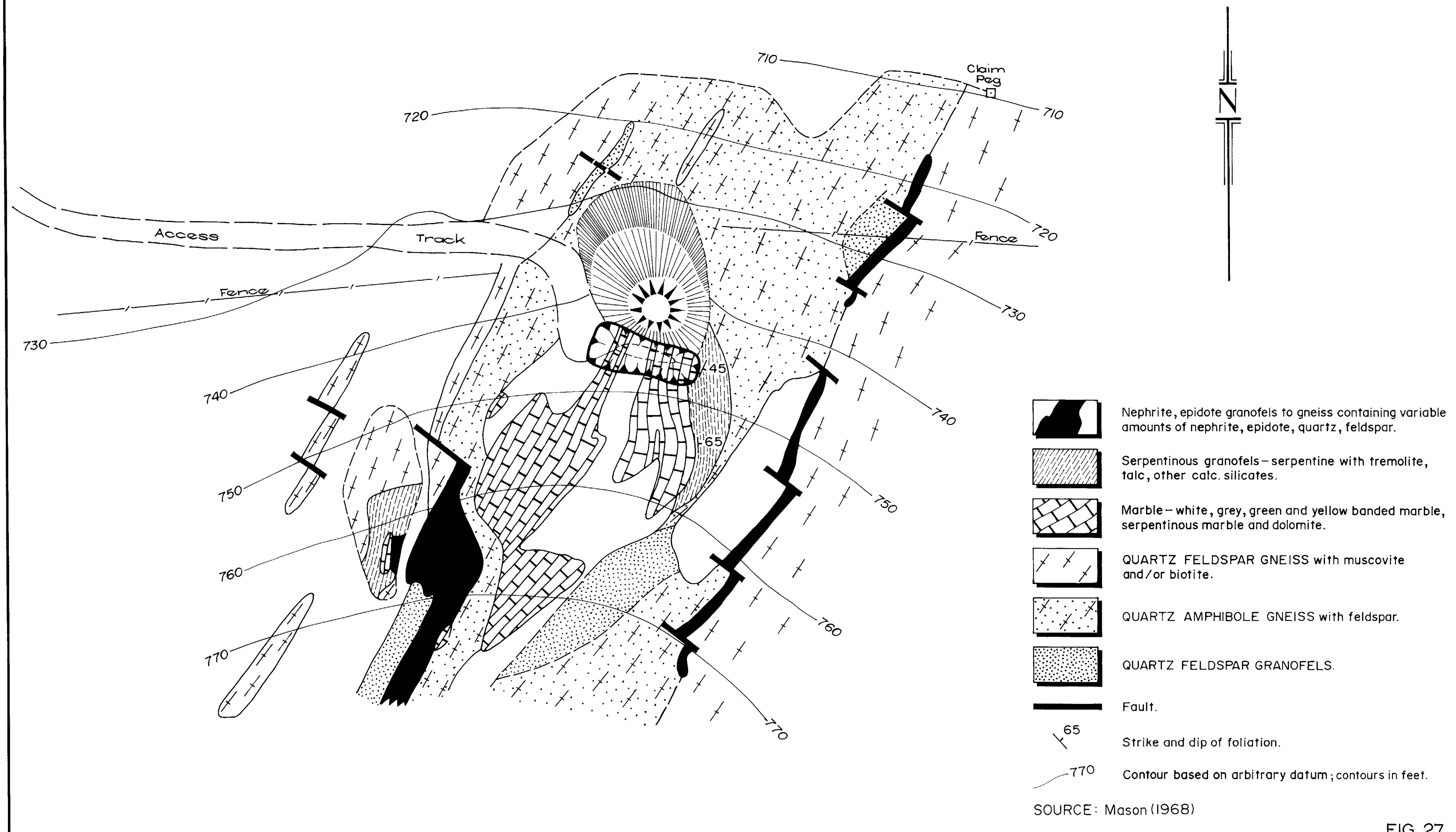


SOURCE: Mason (1968)

FIG. 27

0 10 20 30 40 50
METRES

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 37-38, TALC DEPOSIT
1968 GEOLOGICAL PLAN

COMPILED D.J.Flint	CDO 4.7.91	DATE
DRAWN J.W	SCALE 1:500	
DATE May '89	PLAN NUMBER	
CHECKED	89-272	

EARLY PROTEROZOIC

KIMBAN OROGENY

NEPHRITE AND SEMI NEPHRITE: dominantly dark green and fine grained but tends to have an orange peel texture when polished. Massive to schistose with possible D_3 or D_4 schistosity (strike 015° M) cross-cut by a D_4 crenulation. Contains at least three, late stage planar joints. Outcrop to 2m high and previously drilled by thermic lance. Boulders contain thick coating and rind of pale, opaque, lime green tremolite.

TREMOLITE: massive, coarse grained, grey green.

CHLORITE: massive, dark green, grades to tremolite.

EPIDOTE AND CLINOZOISITE: as clinozoisite (purple) replacing feldspar in pegmatite or as pale-green epidote in retrogressed, banded calc-silicate.

TALC: massive, grey to grey green and speckled with dark green-black chlorite or opaque inclusions. Lighter tone than talc from ML 4576.

LINCOLN COMPLEX

PEGMATITE: grades to quartzofeldspathic segregations in migmatite gneiss.

MIGMATITE GNEISS: grades to granitic or quartzofeldspathic gneiss. Coarse grained, poorly banded, with biotite.

HUTCHISON GROUP

WARROW QUARTZITE

Basal Banded Calc-silicate Gneiss

BANDED CALC-SILICATE GNEISS: banded, often with quartzitic and schist interbeds. Calc-silicate bands invariably retrogressed and epidote rich.

DOLOMITIC MARBLE.

PODDED SILLIMANITE GNEISS: Retrograded and now grades to serecitic schist. Pods (quartzitic or sillimanitic) are to 30mm long but often only 2-5mm wide and are extensively flattened in the D_2 schistosity. Often contains thin quartzitic interbeds.

QUARTZITE: massive to flaggy quartzite. Banded with bands 1-5 cm thick. Contains thin bands of podded sillimanite gneiss.

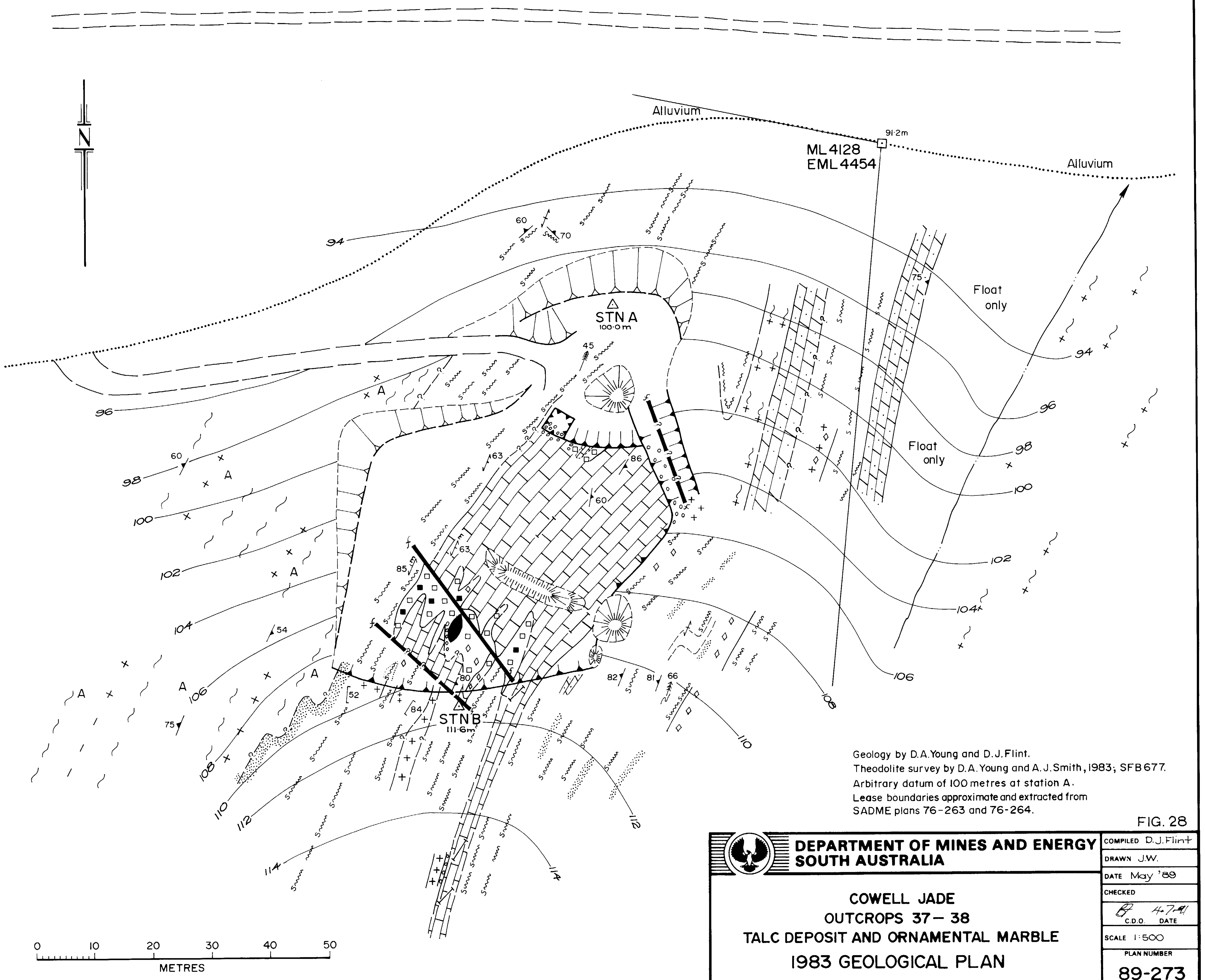
ARCHAEAN

SLEAFORD COMPLEX

MILTALIE GNEISS

GNEISS: coarse-grained, quartzofeldspathic gneiss with abundant pegmatite. Contains bands 1-2 m thick of quartz and biotite gneiss. Gneiss is coarser, more massive and with broader bands than migmatite gneiss of the Hutchison Group.

70	Lithological layering and undifferentiated S_1/S_2 gneissosity; dip and strike.
52	Gneissosity - S_2; dip and strike.
	Gneissosity - S_2; trend only.
75	Shistosity - S_3 and S_m, marked 'm' where mylonitic; dip and strike.
19	Fold axis - plunge and trend, with vergence.
	Geological boundary - mapped.
	Geological boundary - approximate.
?	Geological boundary - inferred.
	Fault - mapped.
?	Fault - inferred.
	Limit outcrop.
	Quarry face.
	Dump.
	Dump.
	Track.
ML4128	Mining Lease No. ML4128.
STN A 100·0m	Survey Station with spot height.
102	Topographic contour; 2m interval.
96·1	Spot height in metres.
	Creek.



Geology by D.A. Young and D.J. Flint.
Theodolite survey by D.A. Young and A.J. Smith, 1983; SFB 677.
Arbitrary datum of 100 metres at station A.
Lease boundaries approximate and extracted from SADME plans 76-263 and 76-264.

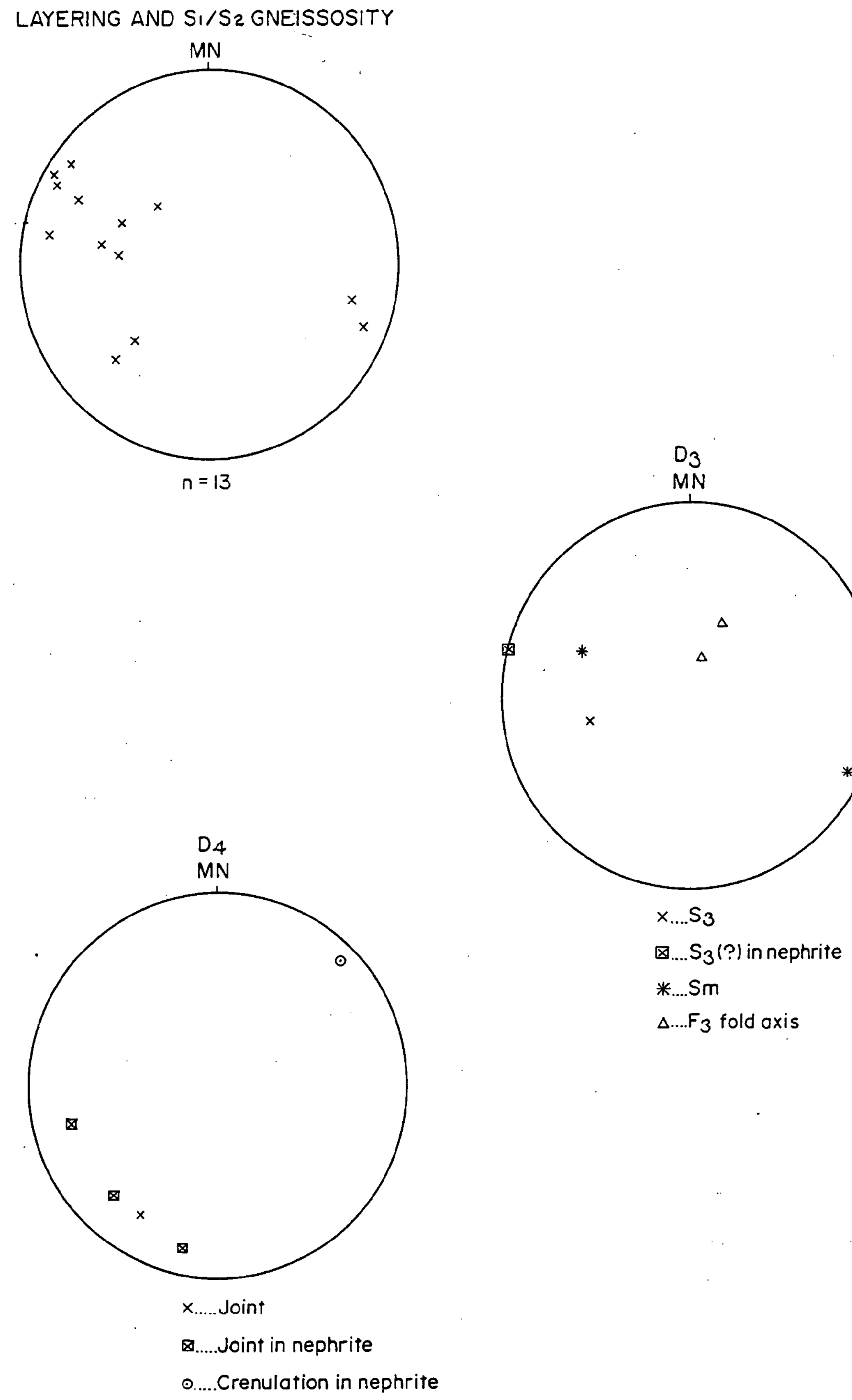
FIG. 28

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 37 – 38
TALC DEPOSIT AND ORNAMENTAL MARBLE
1983 GEOLOGICAL PLAN

COMPILED D.J. Flint
DRAWN J.W.
DATE May '89
CHECKED
4-7-91
C.D.O. DATE
SCALE 1:500
PLAN NUMBER
89-273

39/7



Lower Hemisphere, Wulff nets

FIG. 29

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

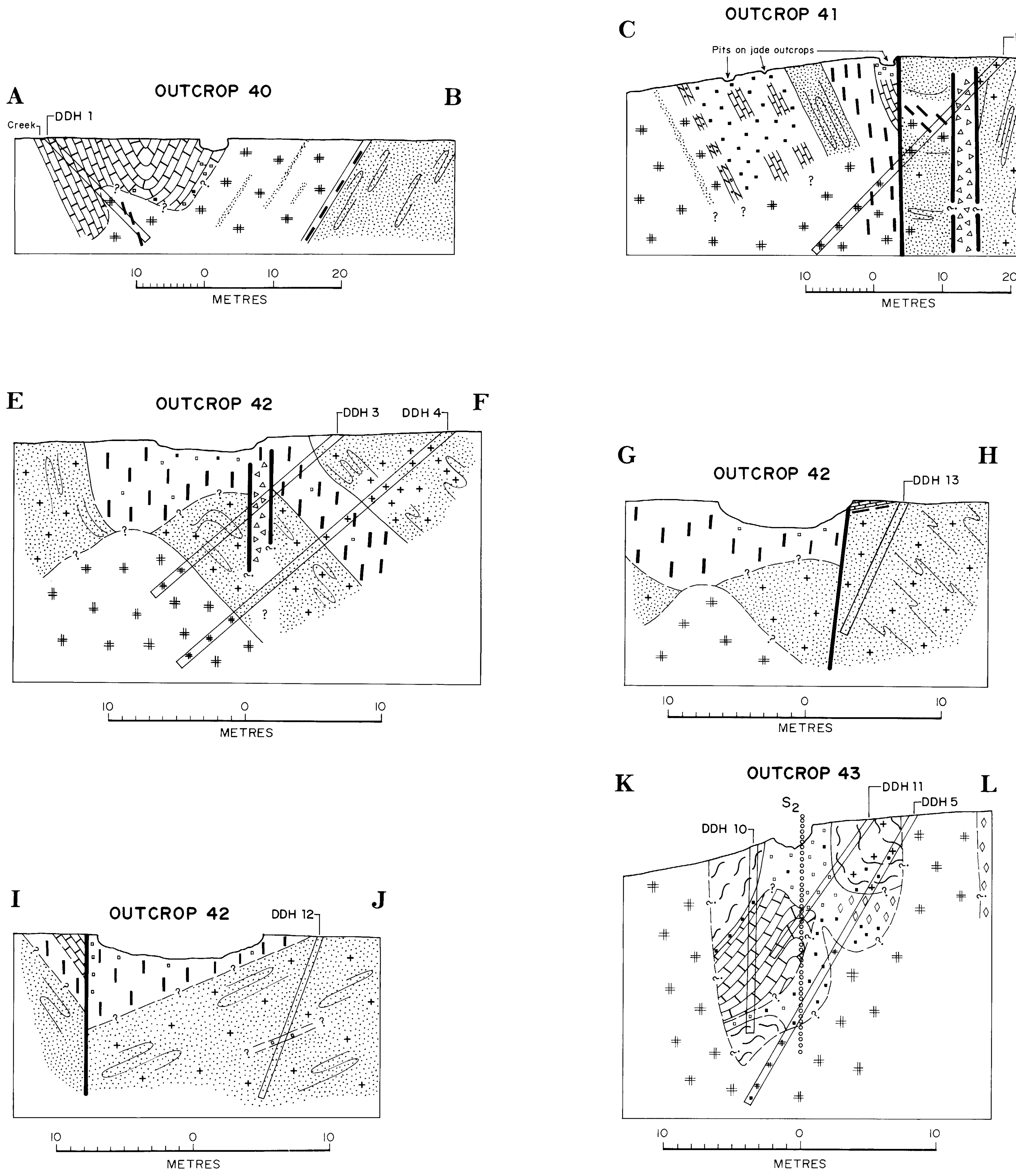
COWELL JADE
OUTCROPS 37-38,
TALC DEPOSIT AND ORNAMENTAL MARBLE
STEREOGRAPHIC PROJECTIONS

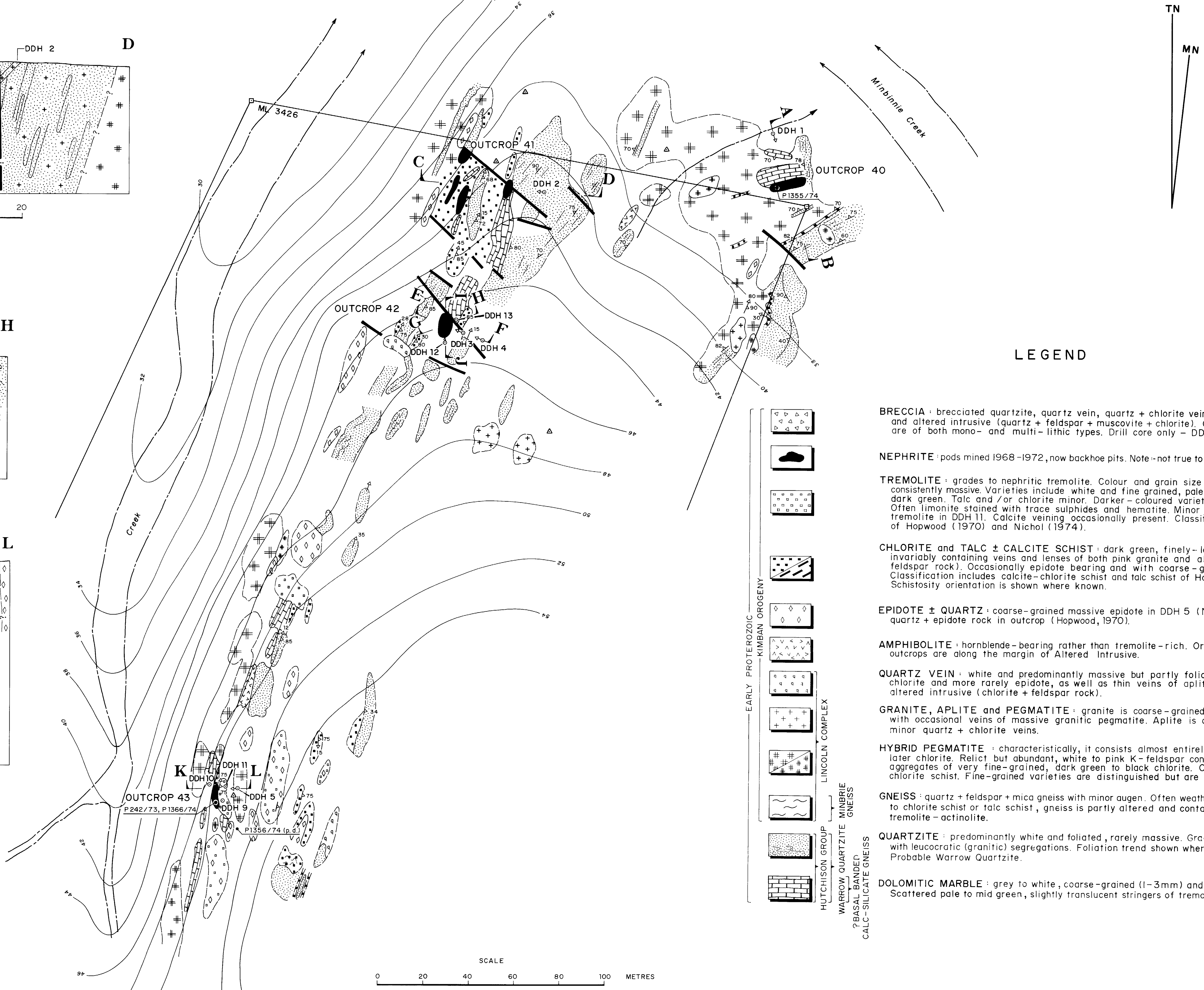
COMPILED D. Flint	C.D.O.	DATE 4-7-91
DRAWN J.W.	SCALE	
DATE May '89	PLAN NUMBER S20830	
CHECKED		

3917

CROSS-SECTIONS

SCALE : Vertical = Horizontal





LEGEND

BRECCIA : brecciated quartzite, quartz vein, quartz + chlorite vein, granite, chlorite schist and altered intrusive (quartz + feldspar + muscovite + chlorite). Clay often present. Breccias are of both mono- and multi- lithic types. Drill core only – DDH 2 and 3.

NEPHRITE : pods mined 1968 –1972, now backhoe pits. Note :- not true to scale; see text for details.

TREMOLITE : grades to nephritic tremolite. Colour and grain size variable but texture is consistently massive. Varieties include white and fine grained, pale to light green, and mid to dark green. Talc and /or chlorite minor. Darker – coloured varieties probably actinolitic. Often limonite stained with trace sulphides and hematite. Minor jade fragments within tremolite in DDH 11. Calcite veining occasionally present. Classification includes 'amphibolite' of Hopwood (1970) and Nichol (1974).

CHLORITE and TALC ± CALCITE SCHIST : dark green, finely – laminated crenulated schist invariably containing veins and lenses of both pink granite and altered intrusive (chlorite + feldspar rock). Occasionally epidote bearing and with coarse – grained tremolite aggregates. Classification includes calcite – chlorite schist and talc schist of Hopwood (1970) and Nichol (1974). Schistosity orientation is shown where known.

EPIDOTE ± QUARTZ : coarse – grained massive epidote in DDH 5 (Nichol, 1974) and massive quartz + epidote rock in outcrop (Hopwood, 1970).

AMPHIBOLITE : hornblende – bearing rather than tremolite – rich. Origin unknown but only outcrops are along the margin of Altered Intrusive.

QUARTZ VEIN : white and predominantly massive but partly foliated. Often with minor chlorite and more rarely epidote, as well as thin veins of aplite, pegmatitic granite and altered intrusive (chlorite + feldspar rock).

GRANITE, APLITE and PEGMATITE : granite is coarse – grained and tends to be foliated, with occasional veins of massive granitic pegmatite. Aplite is distinctly pink and contains minor quartz + chlorite veins.

HYBRID PEGMATITE : characteristically, it consists almost entirely of relict feldspar with later chlorite. Relict but abundant, white to pink K – feldspar contrasts with disseminated aggregates of very fine – grained, dark green to black chlorite. Often grades into chlorite schist. Fine – grained varieties are distinguished but are otherwise identical.

GNEISS : quartz + feldspar + mica gneiss with minor augen. Often weathered. In close proximity to chlorite schist or talc schist, gneiss is partly altered and contains epidote and tremolite – actinolite.

QUARTZITE : predominantly white and foliated, rarely massive. Grades to quartz + mica schist with leucocratic (granitic) segregations. Foliation trend shown where known. Probable Warrow Quartzite.

DOLOMITIC MARBLE : grey to white, coarse – grained (1 – 3mm) and predominantly massive. Scattered pale to mid green, slightly translucent stringers of tremolite.

OUTCROP	DDH No.	TOTAL DEPTH(m)	ANGLE	TREND (°T)
40	1	20·20	45	271
41	2	39·75	45	271
42	3	17·53	45	310
	4	25·53	45	305
	12	12·70	70	358
	13	10·65	65	243
43	5	24·38	60	262
	9	12·20	90	–
	10	13·85	90	–
	11	12·30	55	248

All drilling by J. Jensen, SADME.

DDH 1 – 5 drilled for Analytical Exploration Pty. Ltd., 1970

DDH 9 – 13 drilled for Centamin N.L., 1973

None of the drill sites have been surveyed since drilling

———	Geological boundary – observed
—?——?—	Geological boundary – inferred (cross section only)
– – – –	Outcrop boundary
▬▬▬	Fault
——52——	Topographic contour, 2m interval (arbitary height datum)
A B	Cross section
ML 3426	Mineral Lease No. 3426
△	Survey station
⊙ DDH 5	Diamond drillhole – vertical
⊙→ DDH 4	Diamond drillhole – inclined
⬭	Open pit
75	Foliation, strike and dip
→ 35	Lineation in foliation, plunge and trend
oooooooooo S_2	Axial plane of D_2 fold (cross section only)
P242/74 (p.d.)	Sample locality and number (position doubtful)

Geological map modified from Hopwood (1970)

FIG. 30

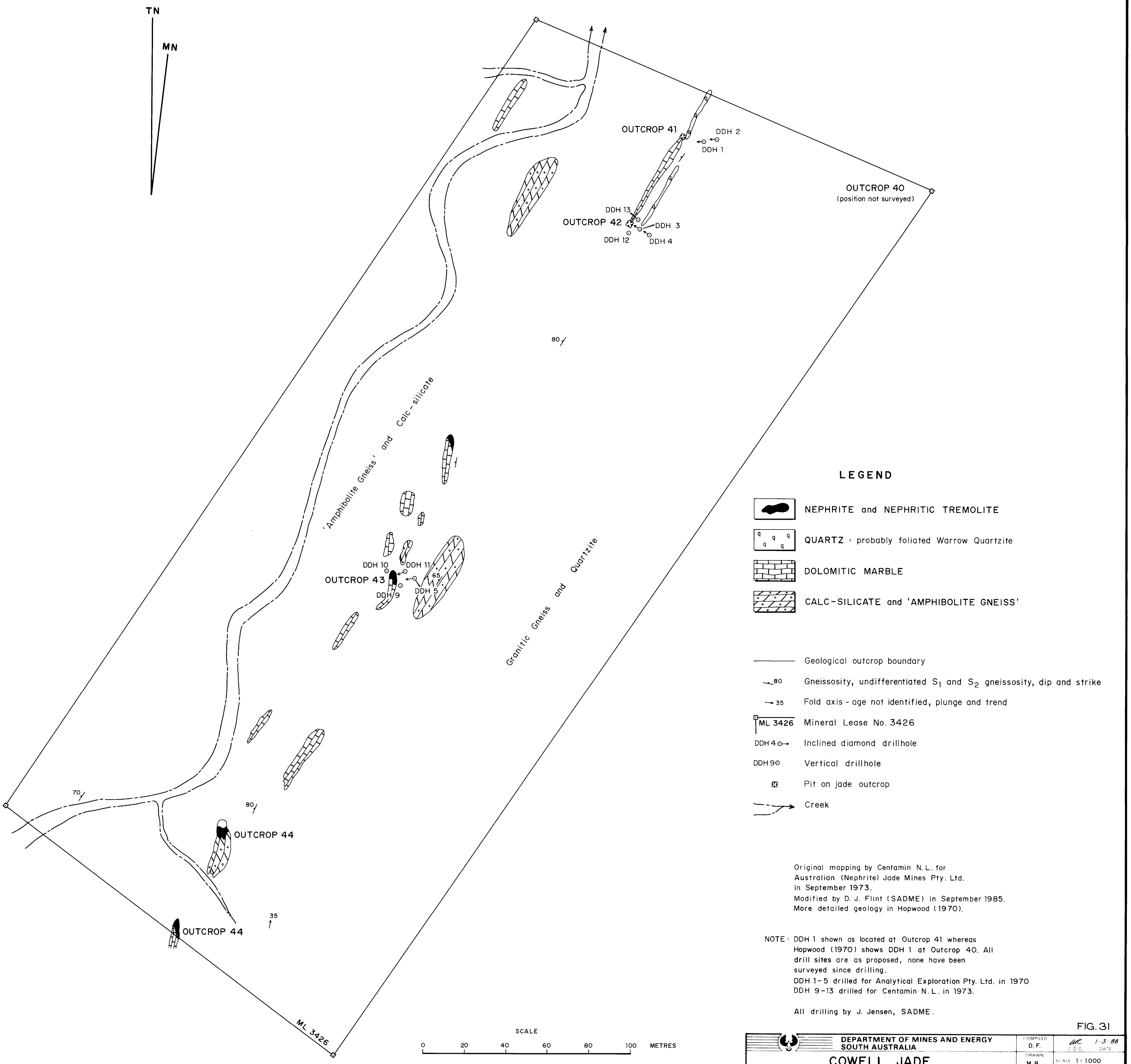
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

OUTCROPS 40-43
INTERPRETATIVE GEOLOGICAL MAP

COMPILED D. F.
WC 1·3·88
DRAWN M.B.
SCALE 1: 1000
DATE Nov '85
CHECKED
PLAN NUMBER 88-88

3917



Original mapping by Centamin N. L. for
Australian (Nephrite) Jade Mines Pty. Ltd.
in September 1973.
Modified by D. J. Flint (SADME) in September 1985.
More detailed geology in Hopwood (1970).

NOTE: DDH 1 shown as located at Outcrop 41 whereas Hopwood (1970) shows DDH 1 at Outcrop 40. All drill sites are as proposed, none have been surveyed since drilling.
DDH 1-5 drilled for Analytical Exploration Pty. Ltd. in 1970
DDH 9-13 drilled for Centamin N. L. in 1973.

All drilling by J. Jensen, SADME.

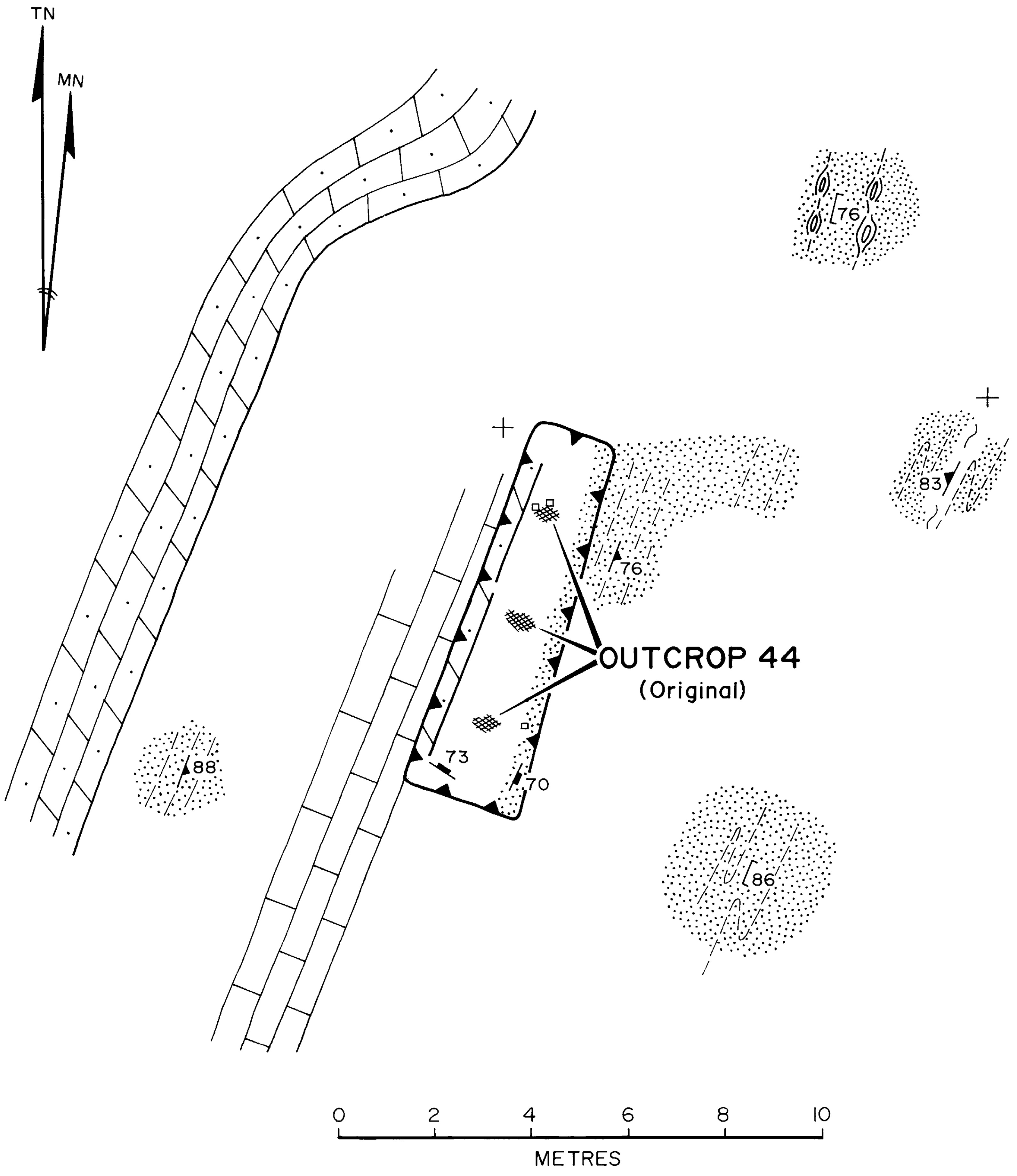
FIG. 31

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

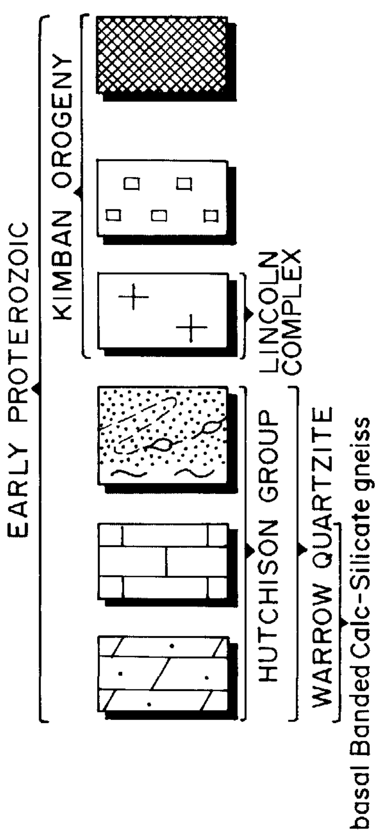
COWELL JADE
OUTCROPS 40-44
GEOLOGICAL MAP

COMPILED D. F.	ue 1-3-88	EDO DATE
DRAWN M. B.	SCALE 1:1000	
DATE Nov '85	PLAN NUMBER	
CHECKED	88-87	

3917



Geology by Robertson and Flint, 1985
Backhoe mining by Cowell Jade Pty Ltd, March 1985.



NEPHRITE and SEMI-NEPHRITE : Massive with no banding or D$_4$ schistosity. Original outcrops small and rubbly. Nephrite variable quality. Highest quality had black, extremely fine grained, homogeneous massive texture but with epidote inclusions to 20 mm across. Also dark green nephrite grading to poorer grades and massive, pale green milky opaque tremolitite. Rarer pieces contain tremolite needles to 20 mm long in nephrite and semi-nephrite matrix.

TREMOLITE : Massive, but with dark green radiating aggregates of tremolite/actinolite needles at least several mm across. Less often, finer grained and milky opaque.

PEGMATITE

QUARTZITE : Grades from quartz + mica schist to rubbly, massive quartzite. Pelitic clots with retrograded sillimanite (-○-) present. Minor quartzofeldspathic (migmatic) gneiss (~). D$_2$ isoclinal folds abundant with axial planar gneissosity containing flattened? sillimanite clots.

DOLOMITIC MARBLE : Coarse grained (2–4mm), grey when fresh but dark brown on weathered surfaces. Relatively pure with only traces of serpentine.

CALC-SILICATE : Massive to poorly banded, quartz-rich and epidote abundant. Hornblende and diopside present.

Lithological layering and undifferentiated S$_1$/S$_2$ gneissosity; dip and strike.

Gneissosity - S$_2$; dip and strike.

Joint-S$_4$; dip and strike.

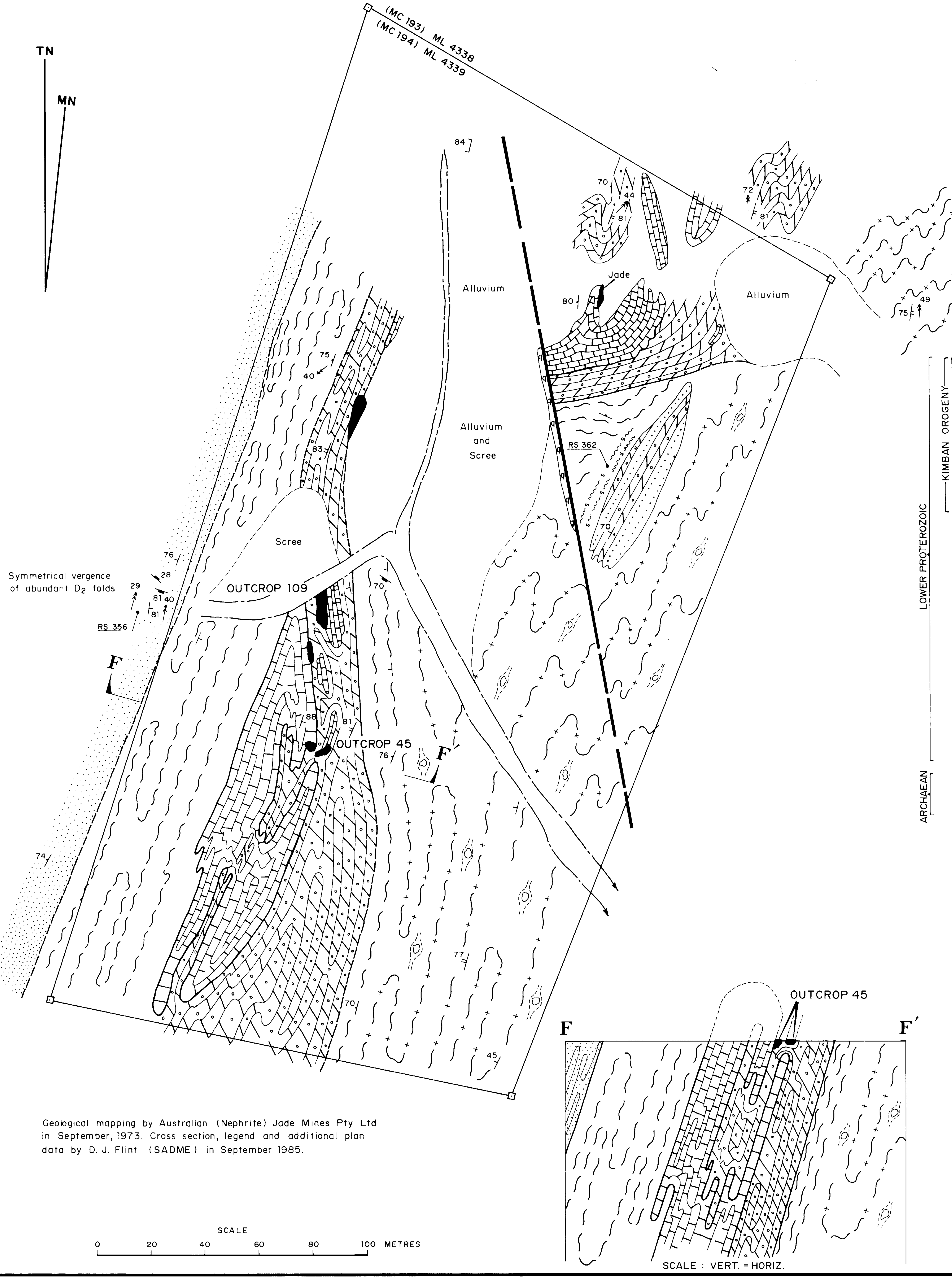
Geological boundary.

Backhoe pit (2·6m deep).

FIG. 32

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED D.J. Flint	4.7.91 CDO DATE
COWELL JADE	DRAWN J.W.	SCALE 1:100
OUTCROP 44 GEOLOGICAL MAP	DATE CHECKED	PLAN NUMBER 88-428

39/7



Geological mapping by Australian (Nephrite) Jade Mines Pty Ltd in September, 1973. Cross section, legend and additional plan data by D. J. Flint (SADME) in September 1985.

LOWER PROTEROZOIC — KIMBAN OROGENY — LINCOLN COMPLEX — MINBRIE GNEISS — HUTCHISON GROUP — WARROW QUARTZITE — BASAL BANDED CALC-SILICATE GNEISS — ARCHAEAN — MILTALIE GNEISS

NEPHRITE and NEPHRITIC TREMOLITE : tends to be coarse-grained, dark green and only of marginal quality. Often foliated with an ? S_2 foliation.

TREMOLITE : coarse-grained with radiating clusters and interwoven mats containing tremolite fibres up to 1-2 cm long.

QUARTZ VEIN : thin vein along a fault interpreted to be synchronous with D_4.

MIGMATITE GNEISS : quartz + feldspar + biotite gneiss with minor muscovite-rich bands.

QUARTZITE : fine to medium-grained, off-white to grey quartzite. Minor small pods of diopside. Interlayed with intrusive grey gneissic granodiorite (RS 356). Abundant mesoscopic isoclinal D_2 folds. Probably Warrow Quartzite.

EPIDOTIC QUARTZITE : grades to calc-silicate but contains a distinctive epidotic quartzite. Adjacent units, including gneiss, are also epidotised.

SERICITIC SCHIST : extensively retrogressed, formerly a gneiss containing plagioclase or an alumino-silicate. Reddish-brown and weathered with sericite-rich aggregates. Dominant foliation is retrogressive and is S_2 or S_3/S_m. RS 362.

CALC-SILICATE : mixed unit containing siliceous banded gneiss, chloritised biotite gneiss and minor micaceous (? pelitic) gneiss. Bands of epidote, tremolite/actinolite and chlorite commonly present. Pegmatite containing epidote veins also present. Abundant D_2 folds. In places, including on eastern margin of jade outcrop 45, calc-silicate is strongly sheared and schistose.

DOLOMITIC MARBLE : grey and coarse-grained. Irregular banding and disseminations of yellow serpentine, pale green tremolite and diopside, and dark green chlorite.

GNEISSIC AUGEN GRANITE : quartz + feldspar + biotite gneiss, locally varying to grey granodiorite gneiss and migmatite. Augen of K-feldspar. Contains abundant mesoscopic D_2 folds and with an axial planar schistosity/gneissosity. Interpreted as a syn-D_2 intrusive.

——	Geological boundary - observed
- - - -	Geological boundary - approximate
▬▬	Fault
76	Compositional banding (S_0/S_1), dip and strike
80	Gneissosity - undifferentiated S_1 and S_2 gneissosity, dip and strike
84	Gneissosity - S_2, dip and strike
81	Axial plane to F_2 fold, dip and strike
29	Fold axis to F_2 fold, plunge and trend
81	Joint, dip and strike
ML 4339	Mineral Lease No. 4339 (formerly Mineral Claim No. 194)
RS 356	Sample locality and number, prefixed by 6230
→	Creek
F F′	Cross - section (schematic)

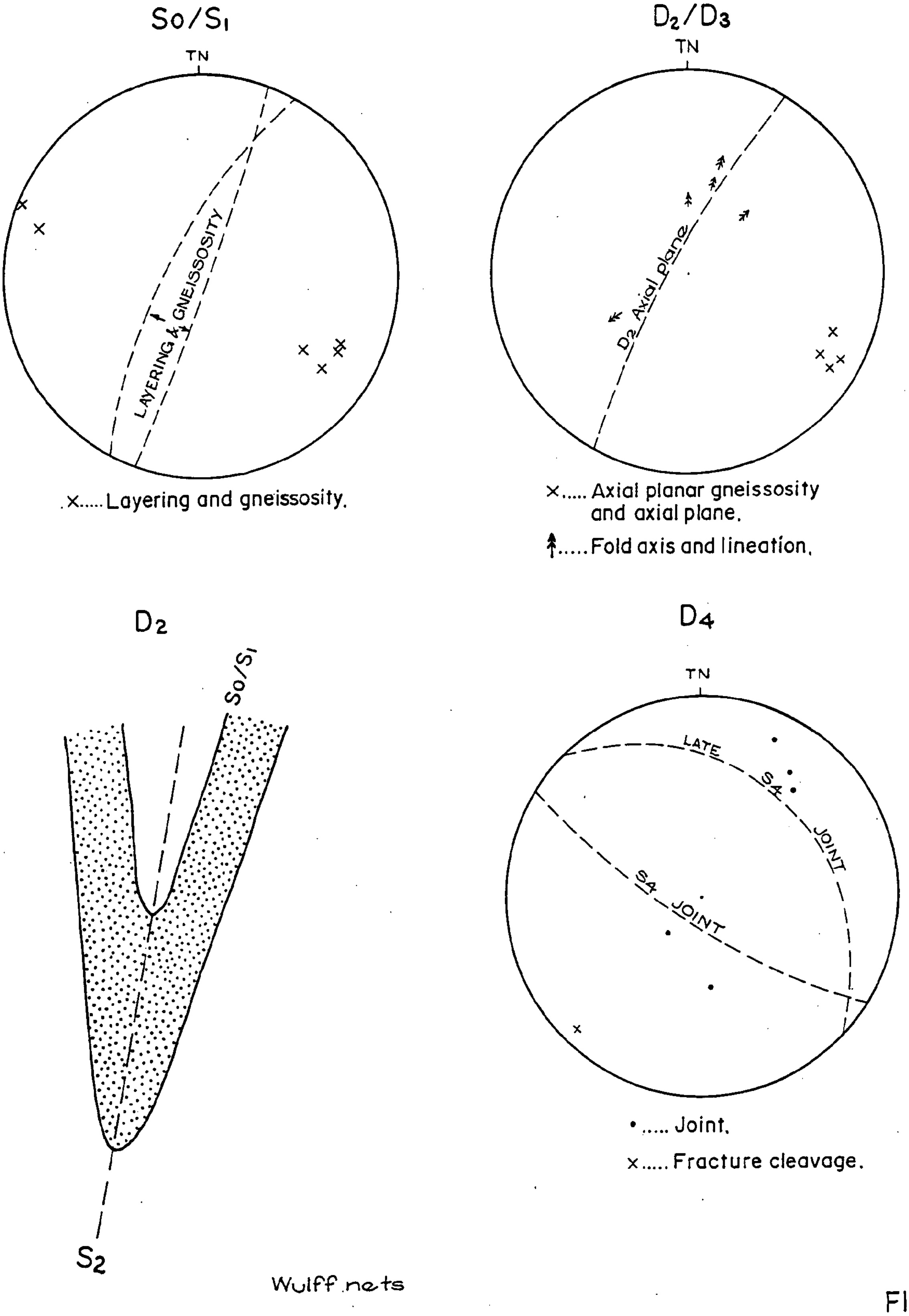
FIG. 33

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
GEOLOGICAL MAP - ML 4339
OUTCROPS 45 and 109, CROSS SECTION F-F'

COMPILED D. F.	C D O DATE 1 · 3 · 88
DRAWN M. B.	SCALE 1 : 1000
DATE Nov '85	PLAN NUMBER 88-89
CHECKED	

3917



×..... Layering and gneissosity.

×..... Axial planar gneissosity and axial plane.

↟..... Fold axis and lineation.

•..... Joint.

×..... Fracture cleavage.

Wulff nets

FIG. 34

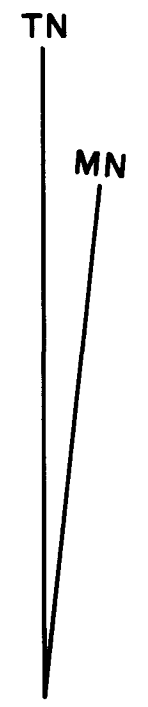
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

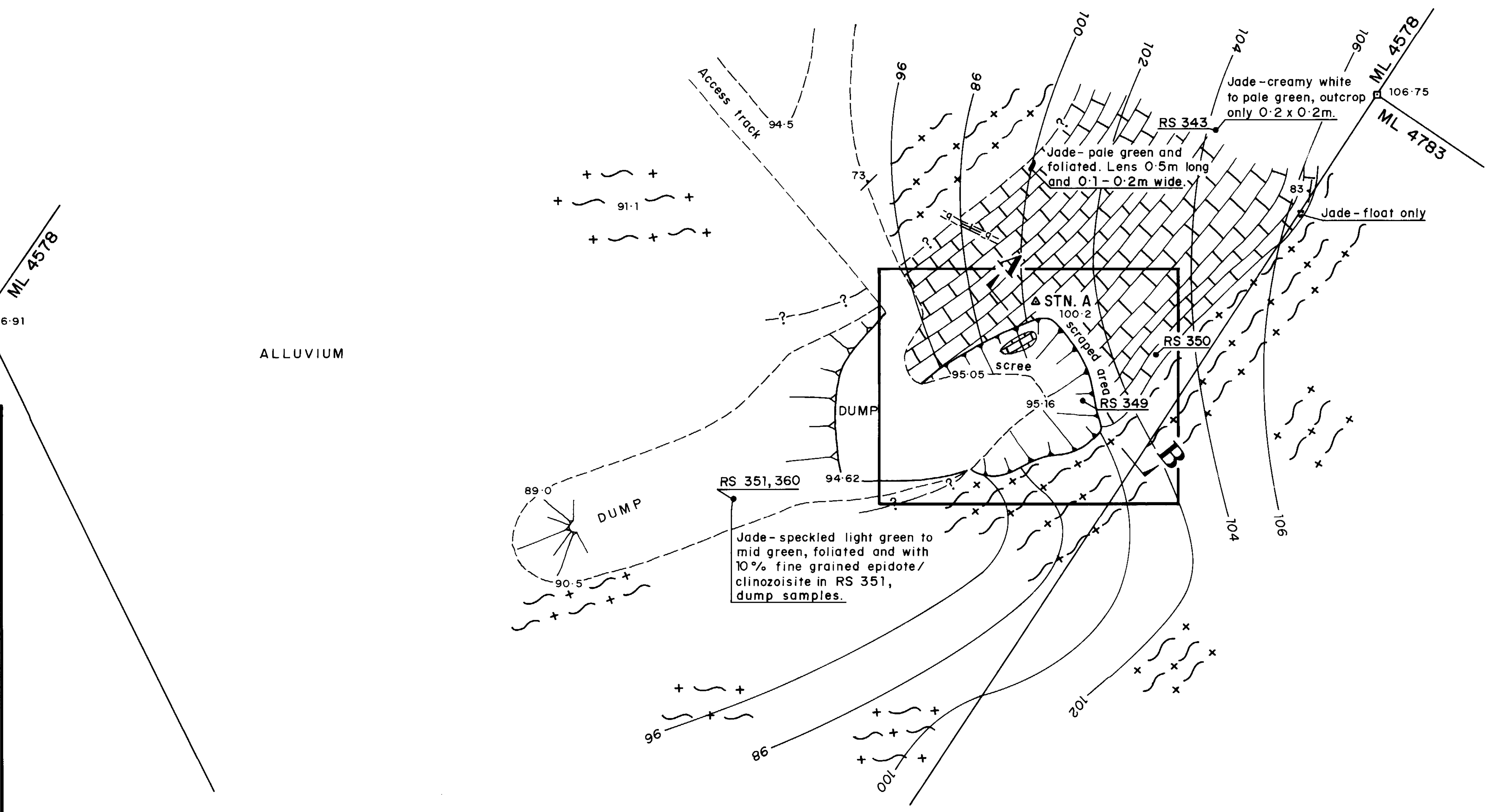
COWELL JADE

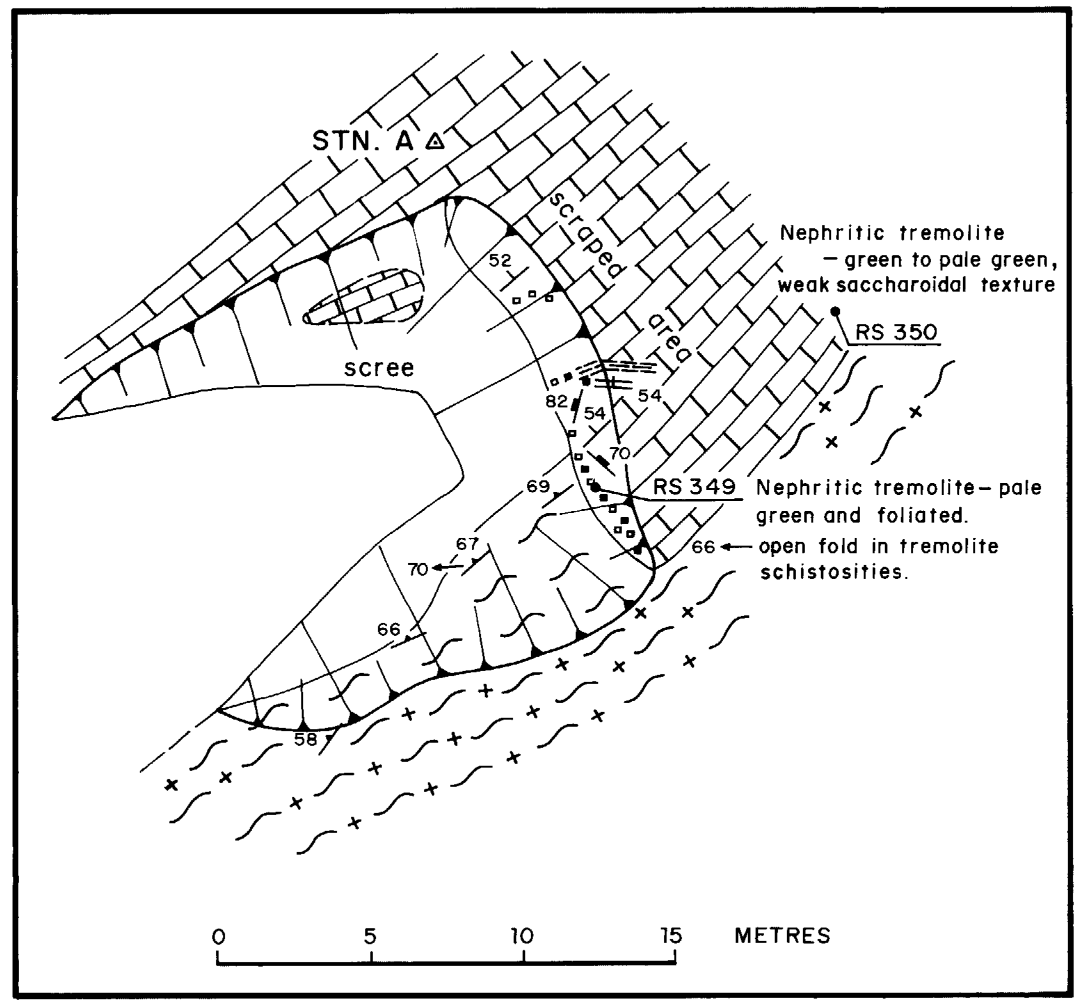
OUTCROPS 45 AND 109
STEREOGRAPHIC PROJECTIONS

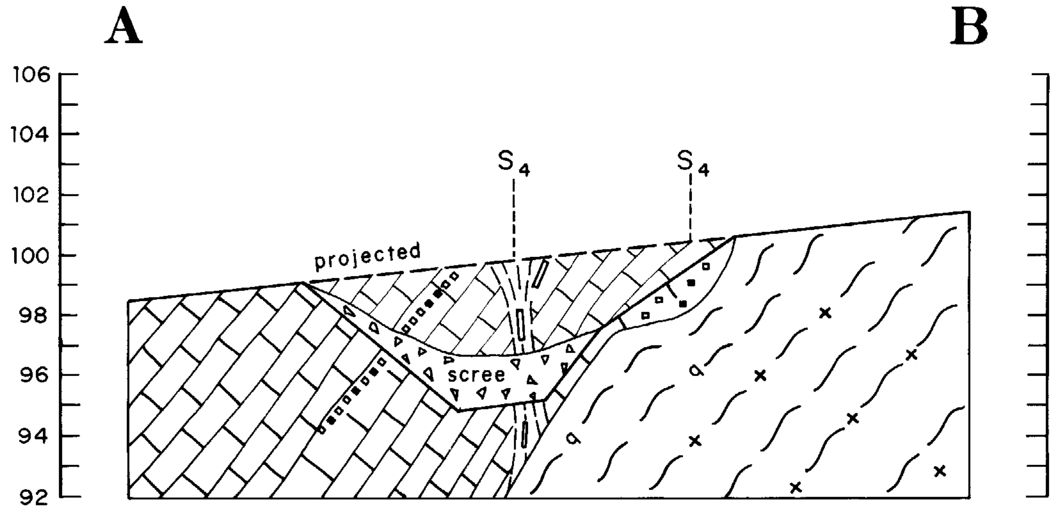
COMPILED D.J. Flint	4-7-91 DATE
DRAWN J.W.	SCALE
DATE 6-9-88	PLAN NUMBER S20218
CHECKED	

3917









SCALE

0 10 20 30 40 50 METRES

Surveying by A. J. Smith, S.F.B. 681

Assumed datum – 100m at Station A

Geological mapping by D. J. Flint and E. A. Dubowski

LEGEND

TREMOLITE : off-white to pale green massive and schistose tremolite with minor chlorite ± talc. Retrogressive assemblage within marble bands parallel to lithological layering and in cross-cutting S_4 shear zones. Grades to nephrite when fine grained.

NEPHRITE and NEPHRITIC TREMOLITE : off-white to pale green but often with colour mottling due to irregular distribution of fine grained green nephrite and off-white patches of coarser tremolite. Saccharoidal texture in RS 350 is from fibrous mats in distinct aggregates up to 4mm and reflecting a relict former grain size of ?carbonate or ?diopside. Often foliated and occasionally crenulated also.

DOLOMITIC MARBLE : grey and coarse grained with an average grain size of 2-3mm. Dark brown on weathered surfaces. Mostly massive with only minor bedding with layer parallel bands of retrogressive serpentine, tremolite ± talc ± chlorite.

MIGMATITE GNEISS : pinkish red migmatite gneiss with massive quartzofeldspathic segregations dominating. On southern wall of quarry, gneiss is banded, dark grey to black and biotite rich.

QUARTZ VEIN : contains an S_4 foliation.

52 Lithological layering; dip and strike

73 Gneissosity (undifferentiated S_1/S_2); dip and strike

54 S_4 foliation and tremolite schistosity; dip and strike

S_4 foliation and tremolite schistosity

→66 F_4 fold axis; plunge and trend

70 Joint; dip and strike

Geological boundary; mapped
; approximate
--?-- ; inferred

scree Quarry face and scree

Dump

Access track

ML 4578 Mining Lease No. 4578

RS 349 Sample locality and number, RS number is prefixed by 6230

△ STN. A Survey station

—96— Topographic contour, 2m interval

95·16 Spot height in metres

A B Cross section

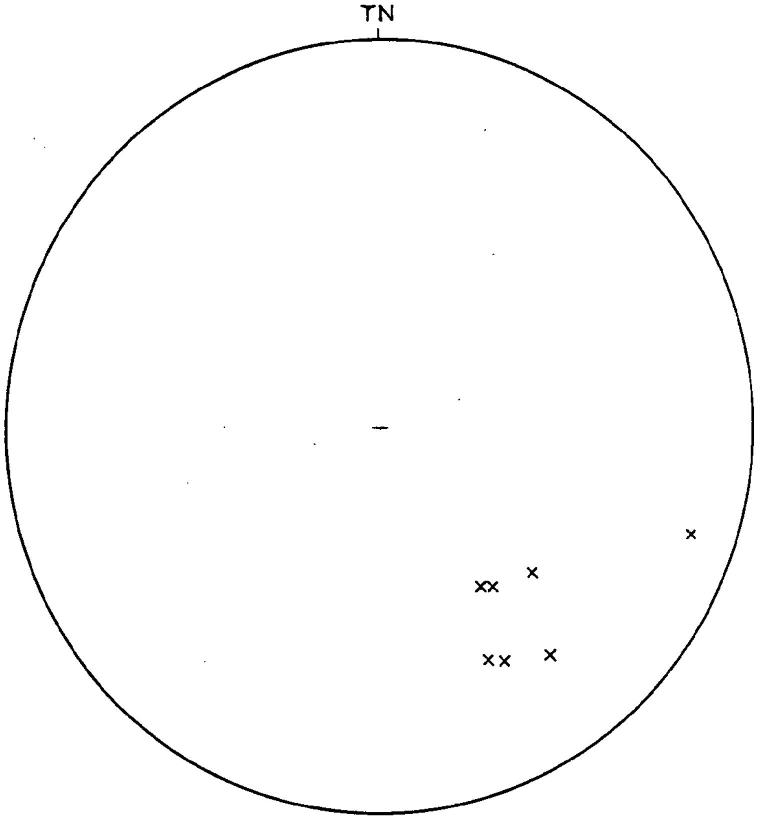
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

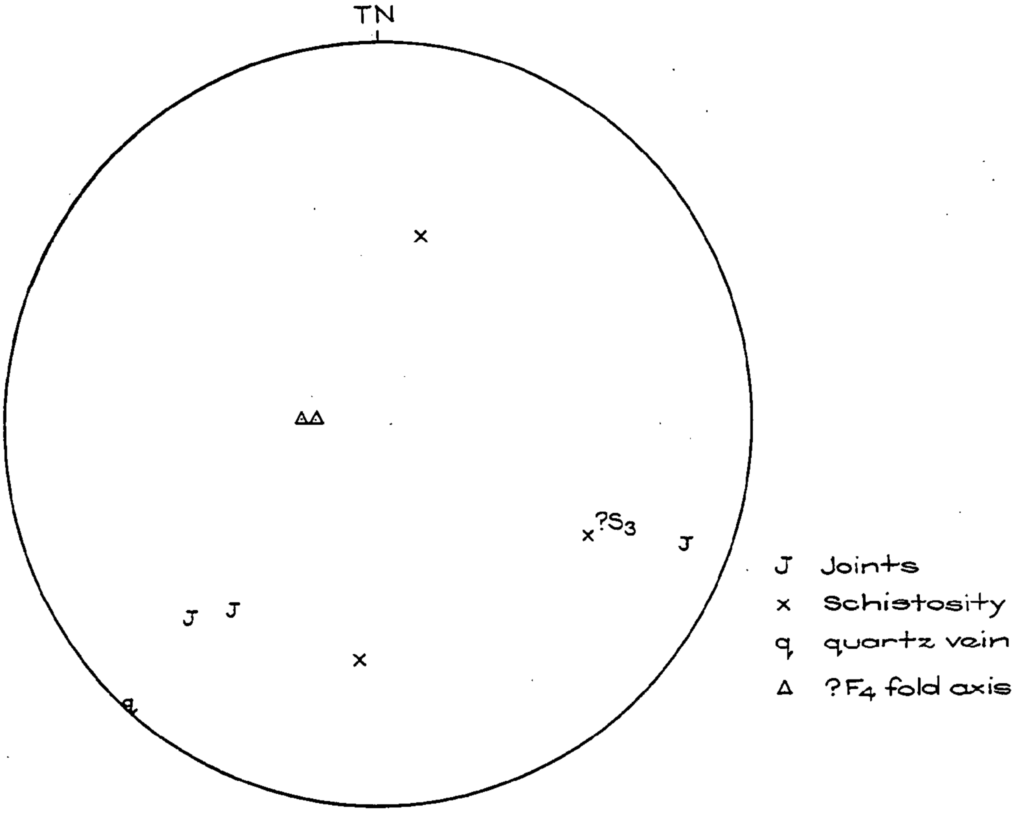
GEOLOGICAL MAP – ML 4578 and 4783
OUTCROP 52, CROSS SECTION A – B

COMPILED D. F.	WR 1·3·88 C D O DATE
DRAWN M. B.	SCALE 1:500
DATE Nov '85	PLAN NUMBER 88-90
CHECKED	

3917



S1/S2 - LAYERING AND GNEISSOSITY



S4 - JOINTS, SCHISTOSITIES AND QUARTZ VEIN

FIG. 36

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 52
STEREOGRAPHIC PROJECTIONS

COMPILED D. Flint	BF C.D.O.	4-7-91 DATE
DRAWN J.W.	SCALE	
DATE 6-9-88	PLAN NUMBER S20219	
CHECKED		

3917

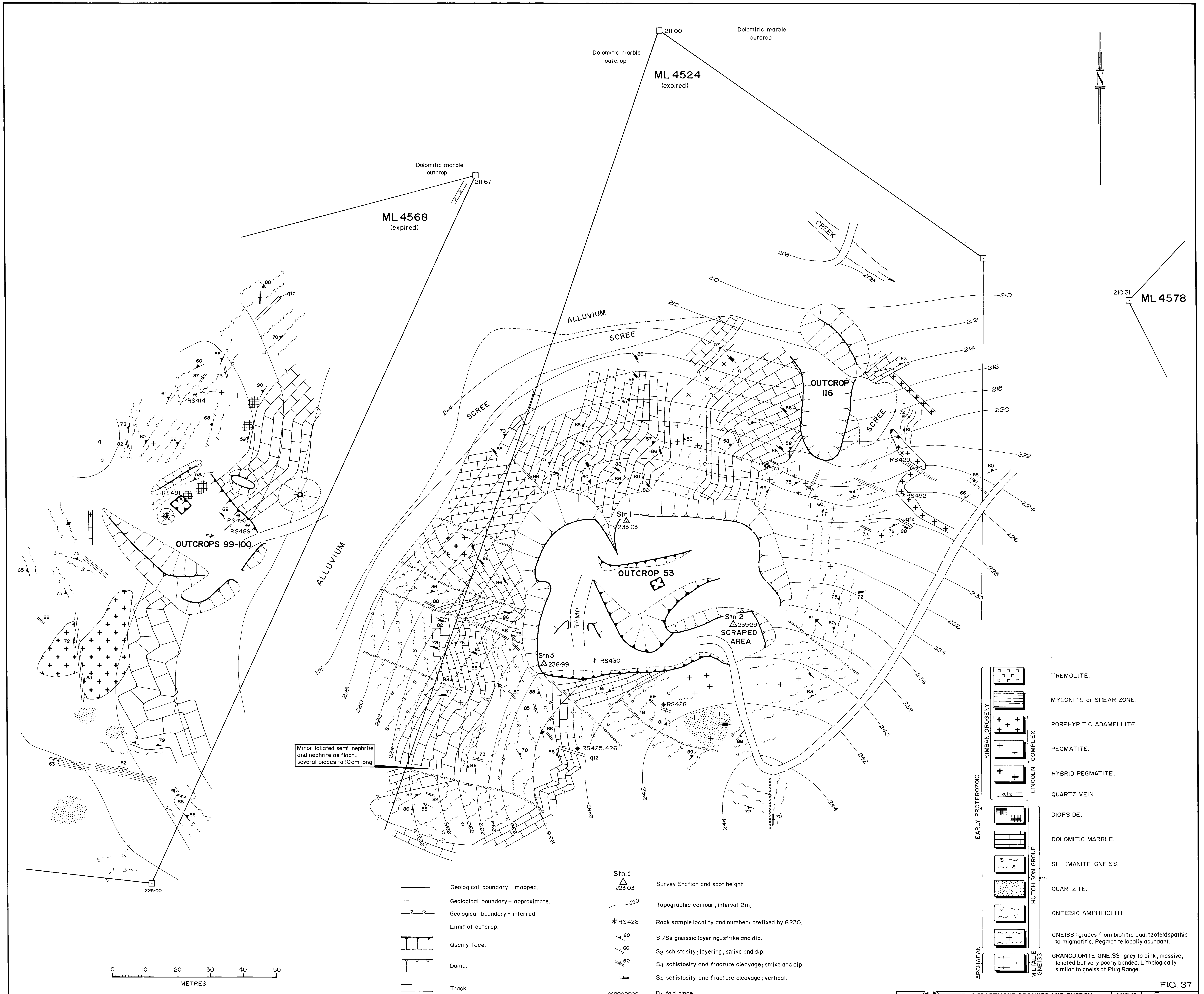


FIG. 37

NOTE : Geological mapping by D.J.Flint, E.A.Dubowski, W.Simandjuntak and A.Sulaeman.
EDM Survey by A.J.Smith, April 1987; SFB 815.
Datum approximate A.H.D. of 211·00m at N corner post of ML4524 (expired). Datum bearing MN.
Lease boundaries from a combination of survey data - this survey and of Hack (1976)
i.e. SADME plans 76-263 and 76-264.
Outcrops 53, 99-100 and 116 and ML4524 and ML4568 tied into Outcrop 52 (ML4578 and ML4783) but not plotted.

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 53, 99-100 AND 116
GEOLOGICAL PLAN

COMPILED D.J.Flint	4·7·91	C.D.O. DATE
DRAWN J.W.	SCALE 1:500	
DATE May '89	PLAN NUMBER	
CHECKED	89-181	

3917

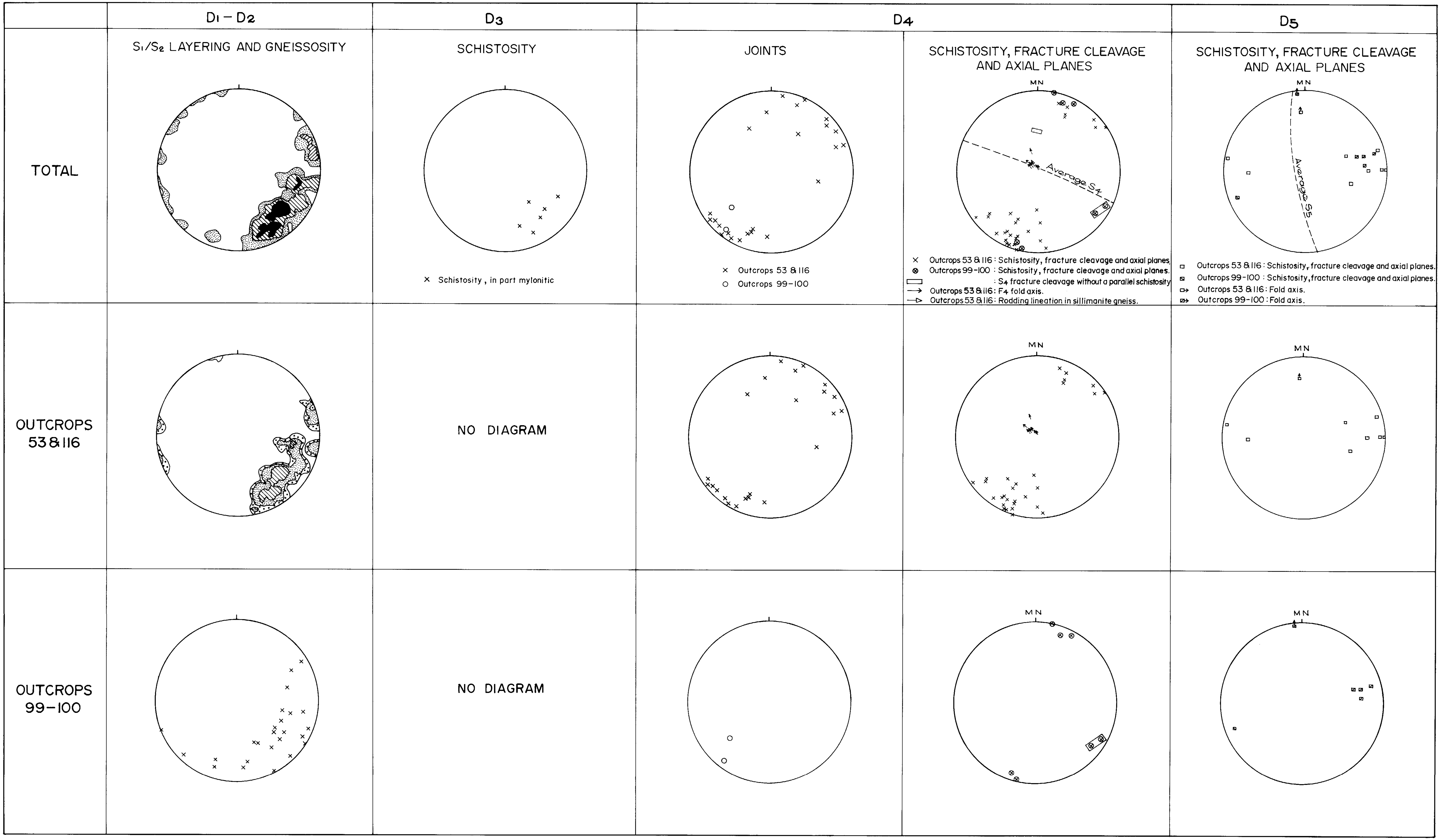


FIG. 38

Lower hemisphere projections:
Contoured – Schmidt net.
Raw data – Wulff net.

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 53, 99-100 & 116
STEREOGRAPHIC PROJECTIONS

COMPILED	D. Flint	C.D.O.	DATE
DRAWN	J.W.	SCALE	
DATE	May '89	PLAN NUMBER	
CHECKED		89-186	

Coarse-grained, light green, massive to foliated (S4) tremolite bands to 30 cm thick along marble contacts.

Light green, massive to foliated, nephrite and semi-nephrite to 8cm thick along diopside contact. Often with sparkle on fractured surface

Light green nephrite foliated

Fine-grained, pale green, tremolitic schist with coarse grained, radiating actinolite aggregates to 4cm

Tremolite schist, 1m thick, pale green fine grained.

Tremolite schist (pale green, fine grained, opaque) grading to nephrite (light to medium green, translucent). Band 10-15cm thick. D4 foliation.

UNLOCATED SAMPLING
RS427 Jade; float.
RS423 Chlorite schist; float.

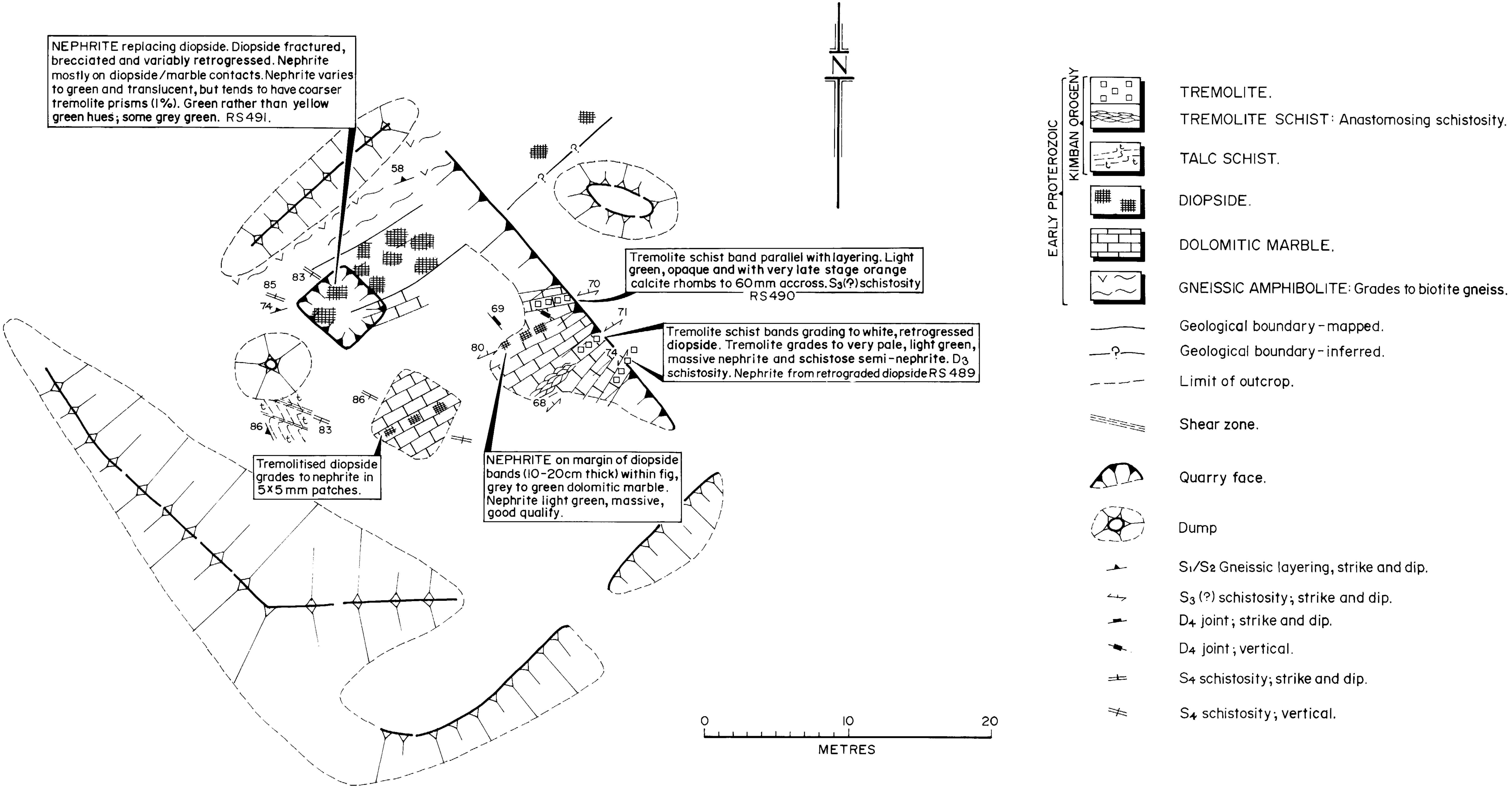
FIG. 39

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 53
GEOLOGICAL PLAN

COMPILED D. Flint	4.7.91 C.D.O DATE
DRAWN J.W.	SCALE 1:250
DATE Feb 1989	PLAN NUMBER 89-180
CHECKED	

3917



NEPHRITE replacing diopside. Diopside fractured, brecciated and variably retrogressed. Nephrite mostly on diopside/marble contacts. Nephrite varies to green and translucent, but tends to have coarser tremolite prisms (1%). Green rather than yellow green hues; some grey green. RS491.

Tremolite schist band parallel with layering. Light green, opaque and with very late stage orange calcite rhombs to 60mm accross. S_3(?) schistosity RS490

Tremolite schist bands grading to white, retrogressed diopside. Tremolite grades to very pale, light green, massive nephrite and schistose semi-nephrite. D_3 schistosity. Nephrite from retrograded diopside RS 489

Tremolitised diopside grades to nephrite in 5×5 mm patches.

NEPHRITE on margin of diopside bands (10-20cm thick) within fig, grey to green dolomitic marble. Nephrite light green, massive, good quality.

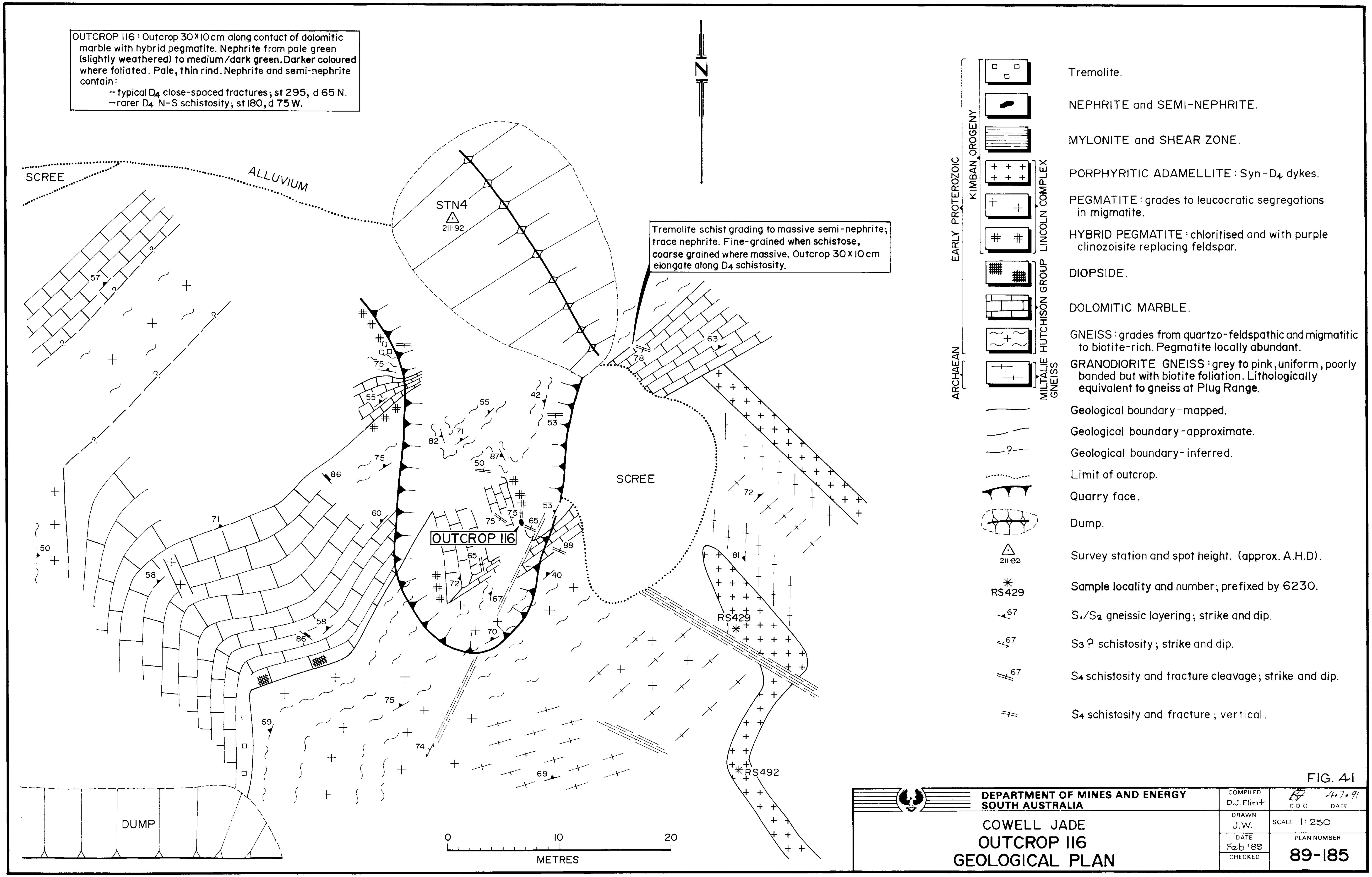
FIG. 40

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

OUTCROPS 99-100
GEOLOGICAL PLAN

COMPILED D.Flint	C.D.O	DATE 4-7-91
DRAWN J.W.	SCALE 1:250	
DATE Feb '89	PLAN NUMBER 89-183	
CHECKED		



OUTCROP 116 : Outcrop 30 x 10 cm along contact of dolomitic marble with hybrid pegmatite. Nephrite from pale green (slightly weathered) to medium/dark green. Darker coloured where foliated. Pale, thin rind. Nephrite and semi-nephrite contain:

- typical D_4 close-spaced fractures; st 295, d 65 N.
- rarer D_4 N-S schistosity; st 180, d 75 W.

Tremolite schist grading to massive semi-nephrite; trace nephrite. Fine-grained when schistose, coarse grained where massive. Outcrop 30 x 10 cm elongate along D_4 schistosity.

EARLY PROTEROZOIC — KIMBAN OROGENY

Tremolite.

NEPHRITE and SEMI-NEPHRITE.

MYLONITE and SHEAR ZONE.

LINCOLN COMPLEX

PORPHYRITIC ADAMELLITE : Syn-D_4 dykes.

PEGMATITE : grades to leucocratic segregations in migmatite.

HYBRID PEGMATITE : chloritised and with purple clinozoisite replacing feldspar.

HUTCHISON GROUP

DIOPSIDE.

DOLOMITIC MARBLE.

GNEISS : grades from quartzo-feldspathic and migmatitic to biotite-rich. Pegmatite locally abundant.

ARCHAEAN — MILTALIE GNEISS

GRANODIORITE GNEISS : grey to pink, uniform, poorly banded but with biotite foliation. Lithologically equivalent to gneiss at Plug Range.

Geological boundary - mapped.

Geological boundary - approximate.

Geological boundary - inferred.

Limit of outcrop.

Quarry face.

Dump.

Survey station and spot height. (approx. A.H.D).

Sample locality and number; prefixed by 6230.

S_1/S_2 gneissic layering; strike and dip.

S_3? schistosity; strike and dip.

S_4 schistosity and fracture cleavage; strike and dip.

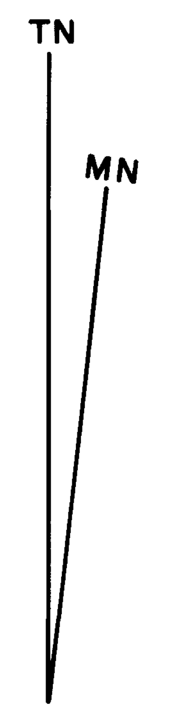
S_4 schistosity and fracture; vertical.

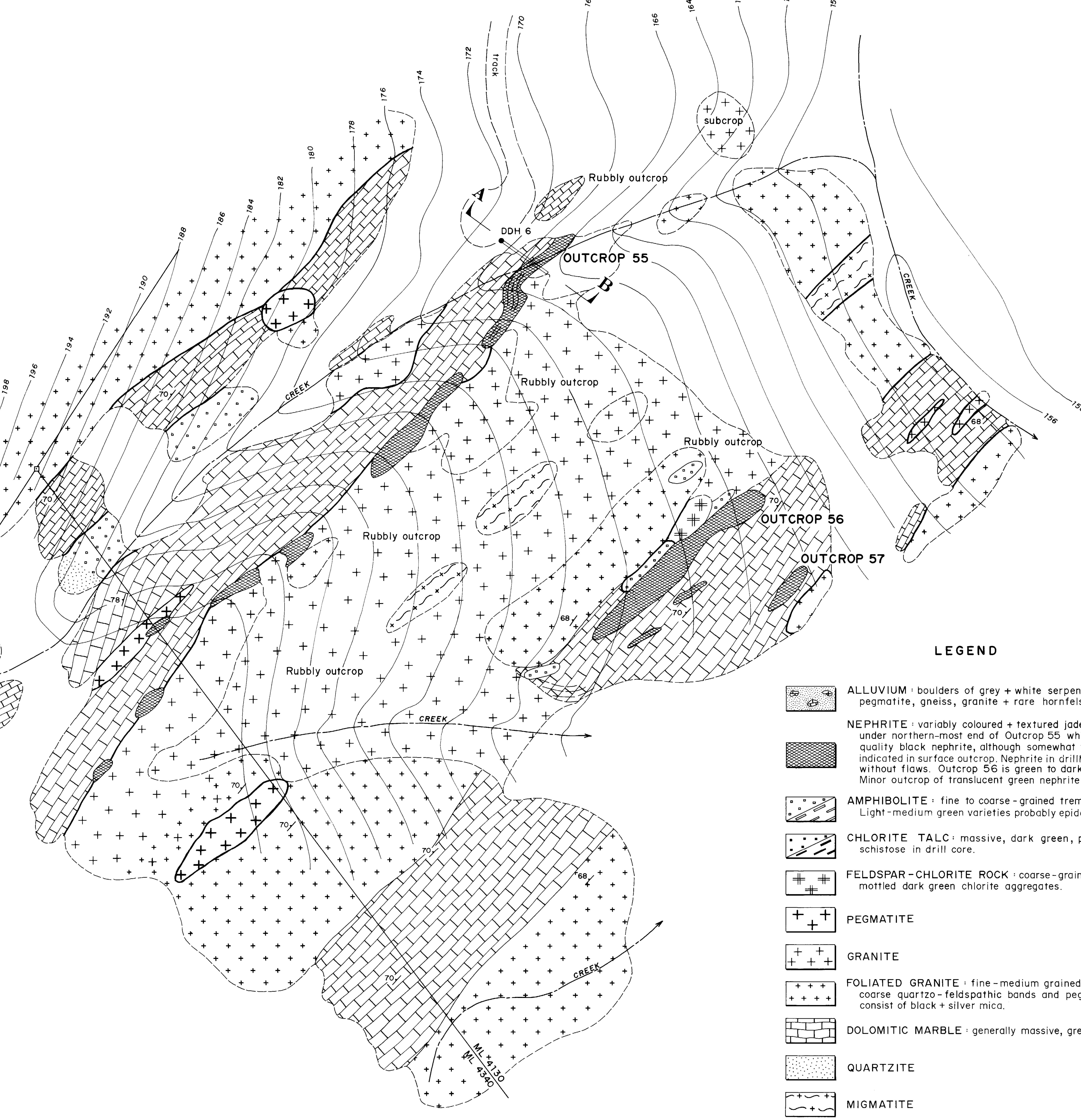
FIG. 4·1

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 116
GEOLOGICAL PLAN

COMPILED D.J. Flint	C.D.O.	DATE 4.7.91
DRAWN J.W.	SCALE 1:250	
DATE Feb '89	PLAN NUMBER	
CHECKED	89-185	



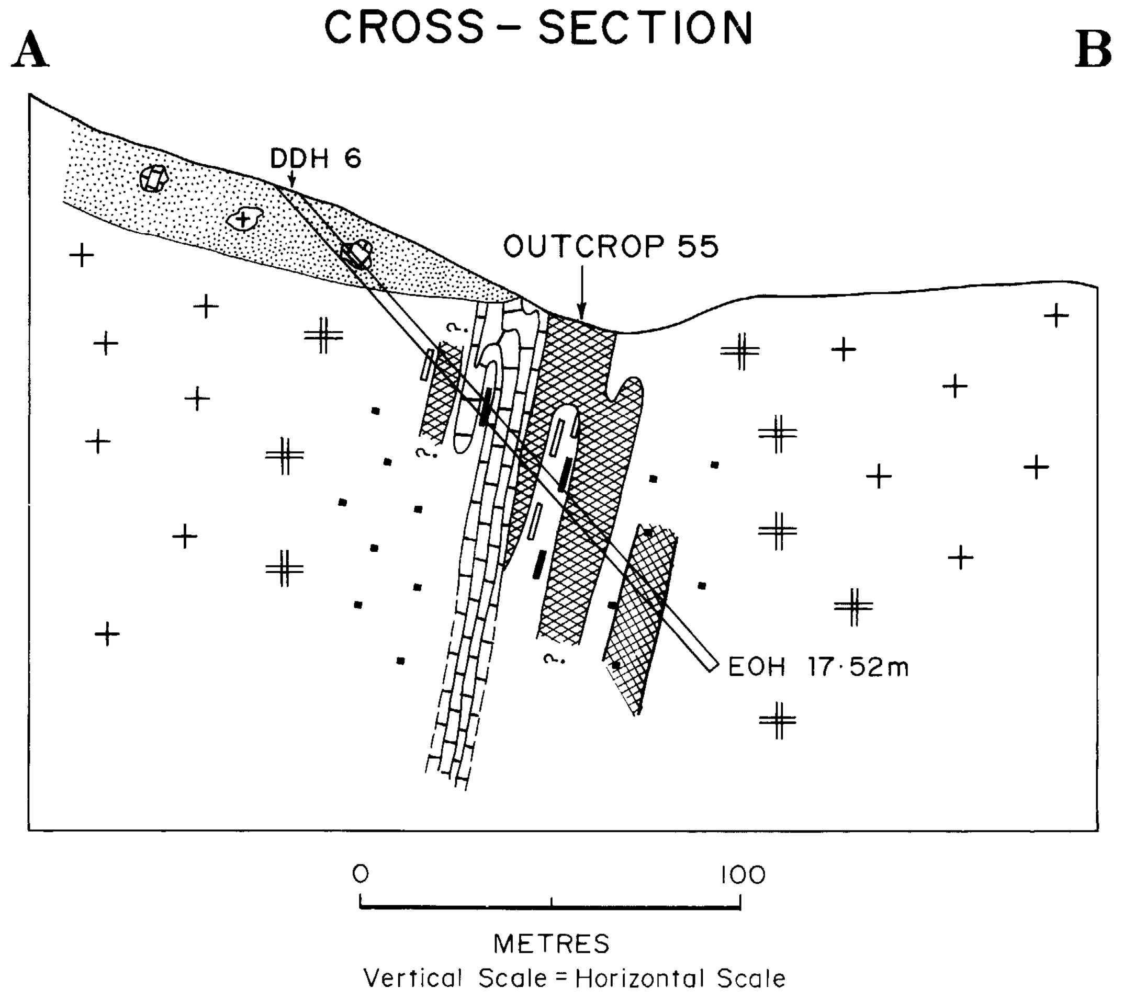


LEGEND

⁘	**ALLUVIUM** : boulders of grey + white serpentinous marble pegmatite, gneiss, granite + rare hornfels.
▩	**NEPHRITE** : variably coloured + textured jade. DDH 6 sited to drill under northern-most end of Outcrop 55 which was described as good quality black nephrite, although somewhat flawed. Foliations are indicated in surface outcrop. Nephrite in drillhole is indicated as black without flaws. Outcrop 56 is green to dark green and coarse-grained. Minor outcrop of translucent green nephrite was recorded.
▫	**AMPHIBOLITE** : fine to coarse-grained tremolite and epidote rocks. Light-medium green varieties probably epidote rich.
▪	**CHLORITE TALC** : massive, dark green, probably foliated and schistose in drill core.
╪ ╪	**FELDSPAR-CHLORITE ROCK** : coarse-grained white-pink feldspar with mottled dark green chlorite aggregates.
+ +	**PEGMATITE**
+ + +	**GRANITE**
+ + + +	**FOLIATED GRANITE** : fine-medium grained grey gneissic granite with coarse quartzo-feldspathic bands and pegmatite; minor schlieren consist of black + silver mica.
▦	**DOLOMITIC MARBLE** : generally massive, grey, coarsely crystalline.
░	**QUARTZITE**
~	**MIGMATITE**

———	Geological boundary - observed
- - -	Outcrop boundary - observed
—168—	Topographic contour, 2m interval, arbitary datum
≈	Trend of foliation in outcrop
70	Undifferentiated S_1/S_2 foliation or gneissosity
A DDH 6 B	Cross section and plan projection of DDH 6
ML 4130	Mineral Lease No. 4130

CROSS-SECTION



SCALE

0 10 20 30 40 50 METRES

Geological map modified from Hopwood & Coles (1971)

FIG. 42

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

OUTCROPS 55-57
GEOLOGICAL MAP

COMPILED E.Dubowski	C.D.O. *[initials]* DATE 1·3·88
DRAWN M.B.	SCALE 1:500
DATE Nov '85	PLAN NUMBER 88-91
CHECKED	

3917

NEPHRITE: Pale grey green, fine grained, weakly foliated in part (S_4)

NEPHRITE: Light grey green, opaque, fine grained, massive, contains relict diopside and diopside masses

NEPHRITE: Grades to light green, fine-grained, tremolite schist. Grades to ? breccia with monominerallic aggregates of epidote, tremolite and chlorite; each to 70 x 30 cm

NEPHRITE: Light grey green, fine grained, opaque, in part foliated with S_4 fracture cleavage and schistosity

NEPHRITE: Translucent, bottle-green, weak ? S_4 foliation. Outcrop 0·4 x 0·4m

SEMI-NEPHRITE grading to TREMOLITE SCHIST: Pale greyish green, schistose, tends to be opaque, tremolite prisms visible and to 0·5–1·0 mm long.

SEMI-NEPHRITE: Main lens 3m long x 0·45m wide. Schistose with interpreted S_3 schistosity–grades to tremolite schist. Pale grey green opaque, distinct sparkle on fracture surfaces with tremolite prisms to 1mm. Outcrop elongate along schistosity.

NEPHRITE: Pale grey-green, medium to coarse grained, S_4 foliation in places, finer grained in narrow bands parallel to D_4 joints

NEPHRITE and SEMI-NEPHRITE: Pale to medium green and foliated in part with both an interpreted S_3 schistosity as well as S_4 joints and schistosity. Diopsidic inclusions. Grey, opaque semi-nephrite has distinct sparkle on fracture surfaces with tremolite prisms to 0·55mm and a partly-granular texture. Nephrite lens averages 0·8m thick

NEPHRITE: Fine to medium grained, pale green, mottled, foliated

OUTCROP 57: Size 1x1m, medium to pale green, S_4 foliation present.

SEMI-NEPHRITE: Fine-grained, very pale green, iron-stained along fractures, moderately foliated. Adjacent marble is diopsidic and partly altered to tremolite/nephrite

NEPHRITE: Scattered bouldery outcrop. Boulders to 30 cm long. Contains coarse-grained inclusions of diopside and tremolite

NEPHRITE: L=35cm, W=15cm, H=20cm Pale green to green grey, opaque, medium to fine grained.

NEPHRITE: 6 boulders of nephrite to 35 cm long along marble contact.

NEPHRITE: L=60cm, W=20cm Dark grey green, medium to coarse grained. Contains S_4 jointing, apparently superimposed after nephrite formation.

Massive, coarse grained diopside with 1mm pyrite cubes and brecciated marble

NEPHRITE: Grey green, opaque, massive to foliated, white spots from relict diopside

Fine grained diopside or zoisite/clinozoisite (off-white with disseminated green chlorite)

NEPHRITE: Variable quality and colour, but mostly massive and not schistose. Substantial core missing (souveneered). Jade remaining is mostly medium to dark grey green, fine grained but opaque/poorly translucent and often speckled with ? relict small, fine grained ? diopside. Grades to very fine grained, light grey green opaque jade with attractive irregular mottling (similar to plate 19, Flint & Dubowski (1986)) Minor dark green, fine grained and moderately translucent nephrite. Minor bands of epidote and chlorite

Quartz + feldspar + biotite gneiss with leucocratic segregations which are metasomatised near contact with talc. Late-stage formation of fine-grained epidote and tremolite

Geology by Flint, Dubowski, Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata; 1987.
Surveying by M.W. Flintoft; SFB 815.
Datum is approximately AHD of 197·00m at southwestern corner post of ML 4130.
Lease boundary directions are approximate and have been extracted from SADME plans 76-263 and 76-264.

76 Gneissosity (undifferentiated S_1 and S_2) and layering; dip and strike.
76 Schistosity – S_3; dip and strike.
76 Schistosity – S_3 in jade; dip and strike.
23 Joint – S_4; dip and strike.
Joint – S_4; vertical.
33 Schistosity – S_4; dip and strike.
33 Schistosity – S_4 in jade; dip and strike.
Schistosity – S_4 in jade; vertical.
Geological boundary – mapped.
Geological boundary – approximate.
Geological boundary – inferred.
Fault.
Mining Lease No. 4130.
A Cross section.
Sample locality and number; prefixed by 6231.
STN 1 178·28 Survey Station and spot height in metres.
195 Topographic contour in metres.
DDH6 Diamond drill hole
DDH6 Diamond drill hole and plan projection.

EARLY PROTEROZOIC

KIMBAN OROGENY

TALC: Fine-grained, milky opaque, pale green, massive. Drillcore only (DDH 6).

CHLORITE: Dark green to green black, fine grained, soft, mostly massive, but can be schistose (S_4 only). Drillcore only (DDH 6).

TREMOLITE (MASSIVE and SCHISTOSE): Light green, fine grained but too coarse to be nephrite or semi-nephrite. Often schistose (S_4 only).

NEPHRITE and SEMI-NEPHRITE: Variable quality and colour – see plan. In part formed from retrograded, coarse-grained diopside. Often contains an interpreted S_3 schistosity. Largest outcrop adjacent to major D_4 fracture. S_4 schistosity commonly present. (RS 209 & 211).

qtz QUARTZ: As thin veins, possibly during D_4.

LINCOLN COMPLEX

PEGMATITE: Massive quartz and feldspar pegmatite of uncertain age. Often contains S_3 mylonitic foliation. Often metasomatised (#) near jade lenses with actinolite as coarse-grained, radiating clusters; epidote as large subidiomorphic crystals; and chlorite as fine-grained aggregates.

HUTCHISON GROUP

?COOK GAP SCHIST ?UPPER MIDDLEBACK JASPILITE

MIGMATITE GNEISS: Medium to coarse grained, quartz + pink K-feldspar segregations with thin biotite laminae.

DOLOMITIC MARBLE: Light grey, medium to coarse grained with average grain size of 3–4mm. S_1/S_2 layering present with serpentiferous bands (after olivine). Diopside very minor.

GNEISSIC AMPHIBOLITE: Foliated amphibolite with S_1/S_2 gneissosity. Hornblende to 5mm. Amphibolites to several metres thick at least but outcrop poor. Leucocratic areas abundant but may be intrusive pegmatite. Grades to, and is inter layered with quartz + feldspar gneiss with biotite laminae.

LOWER MIDDLEBACK JASPILITE

DOLOMITIC MARBLE and MASSIVE DIOPSIDE: Coarse-grained, grey dolomitic marble (RS205) S_1/S_2 layering contains yellow-green serpentinised olivine aggregates to 40cm across which are flattened in the layering. Layered but not banded. Widespread and abundant D_4 joints and dissolution planes. Locally diopside rich. Minor opaques.

IRON FORMATION: Probable Lower Middleback Jaspilite. Regularly Banded with alternating thin bands (0·2-1m) of quartzite, hematite + magnetite quartzite and gneissic amphibolite (6231 RS204 & 206). Grunerite, hedenbergite and garnet present. Amphibolite variably retrogressed and with superimposed mylonitic foliation.

KATUNGA DOLOMITE

DOLOMITIC MARBLE: Pale grey, coarse grained dolomitic marble with average grain size of 3-5mm. Strongly developed S_1/S_2 layering; only minor calc-silicate phases.

WARROW QUARTZITE

QUARTZITE: Massive to foliated quartzite grading to mica schist (P1361/74). Mesoscopic banding and abundant D_3 folds. Pegmatite and ? migmatite abundant. Grades to leucocratic quartz + feldspar gneiss with thin laminae of biotite. Probable Warrow Quartzite.

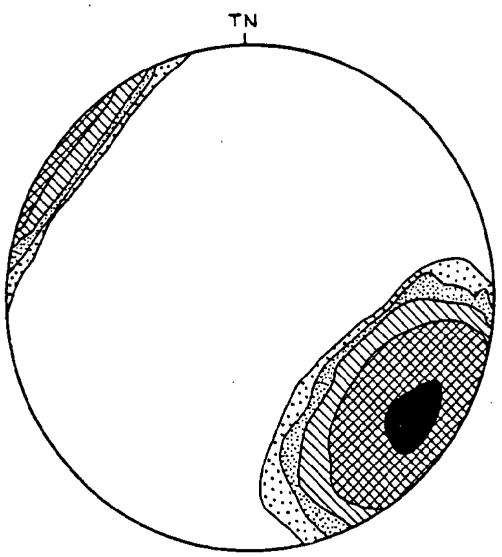
FIG.43

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

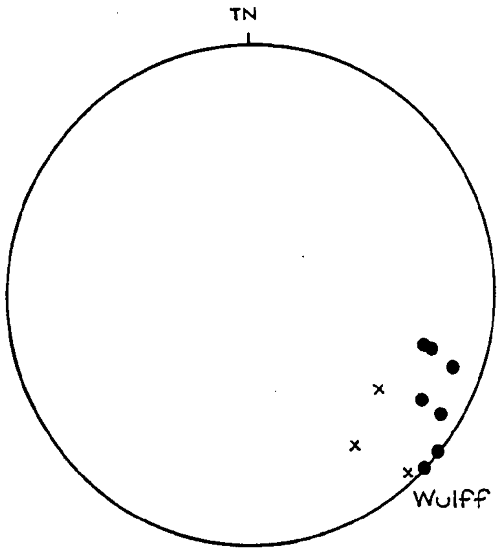
COWELL JADE
OUTCROPS 55-57
GEOLOGICAL MAP

COMPILED D.J.Flint	4.7.91 C D O DATE
DRAWN J.W.	SCALE 1:500
DATE	PLAN NUMBER
CHECKED	88-429

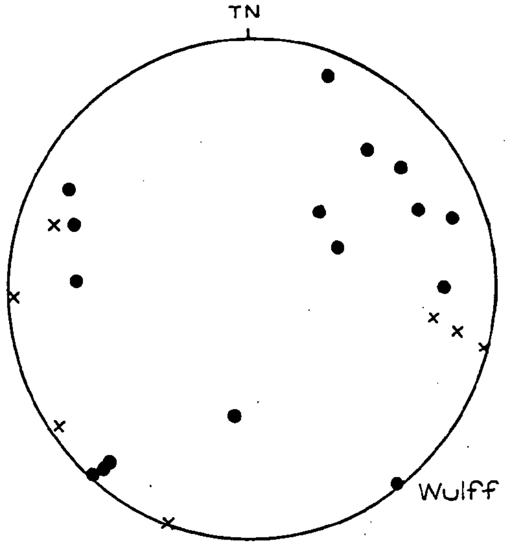
S_1/S_2
Undifferentiated lithological layering
and S_1 and S_2 gneissosities



S_3
S_3 mylonitic foliation and interpreted
S_3 schistosity in nephrite



S_4
S_4 joints and
S_4 schistosity in nephrite



×..... S_3m mylonitic foliation
●...... S_3 foliation in tremolite/nephrite

×........ Schistosity
●........ Joints

Contours at 0.5, 1, 2, 4, 8% per 1% area ; equal area projection.

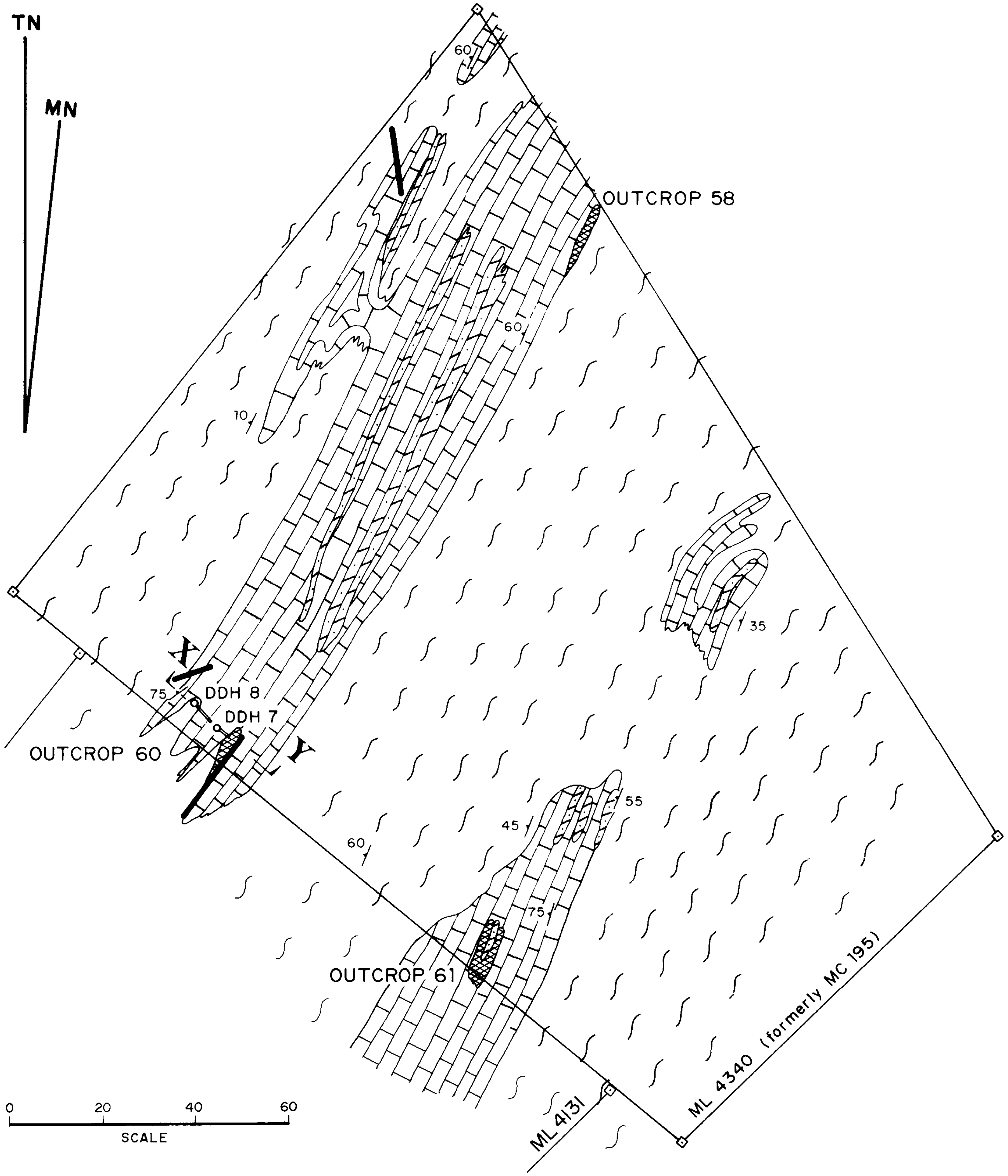
FIG. 44

**DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA**

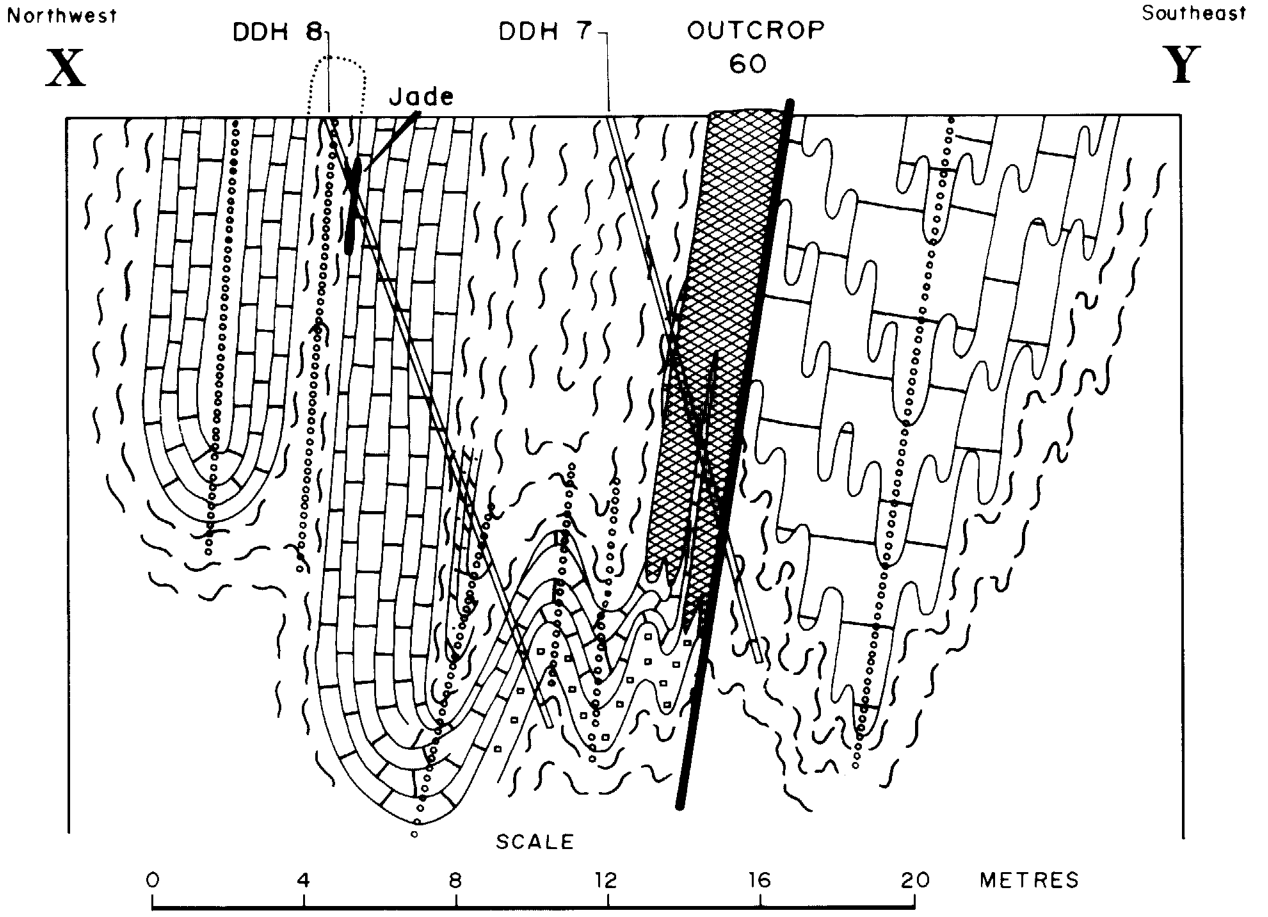
COWELL JADE
OUTCROPS 55-57
STEREOGRAPHIC PROJECTIONS

COMPILED D.J. Flint	B CDO	4.7.91. DATE
DRAWN J.W.	SCALE	
DATE	PLAN NUMBER	
CHECKED	S20220	

39/7



Geological mapping by Centamin N.L. for Australian (Nephrite) Jade Mines Pty Ltd; September 1983.
Drillhole cross-section and interpretation by D.J. Flint (SADME) September 1985. - based on 1973 geological mapping.



EARLY PROTEROZOIC KIMBAN OROGENY

MINBRIE GNEISS

▩ **NEPHRITE and NEPHRITIC TREMOLITE** : variable colour ranging from pale green and fine grained to dark green and grey green varieties. Often coarse grained and tremolitic, including in DDH 7, 8. In DDH 7, nephrite is limonite stained and with talc or chlorite abundance increasing with depth and imparting a darker green colour

TREMOLITE : milky opaque to pale green and limonite stained. Grain size varies from fine grained to coarse but all too coarse to be classed as nephrite. Probably grades into nephrite.

DOLOMITIC MARBLE : grey and coarse grained with scattered pods, bands and disseminations of yellow-green serpentinised olivine and epidote as well as pale to mid green tremolite and darker green chlorite or talc.

UPPER MIDDLEBACK JASPILITE

CALC-SILICATE : original mapping referred to this unit as amphibolitic gneiss and epidotised gneiss whereas Nichol (1974) uses amphibolite.

GNEISS : undifferentiated granitic gneiss, migmatite, leucocratic segregations and intrusives. Predominantly quartz + feldspar + biotite gneiss which is coarse grained and often contains minor amphibole or epidote.

Geological boundary

Fault

D_2 axial plane

DDH 7 Inclined diamond drillhole and number

55 Gneissic foliation and banding, dip and strike

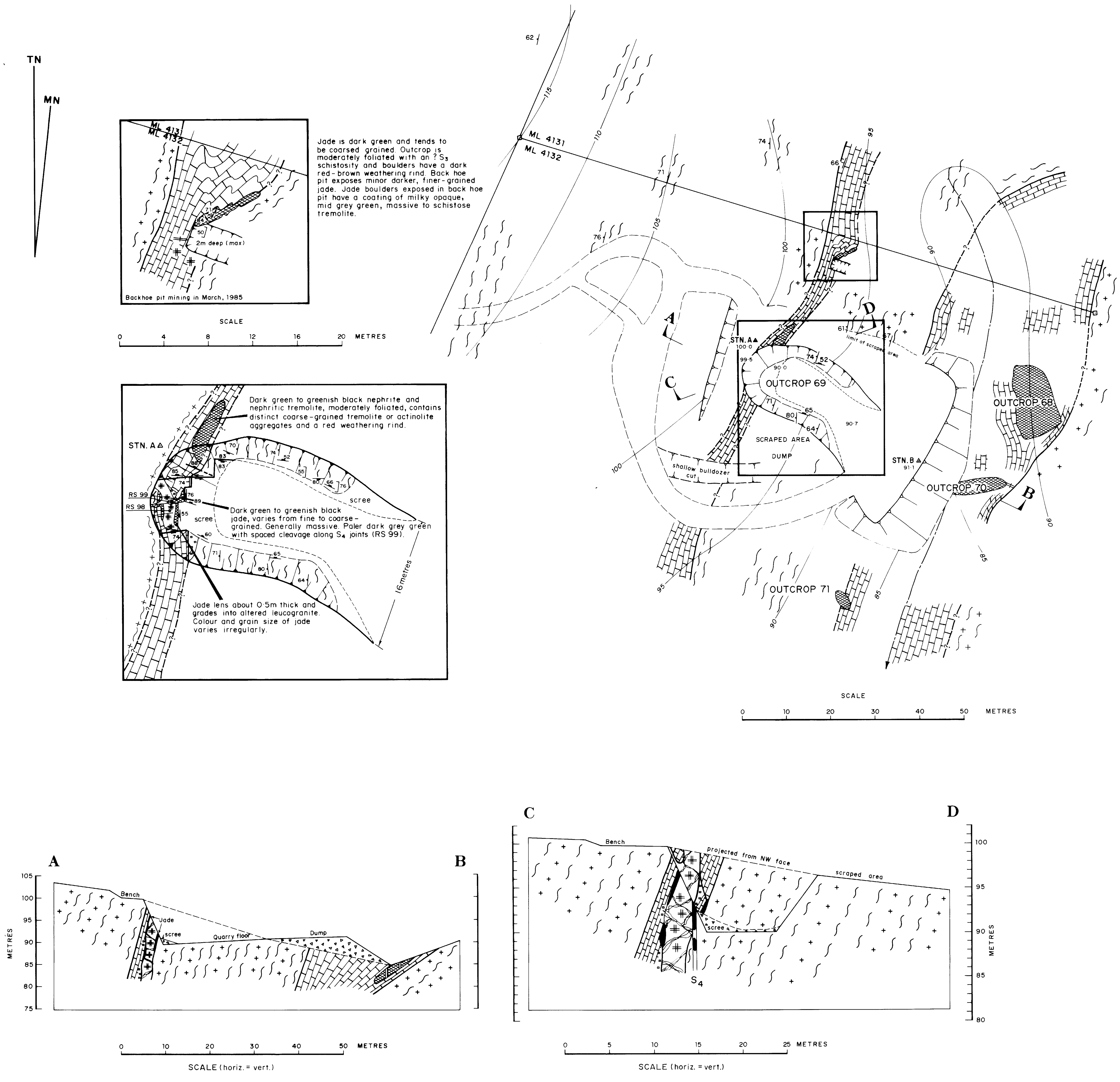
ML 4340 Mineral Lease and number

FIG. 45

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 58-61
GEOLOGICAL MAP

COMPILED D.F.
DRAWN M.B.
DATE Dec '85
CHECKED
WR 1-3-88
CDO DATE
SCALE As shown
PLAN NUMBER
88-92



Jade is dark green and tends to be coarsed grained. Outcrop is moderately foliated with an ? S_3 schistosity and boulders have a dark red-brown weathering rind. Back hoe pit exposes minor darker, finer-grained jade. Jade boulders exposed in back hoe pit have a coating of milky opaque, mid grey green, massive to schistose tremolite.

Dark green to greenish black nephrite and nephritic tremolite, moderately foliated, contains distinct coarse-grained tremolite or actinolite aggregates and a red weathering rind.

Dark green to greenish black jade, varies from fine to coarse-grained. Generally massive. Paler dark grey green with spaced cleavage along S_4 joints (RS 99).

Jade lens about 0·5m thick and grades into altered leucogranite. Colour and grain size of jade varies irregularly.

LEGEND

EARLY PROTEROZOIC — KIMBAN OROGENY — LINCOLN COMPLEX

▨ NEPHRITE and SEMI-NEPHRITE: dominantly dark green to greenish black but with paler grey green bands parallel to main S_4 joint in quarry face. Relict coarse grained tremolite in bands parallel to gneissosity whereas jade parallel to S_4, varies from massive to cleaved (RS 99). Prominent red weathering skin.

TREMOLITE: massive, coarse-grained light-green tremolite rock along the margins of altered leucogranite. Similar composition and texture to jade but much coarser grained.

LEUCOGRANITE: extensively altered in proximity of marble and jade. Coarse-grained plagioclase is dominant (60-70%) but with 15-35% secondary chloritised biotite forming interstitial fine-grained aggregates, and up to 7% late-stage acicular tremolite in radial clusters. Deeply weathered in quarry face (RS 98) but fresher samples in the dump (RS 150).

EARLY PROTEROZOIC — HUTCHISON GROUP

DOLOMITIC MARBLE: coarse-grained with average grain size of 2-3 mm. Grey when fresh but dark brown on weathered surfaces. Dolomite dominant over calcite, with small quantities of disseminated chlorite, tremolite, diopside and yellow aggregates of serpentinised olivine. (PI357/74).

CALC-SILICATE: variety of dolomitic marble where calc-silicate and Fe-Mg minerals of tremolite, diopside, chlorite and serpentine are locally abundant.

MIGMATITE GNEISS: banded quartzofeldspathic gneiss with well foliated biotite-rich gneiss bands alternating with leucocratic quartz + feldspar segregations or sills. Banding from centimetres to metres thick. Isoclinal folds are present rarely, and the gneissosity (S_2) is occasionally across apparent primary compositional banding (S_0/S_1).

ARCHAEAN — SLEAFORD COMPLEX

MILTALIE GNEISS: foliated, granodiorite gneiss grading to poorly-banded, quartz + feldspar + biotite gneiss with pegmatite. Essentially not distinguished from migmatised Hutchison Group.

67 Lithological layering in marble (undifferentiated $S_0/S_1/S_2$); dip and strike

61 Gneissosity (undifferentiated S_1/S_2); dip and strike

76 Gneissosity – S_2; dip and strike

Schistosity – S_4; vertical

69 Joint – S_4; dip and strike; and observed displacement

67 Joint – S_4; vertical

Geological boundary – mapped

– approximate

–?–?– – inferred

Quarry face with scree

Dump

Track

ML 4132 Mining Lease No. 4132

A B Cross section

RS 99 Sample locality and number, RS No. prefixed by 6231. RS 150 collected from dump

△STN. A Survey Station

90 Topographic contour, 5m interval

90·7 Spot height in metres

Creek

UNLOCATED PREVIOUS SAMPLING

SAMPLE No.	REFERENCE	ROCK TYPE
PI357/74	Nichol (1974)	Serp. marble
6231 RS 24	Amdel GS 3146/80	Nephrite
6231 RS 25	Amdel GS 3146/80	Nephrite

Geology by D. J. Flint and E. A. Dubowski
Theodolite survey by A.J. Smith; SFB 680 & 681

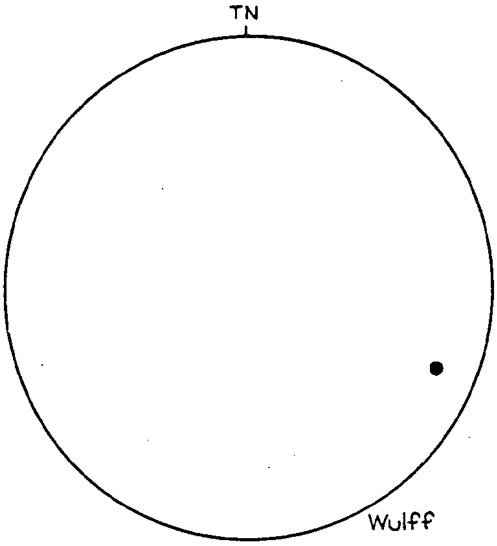
FIG. 46

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 68-71
GEOLOGICAL MAP

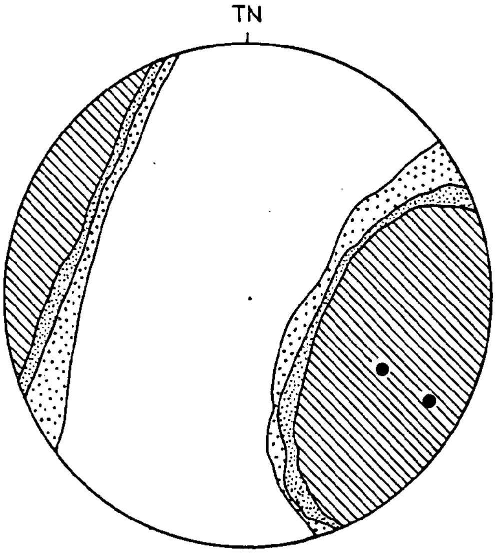
COMPILED D. F.	1·3·88 DATE
DRAWN M. B.	SCALE 1:500
DATE Nov '85	PLAN NUMBER 88-93
CHECKED	

So
Lithological layering



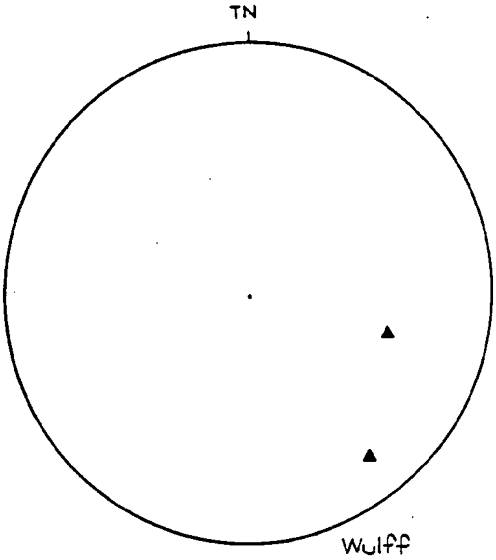
● .... So

S_1/S_2
Undifferentiated lithological layering
and S_1 and S_2 gneissosities (contoured)



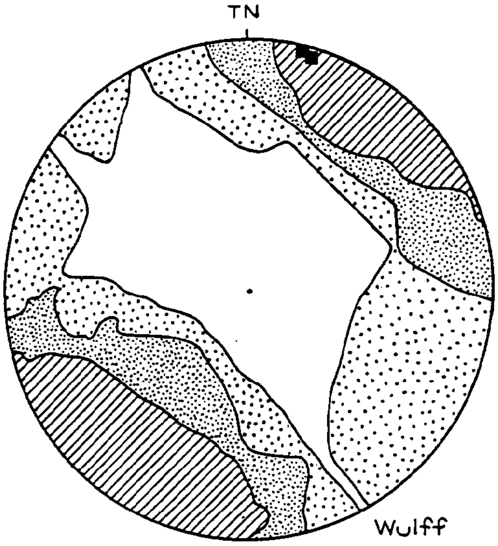
● .... S_2

S_3
Interpreted ? S_3 schistosity
in nephrite of outcrop 69



▲.......... S_3

S_4
S_4 joints (contoured)



■....... S_4 schistosity in nephrite

Contours at 0.5, 1, 2, 4 % per 1% area; equal area projection.

FIG. 47

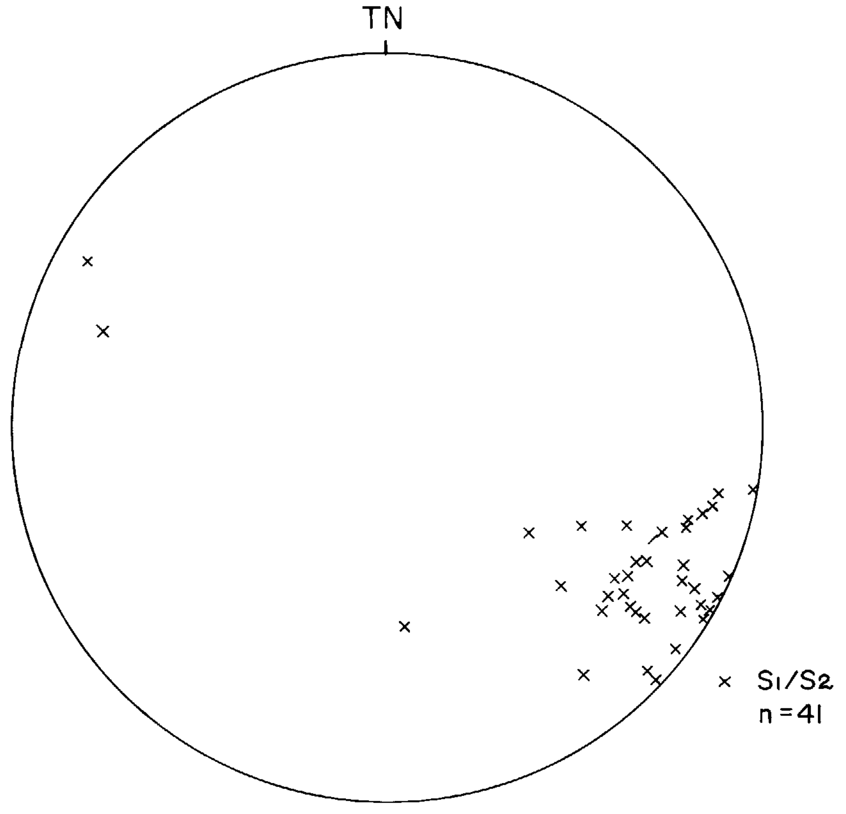
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROPS 68-71
STEREOGRAPHIC PROJECTIONS

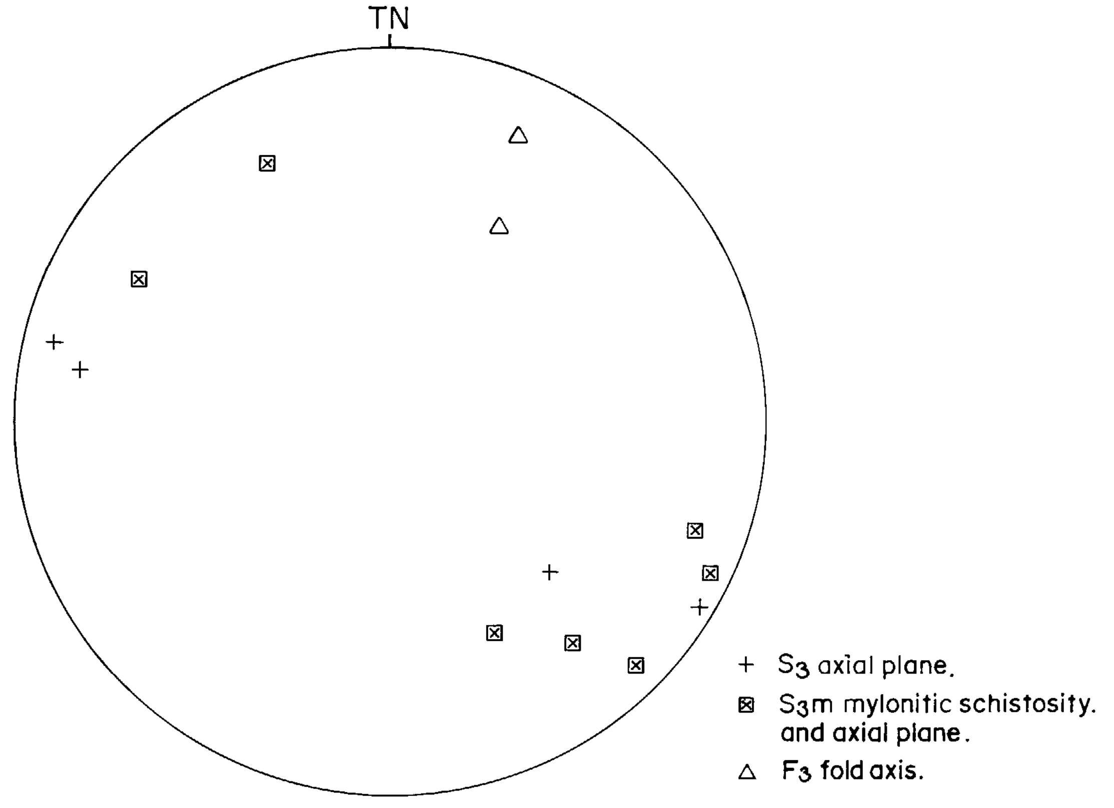
COMPILED D.J. Flint	B C.D.O.	4-7-91 DATE
DRAWN J.W.	SCALE	
DATE 6-9-88	PLAN NUMBER S20221	
CHECKED		

39/7

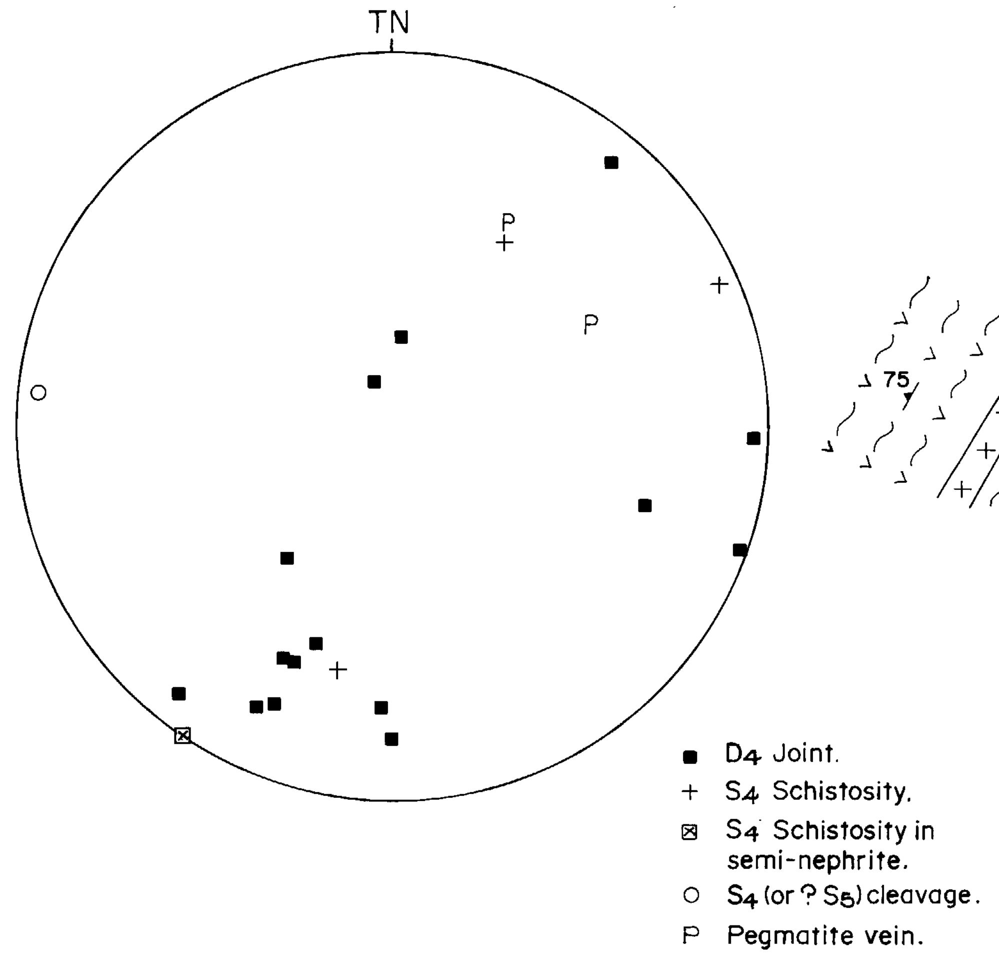
D_1/D_2 GNEISSIC LAYERING

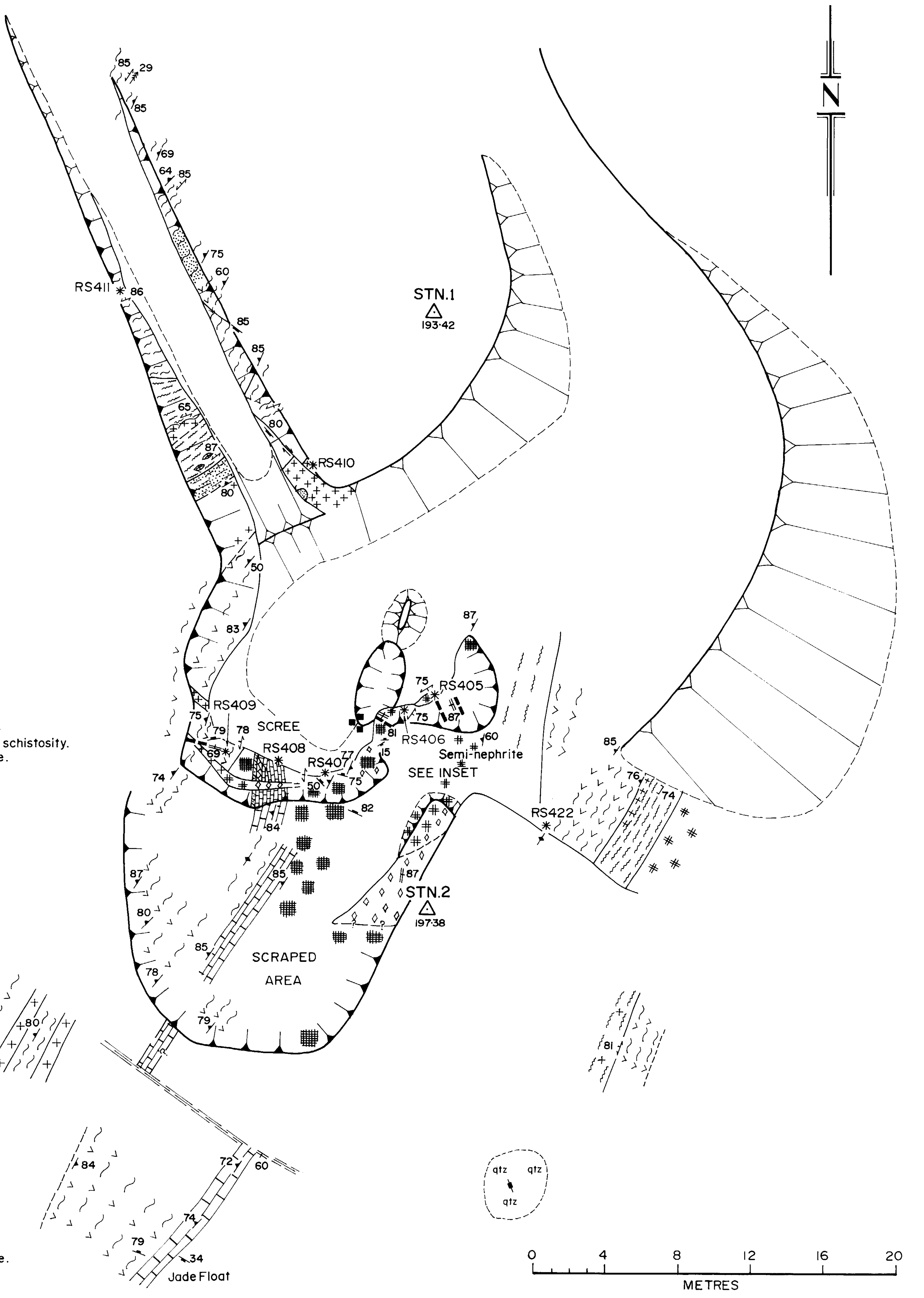


D_3



D_4





EARLY PROTEROZOIC

KIMBAN OROGENY

LINCOLN COMPLEX

HUTCHISON GROUP

CHLORITE: Dark green black to oxidised pale yellow green. Carbonate veins along D_4 shears. Predominantly as bands along D_4 shears. Commonly with a D_4 schistosity (▬).

EPIDOTE: Grades from massive epidote rock (retrogressed gneissic amphibolite) to abundant epidote within hybrid pegmatite where it often forms 10-20 mm radiating aggregates.

MYLONITE: D_4 shear zones, though S_3 grades to a mylonitic schistosity.

QUARTZ: Massive quartz blow.

PEGMATITE: Pink K-feldspar and quartz.

HYBRID PEGMATITE: Coarse-grained, quartz-feldspar pegmatite but variably contaminated and altered. Feldspar often altered to pink clinozoisite. Two styles of more intense alteration :-1. Chlorite + feldspar rock with minor epidote i.e. silica has been reactive.-2. Quartz + epidote rock with bands of radiating actinolite i.e. feldspar has been reactive. Two types tend to be mutually exclusive.

DIOPSIDE: Coarse-grained, off-white diopside but extensively fractured and partially retrogressed with tremolite/actinolite and epidote. Minor pyrite aggregates to 40mm across. In places, retrogressive assemblage dominant. Original diopside (D_1/D_2) coarse grained and only very poorly banded.

DOLOMITIC MARBLE: Coarse grained, grey and metasomatised along D_4 joints.

QUARTZITE: Grades from quartzite to flaggy quartzite and quartz-rich gneiss.

SCHIST and GNEISS: Biotite schist (~~) grading to coarser-grained biotite gneiss and quartz + feldspar + biotite gneiss (~) often with pegmatitic segregations.

GNEISSIC AMPHIBOLITE: Characterised by abundant bands of dark green-black amphibole (hornblende/actinolite and/or ? grunerite) aligned in S_1/S_2. Strongly banded (1-10 cm common) with alternating amphibole-rich, epidote-rich and quartz-rich bands; grades to banded calc-silicate gneiss. Contains quartz + feldspar augens.

Geological boundary - mapped.

Geological boundary - approximate.

Geological boundary - inferred.

Quarry face.

Dump.

75 S_1/S_2 gneissic layering; strike and dip.

75 S_3 schistosity, in places mylonitic; strike and dip.

S_3 schistosity, in places mylonitic; vertical.

75 S_4 foliation, schistosity and fracture cleavage; strike and dip.

85 D_4 joint; strike and dip.

STN 1 △ 193·42 Survey station and spot height.

RS407 ✳ Rock sample locality and number; prefixed by 6230.

NOTE: Survey by M.W. Flintoft; S.F.B. 815. Datum approx. A.H.D of 212·00m at S.E. corner post of ML 4339.
Geology by E.A. Dubowski, D.J. Flint, W. Simandjuntak, A. Sulaeman and S. Atmanwinata.

UNLOCATED PREVIOUS SAMPLING: P1374/74 Nichol (1974).
: P1695/76 Scott et al (1978).

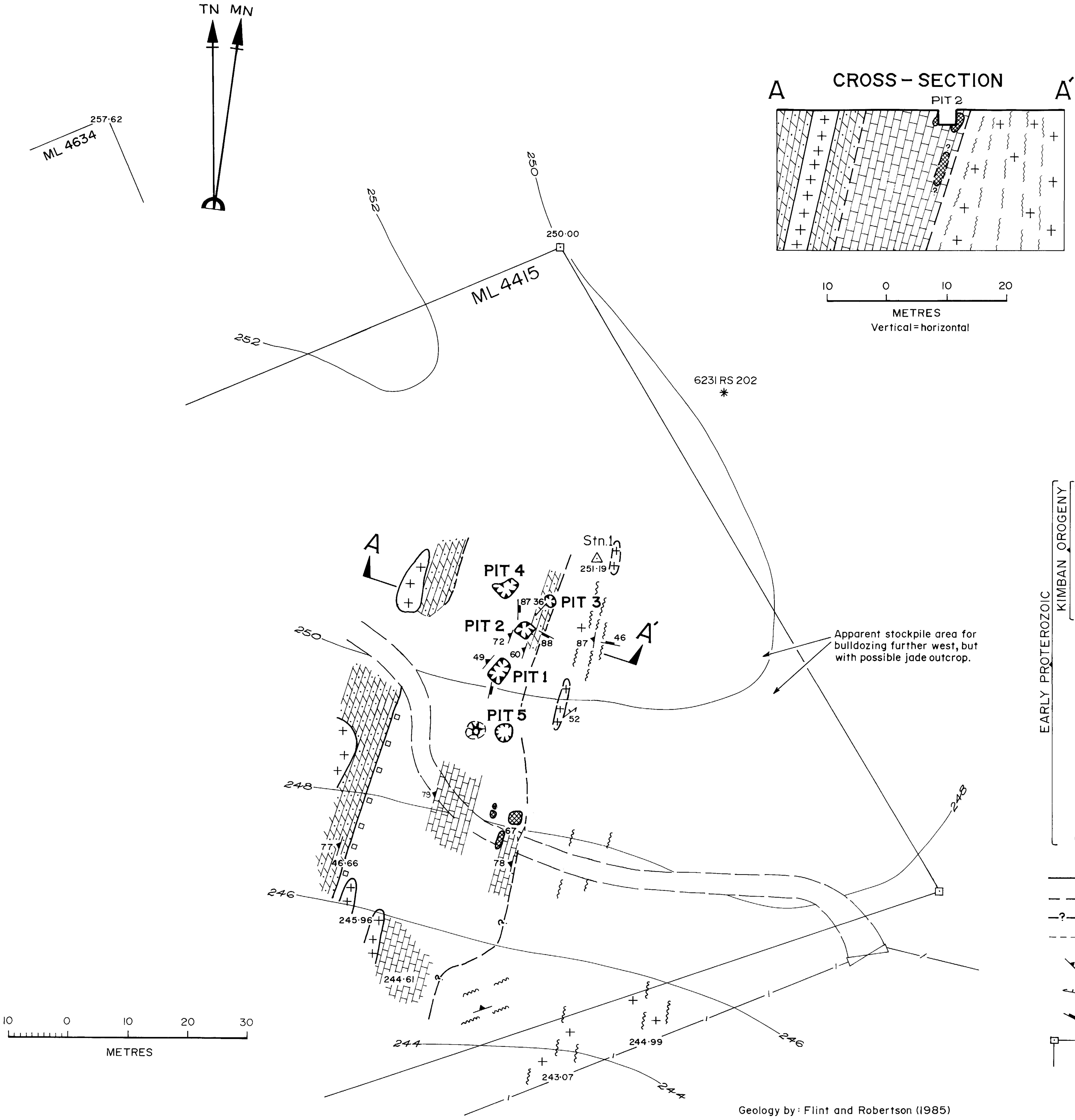
FIG. 48

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 76
GEOLOGICAL PLAN AND STEREOGRAPHIC PROJECTIONS

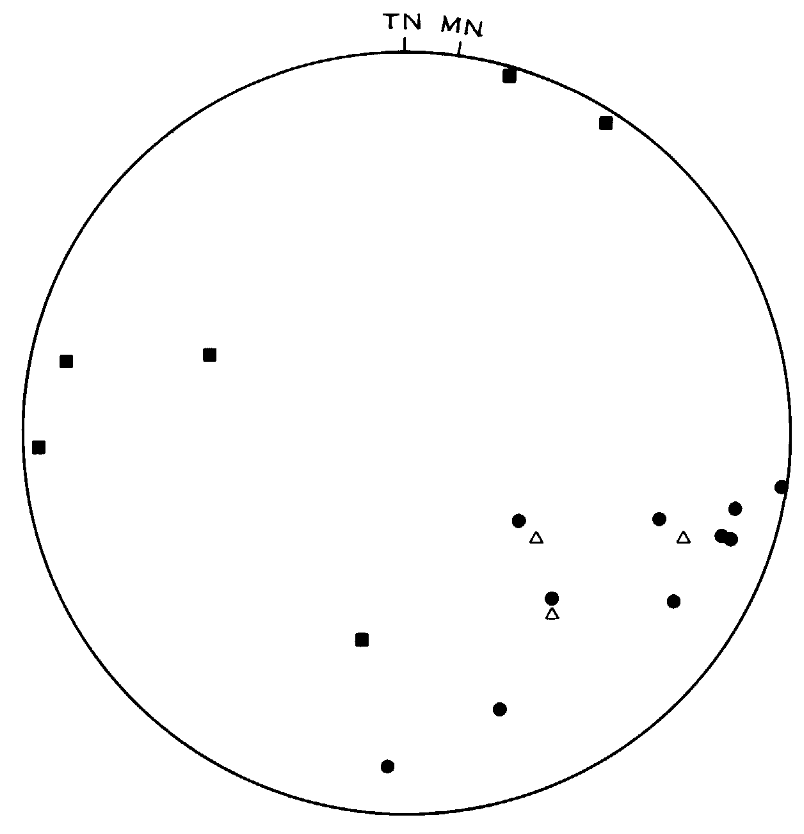
COMPILED E. Dubowski	4-7-91 C D O	DATE
DRAWN J.W	SCALE 1:200	
DATE May '89	PLAN NUMBER	
CHECKED	89-182	

3917



Apparent stockpile area for bulldozing further west, but with possible jade outcrop.

CROSS-SECTION



STRUCTURE	NO OF READINGS
● S1/S2.....Gneissic layering	10
△ S3..........Schistosity	3
■ S4..........Joints	6

EARLY PROTEROZOIC

KIMBAN OROGENY

LINCOLN COMPLEX

HUTCHISON GROUP

▩ NEPHRITE and SEMI-NEPHRITE: Grain size is variable ranging mostly from medium grained to coarse grained. Earlier-mined nephrite described as fine-grained and black. Colour dark green to black, lesser dark grey green. Texture mostly massive but with minor D3? schistosity in boulders in Pit 2. Outcrop and float have very dark red weathering skin. Boulders in Pit 2. coated with calcrete and magnesite.

+ PEGMATITE: Coarse-grained quartz, potash feldspar and plagioclase; leucocratic with minimal mica. As veins intruding all units. Also as segregations with biotite gneiss.

~ BIOTITE SCHIST/GNEISS: Dark grey-black to black, quartz + biotite schist grading to gneiss. Contains abundant pegmatitic segregations parallel to the strongly developed S1S2 layering.

▦ DOLOMITIC MARBLE: Grey, medium to coarse-grained with an average grain size of 1-2 mm. Minor disseminated tremolite, serpentine and pyrite. In places well banded (eg Pits 1 and 4) with massive tremolite bands 1-15 cm thick. Locally grades to banded calc-silicate. Crops out poorly.

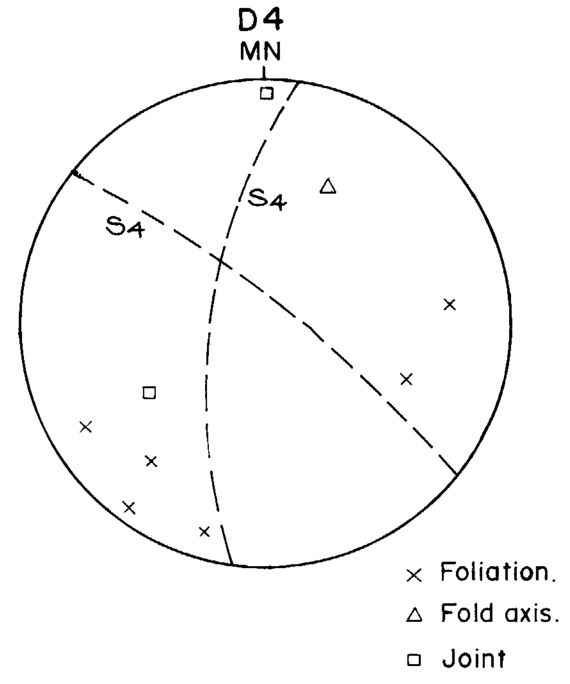
▨ BANDED CALC-SILICATE: Composite unit containing alternating bands of pale-brown cherty quartzite, coarse-grained quartz + biotite gneiss and the characteristic and diagnostic calc-silicate bands. The latter usually consist of massive, light to dark green tremolite / actinolite probably after diopside. Cherty quartzite contain very thin laminae down to 1mm thick. The gneiss is quartz-rich and contrasts with the overlying biotite rich biotite schist gneiss.

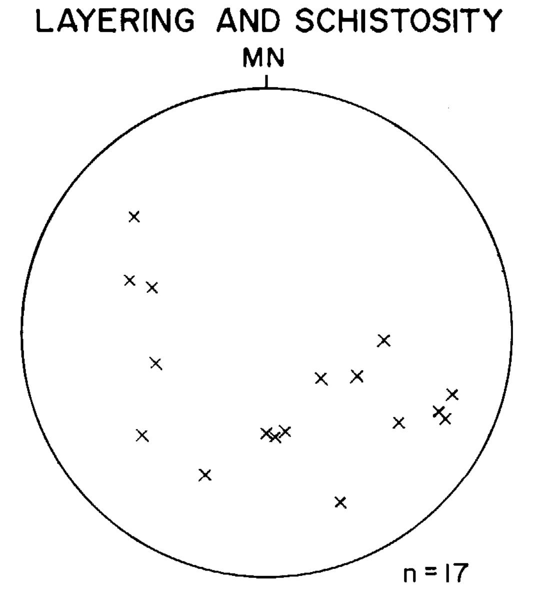
———	Geological boundary — observed.
— — —	Geological boundary — approximate.
—?—?—	Geological boundary — inferred.
- - - - -	Outcrop boundary.
	Gneissosity and lithological layering ($S_0/S_1/S_2$ undifferentiated); strike and dip.
	Schistosity, S_3; strike and dip.
	Joint, probably D_4; strike and dip.
	Mineral lease No. 4415.
Stn.1 △ 251·19	Survey station and spot height.
248·69	Spot height in metres; approximately A.H.D.
250	Topographic contour in metres. approximately A.H.D.
	Backhoe pit; for additional details see text.
	Track.
	Cross-section A A′.

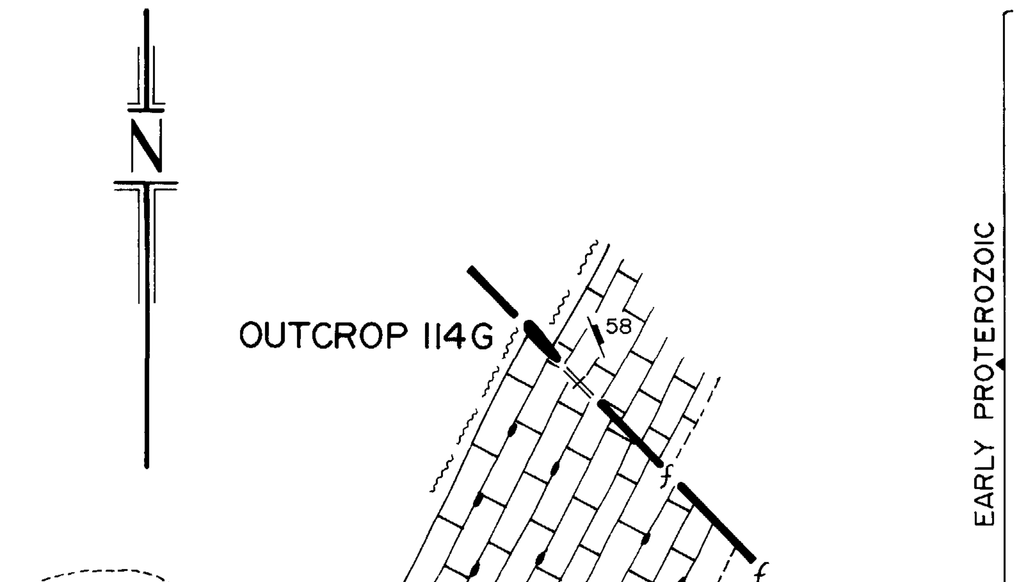
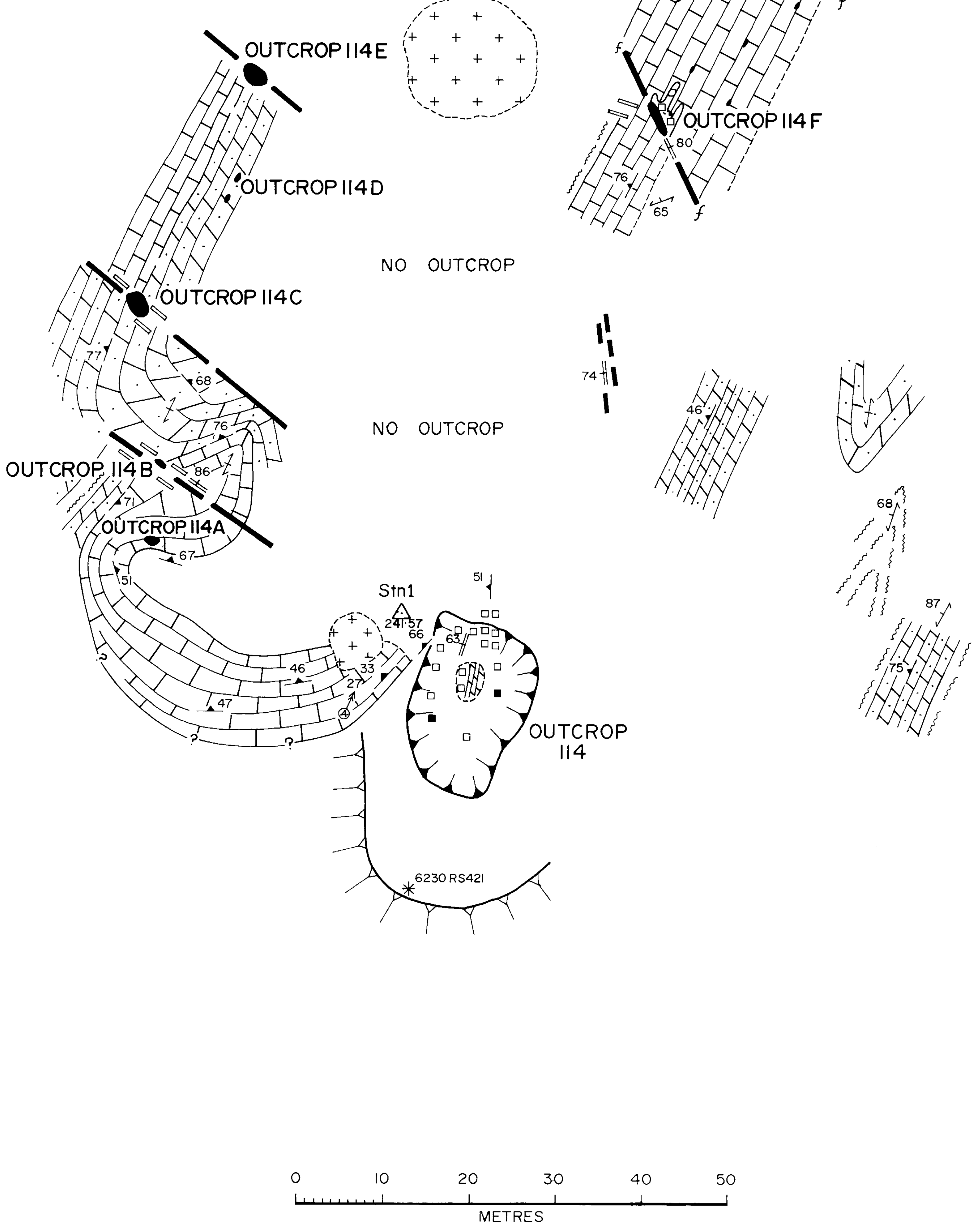
Geology by: Flint and Robertson (1985)
: Flint, Dubowski, Wilher Simandjuntak, Andi Sulaeman and Sumitra Atmanwinata (1987).
Surveying by M.W. Flintoft; SFB 815
Datum is approximately A.H.D. of 250·00m at northern corner post of ML 4415. Lease boundary directions for ML 4415 extracted from SADME plans 76-263 and 76-264.

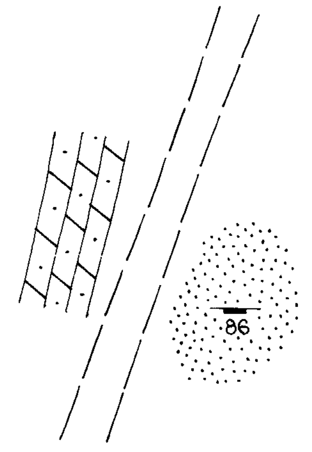
FIG. 49

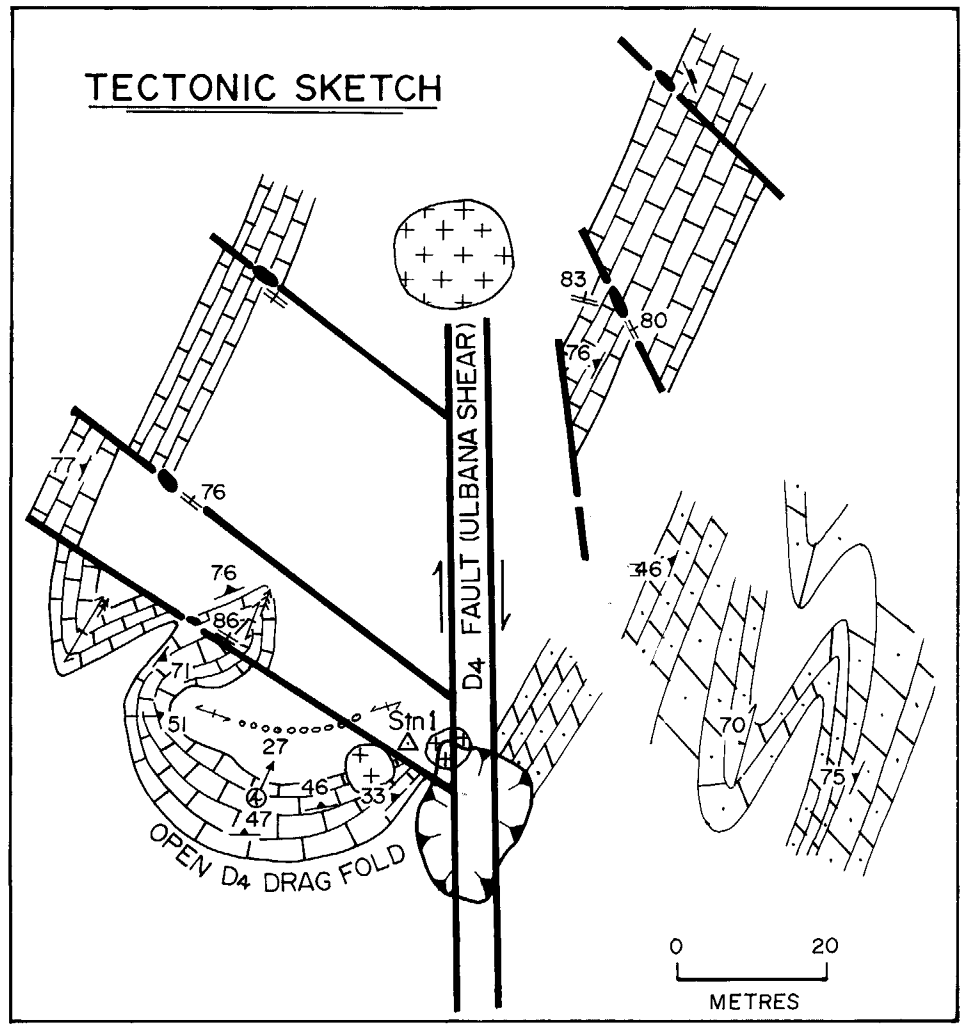
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED D.J. Flint	4-7-91 C.D.O. DATE
COWELL JADE OUTCROP 107 GEOLOGICAL MAP	DRAWN J.W.	SCALE 1:500
	DATE	PLAN NUMBER
	CHECKED	88-430

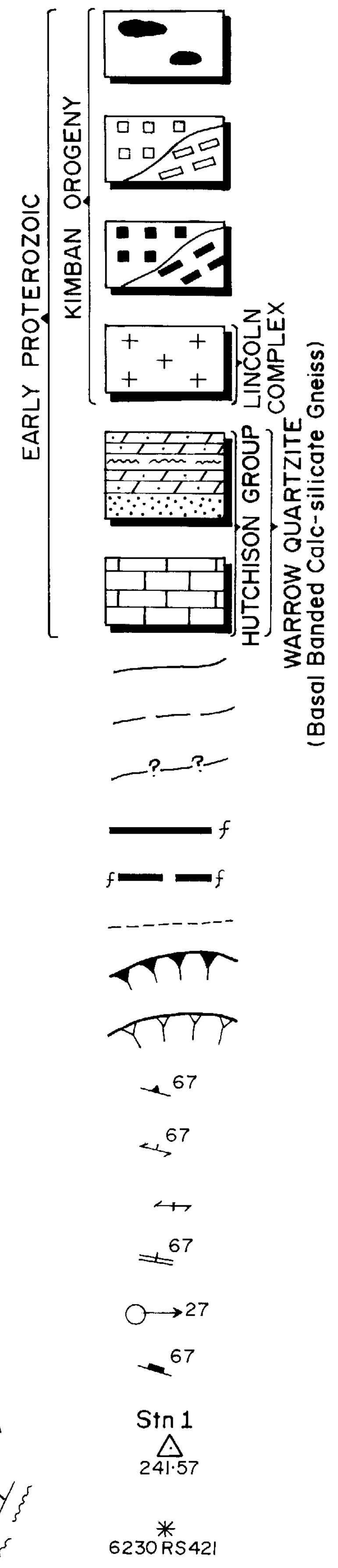










NEPHRITE and SEMI-NEPHRITE: Variable colour but mostly in pale green and grey-green with light tones. Minor massive, fine-grained nephrite but more commonly foliated (D4) and grading to coarse grained.

TREMOLITE: Varies from massive (□) to schistose (▭). Pale green, opaque, deeply weathered.

CHLORITE: Varies from massive (■) to schistose (▬). Dark green.

PEGMATITE: Mostly coarse-grained and leucocratic, but locally metasomatised with dark green-black chlorite aggregates, minor pale green tremolite and pink-purple clinozoisite after feldspar.

BANDED CALC-SILICATE GNEISS.
BIOTITE SCHIST: Chloritised.
QUARTZITE: Flaggy.

DOLOMITIC MARBLE: Varies from coarse grained (av. grain size 5mm) and grey to fine-grained and green with uniform to mottled green colouring. Banded.

Geological boundary - mapped.

Geological boundary - approximate.

Geological boundary - inferred.

Fault - mapped.

Fault - inferred.

Outcrop boundary

Quarry face.

Dump.

Lithological layering and S1/S2 gneissosity; dip and strike.

S3 axial plane or schistosity; dip and strike.

S3 axial plane or schistosity; trend only.

S4 schistosity; dip and strike.

D4 fold axis; plunge and trend.

D4 joint and dissolution plane; dip and strike.

Survey station and height.

Rock sample locality and number.

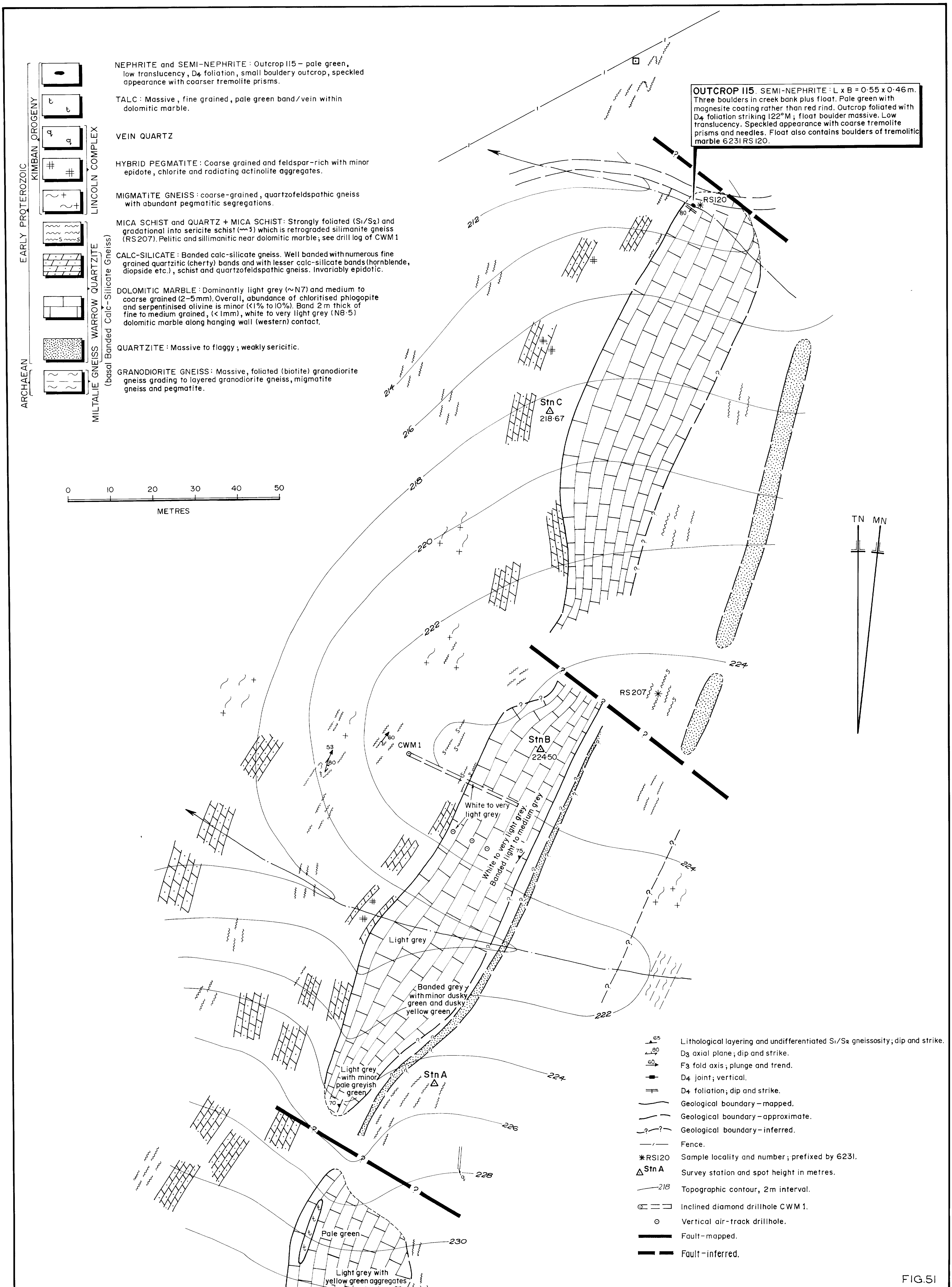
EDM Survey by M.W. Flintoft; S.F.B. 815.
Geology by D.J. Flint, E.A. Dubowski, W. Simandjuntak,
A. Sulaeman and S. Atmanwinata.
Approximate A.H.D; reference point 230·0m
at N-NW corner post ML 4381.

FIG.50

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 114 - GEOLOGICAL PLAN,
TECTONIC SKETCH AND STEREOGRAPHIC PROJECTIONS

COMPILED D.J.Flint
DRAWN J.W.
DATE March '89
CHECKED
C.D.O. DATE 4.7.91
SCALE 1:500
PLAN NUMBER 89-184



NEPHRITE and SEMI-NEPHRITE : Outcrop 115 – pale green, low translucency, D_4 foliation, small bouldery outcrop, speckled appearance with coarser tremolite prisms.

TALC : Massive, fine grained, pale green band/vein within dolomitic marble.

VEIN QUARTZ

HYBRID PEGMATITE : Coarse grained and feldspar-rich with minor epidote, chlorite and radiating actinolite aggregates.

MIGMATITE GNEISS : coarse-grained, quartzofeldspathic gneiss with abundant pegmatitic segregations.

MICA SCHIST and QUARTZ + MICA SCHIST: Strongly foliated (S_1/S_2) and gradational into sericite schist (~~s) which is retrograded silimanite gneiss (RS207). Pelitic and sillimanitic near dolomitic marble; see drill log of CWM 1

CALC-SILICATE : Banded calc-silicate gneiss. Well banded with numerous fine grained quartzitic (cherty) bands and with lesser calc-silicate bands (hornblende, diopside etc.), schist and quartzofeldspathic gneiss. Invariably epidotic.

DOLOMITIC MARBLE : Dominantly light grey (~N7) and medium to coarse grained (2–5 mm). Overall, abundance of chloritised phlogopite and serpentinised olivine is minor (<1% to 10%). Band 2 m thick of fine to medium grained, (< 1mm), white to very light grey (N8·5) dolomitic marble along hanging wall (western) contact.

QUARTZITE : Massive to flaggy; weakly sericitic.

GRANODIORITE GNEISS : Massive, foliated (biotite) granodiorite gneiss grading to layered granodiorite gneiss, migmatite gneiss and pegmatite.

OUTCROP 115. SEMI-NEPHRITE : L x B = 0·55 x 0·46 m. Three boulders in creek bank plus float. Pale green with magnesite coating rather than red rind. Outcrop foliated with D_4 foliation striking 122°M; float boulder massive. Low translucency. Speckled appearance with coarse tremolite prisms and needles. Float also contains boulders of tremolitic marble 6231 RS 120.

65	Lithological layering and undifferentiated S_1/S_2 gneissosity; dip and strike.
80	D_3 axial plane; dip and strike.
60	F_3 fold axis; plunge and trend.
	D_4 joint; vertical.
	D_4 foliation; dip and strike.
	Geological boundary – mapped.
	Geological boundary – approximate.
? ?	Geological boundary – inferred.
	Fence.
✱RS120	Sample locality and number; prefixed by 6231.
△Stn A	Survey station and spot height in metres.
218	Topographic contour, 2m interval.
	Inclined diamond drillhole CWM 1.
⊙	Vertical air-track drillhole.
	Fault – mapped.
	Fault – inferred.

FIG.51

Geological mapping and compilation by D. A. Young and D. J. Flint.
Theodolite surveying by A. J. Smith; SFB 689.
Approximate A.H.D. of 225m at Station A.

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE
OUTCROP 115 AND WHITE MARBLE PROSPECT
(ML 4338)
GEOLOGICAL MAP

COMPILED D.J. Flint	C.D.O	DATE 4.7.91
DRAWN J.W.	SCALE	
DATE	PLAN NUMBER 88-431	
CHECKED		

3917

DEPARTMENT OF MINES AND ENERGY – SOUTH AUSTRALIA

LOG OF DIAMOND DRILL HOLE

NON – METALLIC RESOURCES DIVISION

HOLE No CWM 1

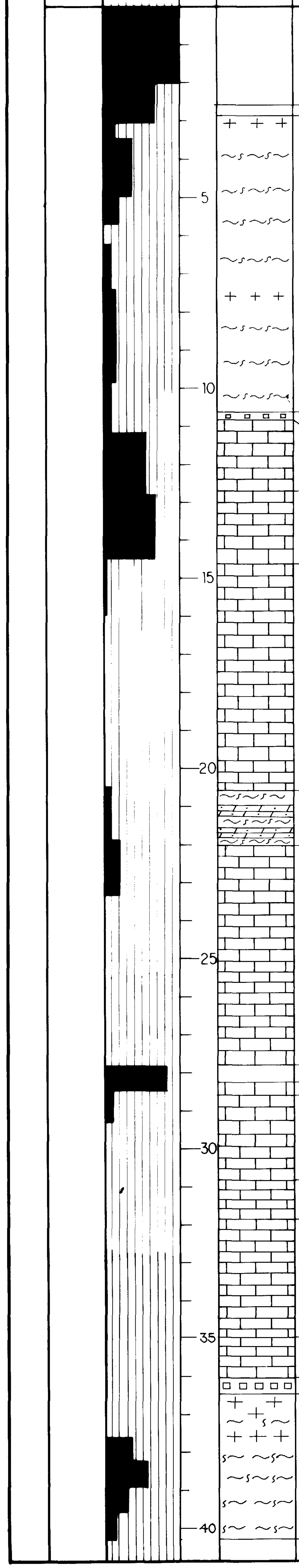
PROJECT COWELL MARBLE
LOCATION 6231 (ML4338)
HUNDRED **MINBRIE** SECTION 123

ELEVATION
DATUM
INCLINATION 45°
AZIMUTH 110° MN
DEPTH 40·30m

DRILLER D.E. WHITE
COMMENCED 24-6-83
COMPLETED 1-7-83
LOGGED D.J. FLINT

UNIT / STATE No 615/83
DOCKET NUMBER 306/82
PLAN REFERENCE 88-431
DRAWING No

CORE SIZE | CORE LOSS (%) 0 50 100 | DEPTH (m) | GRAPHIC LOG | LITHOLOGICAL DESCRIPTION | DEPTH (m) | FRACTURES | STRUCTURES



LITHOLOGICAL DESCRIPTION

LOST CORE

ALLUVIUM

SERICITE GNEISS: Pelitic gneiss with abundant, thin, grey sericite schist bands. Sericite is very fine grained and is probably retrogressed sillimanite. Sericite bands alternate with quartzofeldspathic bands. In addition leucocratic segregations are common, containing very coarse-grained pink K-feldspar – particularly at 2·8 - 3·0m and 7·54 - 7·67m.

Gneiss, strongly folded and crenulated with open to tight folds. Tighter kink folds often with new, axial planar, sericitic schistosity. Probable D3 folding.

TREMOLITE: Massive with random fabric, weakly banded with light and dark green tremolite. Not apparently schistose

DOLOMITIC MARBLE: Marble particularly dolomitic, fine to medium grained with an average grain size of less than 1mm. Colour is a uniform white to very light grey N8·5, and lacks inclusions of chlorite, serpentine and tremolite. Rubbly core, poor core recovery with weathered and calcreted limestone rubble. Largest piece of core only 9 cm long.

DOLOMITIC MARBLE: Particularly poor core recovery. Marble is distinctly impure with dusky, green chloritic spots to 1mm. Numerous clay-rich zones. Minor white N8·5 dolomite as in above zone.

DOLOMITIC MARBLE: A grey diffusely-banded dolomitic marble. Overall, colour is dominantly very light grey N8 with light grey N7 in darker bands. Massive with medium grain size. Colour quite uniform with only minor impure bands containing chlorite and serpentine; banding more pronounced when impure.

Impure chloritic and serpentiferous bands at :-

15·72 – 15·79 m	
16·14 – 16·28m	Spots of light olive 10Y5/4 serpentine with dusky yellowish green 10 GY 3/2 chlorite.
16·50 - 16·53 m	
17·26 - 17·27 m	
17·58 - 17·63m	
18·24 - 18·35m	
18·42 - 18·58m	Colours as above.
19·53 - 20·57m	Greens are brighter and paler i.e. moderate yellowish green 10 GY 5/3

SERICITIC GNEISS and BANDED CALC-SILICATE: Sericitic gneiss as above but without the folds and with a strong layer-parallel schistosity (probably S3). Mixed with banded calc-silicate grading to chert containing abundant bands of massive, coarse-grained, dark green tremolite up to 50mm thick; minor clinozoisite. Overall pronounced retrogressive assemblages

DOLOMITIC MARBLE: Medium-grained, light grey N7 to N8 dolomitic marble with grey tones defining a diffuse banding 10 - 20mm wide. Overall, contains only minor (< 1%) disseminated chlorite and serpentine spots except in narrow bands where they are locally abundant i.e. :–

22·0 - 22·22 m	Dominant, very light grey N8 background with 15% spots of moderate yellowish green 10GY5/4 chlorite,
22·79 - 23·05 m	
23·14 - 23·20 m	
26·0 - 26·30 m	Green chlorite specks of 5G 6/3.
27·54 - 27·80 m	Dominant N7-N8 background with speckled yellow greens of - light olive 10Y 5/4 and green 5G 5/3.

LOST CORE.

CLAY with fragments of banded calc-silicate and phlogopite marble.

DOLOMITIC MARBLE: Dominantly light grey to very light N7-N8, medium to coarse grained, massive with only diffuse and minor banding. Pale green ? chlorite or tremolite form disseminated small aggregates of 3-10% by volume. Strongest banding is at 29·55 - 29·68 m with spots of greyish-green 10 GY 5/2 and lesser dusky yellow green 5GY 5/2, and at 30·64 - 30·73 m with dusky yellow green spots of 10GY 4/2. Phlogopite-rich band at 30·49 - 30·54 m.

DOLOMITIC MARBLE: Medium grained. Attractive blend of 3 colours in diffuse bands up to 15 mm wide. Yellow-greens absent; bands consist of very light grey N8, medium light grey N6, and fine to medium-grained greens of 5G 5/3 with paler 5G6/3. Irregular mottling of colours also superimposed on banding. 3 colours in equal proportions.

DOLOMITIC MARBLE: Distinctly coarse-grained and medium light grey N6·5 with randomly-distributed areas of speckled yellow green serpentine after olivine, with minor very light grey N8 and pale yellowish green 5G 8/2 zones. Light olive 10Y 5/4 aggregates and spotting of serpentine concentrated at :-

32·87 - 32·93 m
33·34 - 33·38 m
33·47 - 33·50 m
34·18 - 34·20 m
34·60 - 34·68 m

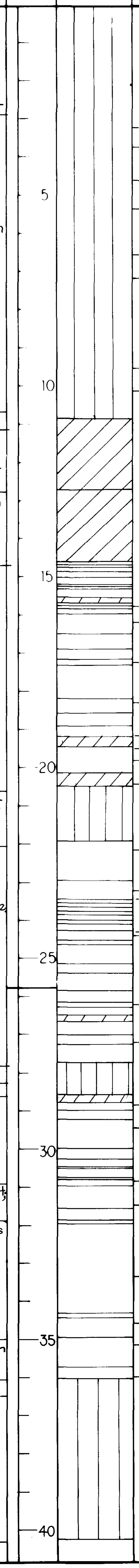
DOLOMITIC MARBLE: Medium to coarse grained. Dominantly light grey N7, dolomitic, and with pronounced yellow-brown stringers and bands of very fine-grained ?antigorite of yellowish grey 5Y 7/2 and greyish yellow 5Y 8/3 with darker 1-2mm small specks of moderate olive brown 5Y4/6. Green and yellow greens absent.

TREMOLITE: Massive to schistose, when massive is in coarse-grained radiating clusters.

SERICITE GNEISS and PEGMATITE: Sericitic gneiss as above with abundant veining of pinky-red very coarse-grained feldspar + quartz. Main pegmatite zones at 36·5 - 37·19 m and 37·45 - 37·68 m.

Sericite gneiss is mylonitised with new schistosity at 37·36 m.
Core rubbly and fragmentary, particularly of sericite gneiss intervals.

END OF HOLE 40·30 m



STRUCTURES

Gneissic banding at 45° to core axis.
Gneissic banding at 60° to core axis, with a layer-parallel new S3 schistosity.
Gneissic banding at 60° to core axis.
D3 axial plane to kink folds at 45° to core axis.
Gneissic banding and new S3 sericitic schistosity at 60° to core axis.
Gneissic banding at 65° to core axis.
Axial plane with new sericitic schistosity at 75° to core axis.
New sericitic schistosity at 70° to core axis.
Rubble.
Rubble.
Fractures at 75 - 80° to core axis
Fractures/joints at 65-80° to core axis
Fractures/joints at 60-75° to core axis and compositional banding at 75° to core axis.
Compositional banding at 80° to core axis.
Fracture/joint at 65° to core axis.
Fracture/joint at 30° to core axis.
Fracture/joint at 60-75° to core axis and compositional banding at 80° to core axis.
Fracture/joint at 65° to core axis and compositional banding at 75° to core axis.
Fracture/joint at 85° to core axis.
Fracture/joint at 10° to core axis.
Rubble.
Compositional banding at 70° to core axis.
Compositional banding at 60° to core axis.
Compositional banding at 85° to core axis.
Joint at 85° to core axis.
Compositional banding at 80° to core axis.
Joints at 85° and parallel with core axis.
Compositional banding at 75° to core axis.
Joints at 85° to core axis.
Joints at 70° to core axis and parallel with compositional banding.
Joint.
Joints at 55-70° to core axis and compositional banding at 50° to core axis.
Rubble.
Joint at 65° to core axis.
Joint at 20° to core axis and compositional banding at 70° to core axis.
Compositional banding at 70° to core axis.
Fracture/joint at 20° to core axis.
Fracture/joint at 60° to core axis.
Compositional banding at 55° to core axis.
Fracture/joint at 60° to core axis.
Fracture/joint at 65° to core axis.
Fracture/joint at 65° to core axis and compositional banding at 70°.
Fracture/joint at 80° to core axis.
Fracture/joint at 45° to core axis.
Fracture/joint at 70° to core axis.
Compositional banding at 65° to core axis.
Fracture/joint at 50° to core axis
Compositional banding at 80° to core axis.
Compositional banding at 75° to core axis.
Close-spaced jointing, partly mylonitic, at 85° to core axis.
Compositional banding at 70° to core axis.

FIG. 52

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

COWELL JADE

LOG OF DIAMOND DRILL HOLE CWM 1

COMPILED	C.D.O. DATE 4.7.91
DRAWN	SCALE
DATE	PLAN NUMBER 88-432
CHECKED	

39/7