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THE GENESIS OF JADE AND HOST ROCKS IN DDH14 AT OUTCROP 15 COWELL JADE PROVINCE, SOUTH AUSTRALIA

GEOLOGICAL SURVEY

by

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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 content 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 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 crysotile 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 postdates 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.

DISCUSSION

A. Summary

Petrographic evidence indicates that Cowell Jade is the product of retrograde alteration processes on a magnesium-rich calc-silicate assemblage derived from the regional metamorphism of sedimentary siliceous dolomites. The best jade is produced at a late, but not terminal, stage in the alteration and consists of a tightly felted mass of very fine nephrite, developed by recrystallisation of coarser grained tremolite and subject itself to replacement by a redevelopment of coarse tremolite and the introduction of volatile-rich calcium minerals such as fluorite and apatite. Regional deformation is not a requirement for the formation of jade and the minor granulation in evidence is probably the result of volume changes during alteration.

Mobility of chemical components is evident in the thin sections on the scale of a few centimetres and may be presumed on a metre scale at the contacts of a granitoid (specimen RS 186) with the Warrow Quartzite below and the calc-silicate sequence above. The amphibolitisation of diopside and the replacement by nephrite of such minerals as epidote are metasomatic reactions involving the movement of at least silica and calcium. However, these movements are on a relatively small scale and in many instances the mobilised constituents are not lost to the system but reappear in reverse reactions at a later stage in the alteration process. There is no evidence of metasomatism on a regional scale and as far as Cowell Jade and adjacent host rocks are concerned, the reactions appear to be essentially isochemical.

On the evidence of petrographic observation and geochemical analysis the significant chemical controls of jade formation at Cowell are the silica content of the system and the ratio of magnesium to calcium. At silica contents of below about 40%, olivine and its serpentinite alteration products form in preference to the diopside, tremolite, nephrite sequence. With silica above about 50%, assuming an adequate calcium content, epidote forms in addition to diopside. Diopside forms at the expense of epidote, to be subsequently amphibolitised to tremolite and nephrite, at magnesium to calcium ratios of about 3:2 and above, in the presence of adequate silica. Epidote and diopside form a stable assemblage when calcium is more abundant than 2:3 against magnesium, with adequate silica and alumina. At very high levels of silica, alumina and sodic plagioclase rather than epidote appears to be the stable calcium silicate. Magnesium silicates tend to form at lower silica levels than calcium silicates and marbles without silicates tend to be richer in calcite than dolomite.

Elements other than those mentioned are generally minor in both abundance and petrogenetic significance.

Attempts are made below to illustrate phase equilibria in the prograde and retrograde rocks in terms of the three major components; SiO_2, MgO and CaO. The phase boundaries are drawn from parageneses observed in the thin sections examined. Discrepancies may be explained by the unrepresentative nature of a thin section in a coarsely banded metamorphic rock with compositionally differentiated bands, by the superimposition of retrograde alteration assemblages on the prograde assemblage, non-equilibrium assemblages and, in a few instances, uncertainties in optical identification. Recommendations for non-optical identification of some minerals have been made in the descriptions.

Factors in the formation of Cowell Jade are considered in more detail below.

B. Petrogenetic History

1. Carbonate sedimentation

Evidence from field relationships as well as from microscopic examination of thin sections and from chemical analyses is definitive that the nephrite jade at Cowell is derived from dolomitic carbonate sediments rather than from ultrabasic magmatic rocks. Because of prograde and retrograde metamorphic events the exact nature of the original sedimentation is obscure. Compositional banding is approximately perpendicular to the drill core but it is not clear whether the banding was inherited from original sedimentary bedding or imposed by metamorphic differentiation in the prograde episodes, possibly at an angle to the bedding. The two fabrics may in fact coincide.

The possible introduction of silica and other constituents is discussed below but there is no reason to suppose that the original sediments did not contain enough quartz and clay to account for the silicates and aluminosilicates subsequently produced by metamorphic processes. The metasediments of the Hutchinson Group include former siliceous and argillaceous sediments as well as the carbonate facies which forms the host rocks to the jade (Barnes et al., 1980).

2. Prograde metamorphism

The sediments underwent amphibolite grade metamorphism about 1800 Ma (Parker, 1981). Minor granitoid intrusion coincided with this event and provides a potential source for the introduction of at least silica into the sediments. Microscopic textures do not indicate such metasomatic processes except in pre-tectonic granitoids and the limit of mobility in the sediments supported by the petrographic evidence is the compositional banding produced by metamorphic differentiation, possibly based on original sedimentary bedding, on a scale of a few centimetres at most.

Whatever the basis of compositional variation, the parageneses produced in the prograde alteration are described below.

a) Marbles. Carbonates low in silica recrystallise as coarse grained marbles in which metamorphic differentiation has separated calcite and dolomite into zones of concentration but in which neither phase occurs to the exclusion of the other.

b) Marbles with magnesium silicates. A silica content of about 5% or more results in the formation of silicates in magnesium-rich marbles but not in calcite marbles. The identity of the silicate is not directly visible in the samples examined but from the nature of, and textural indications in, pseudomorphous alteration products and from descriptions of such minerals in other publications, the mineral is almost certainly a forsteritic olivine.

c) Pyroxenes. Silicates with a substantial calcium content appear to be stable in the environments of the samples investigated only where the silica content is in the order of 40% or more. The pyroxenes identified in the specimens from DDH14 are a diopside of normal optical properties and a diopside with optical properties close to pigeonite. A magnesium-rich pyroxene composed of almost 90% of the clinoenstatite molecule has the low birefinrgence, 2V of about 25°-30° and low refractive indices of the second pyroxene found in some specimens from DDH14. The iron content of both pyroxenes appears to be insignificant.

d) Epidote. Intersections in DDH14 tend to be of material richer in calcium than most Cowell material analysed to date. A substantial proportion of the specimens contain epidote as a major, sometimes as the dominant, component. Epidote apparently coexists in equilibrium with diopside if the silica content of the specimen is about 50% or over and the calcium to magnesium ratio exceeds about 3:2. Some epidote is yellow and weakly pleochroic but the iron content of most grains is low and the place of iron is taken by aluminium. The epidote is typically patchy in composition.

Sphene is a frequent minor associate of the epidote.

e) Phlogopite. Little original mica remains unaltered and the potash content of most samples is well below 1% K_2O. In a few samples, however, it is certain that a few grains of a mica, probably phlogopite, were originally present. Aluminium contents are also generally low but enough is present, probably from original clay, to form a low percentage of mica.

f) Plagioclase. In the few samples with substantial sodium, silica and alumina, the stable calcium mineral is plagioclase. These samples are near the base of the sequence where granitic gneiss lies above the Warrow Quartzite. On balance of evidence the granitoid rocks are probably intrusive rather than metamorphosed arkoses or tuffs but field relationships may be more significant than optical microscopy in determining the origin of the gneissic lithologies.

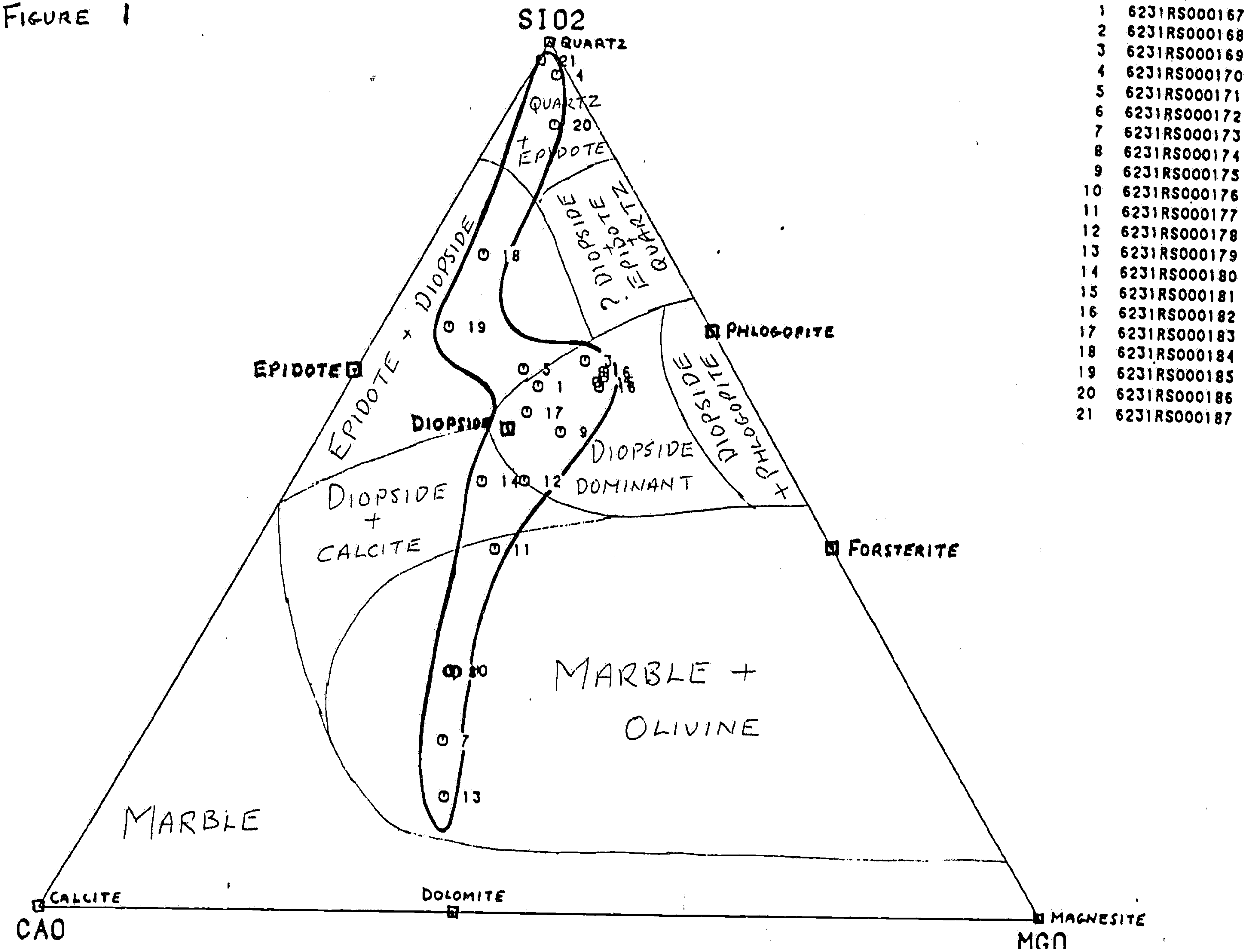
Using the parageneses identified and assumptions about the parental minerals of some of the products of retrograde metamorphism, a diagram has been drawn up as Figure 1 illustrating hypothetical stability fields of the prograde metamorphic minerals referred to the three components SiO_2, MgO and CaO. These are the major chemical controls of the mineralogy. Iron, aluminium, and alkalies play a secondary role and manganese a very minor part.

Figure 1 Hypothetical paragenetic fields in prograde metamorphism referred to system SiO_2-CaO-MgO. Inferred from observed mineral associations in DDH14 at Cowell.

KEY:

	Field of analysed samples.
	Inferred paragenetic boundaries.
EPIDOTE ▣	Mineral compositions.
▢	Sample compositions.

FIGURE 1


SI02
QUARTZ
21
4
QUARTZ + EPIDOTE
20
? DIOPSIDE + EPIDOTE + QUARTZ
EPIDOTE ± DIOPSIDE
18
19
EPIDOTE
PHLOGOPITE
5
3
16
1
8
15
17
9
DIOPSIDE
DIOPSIDE DOMINANT
DIOPSIDE + PHLOGOPITE
14
12
DIOPSIDE + CALCITE
11
FORSTERITE
10
MARBLE + OLIVINE
7
13
MARBLE
CALCITE
DOLOMITE
MAGNESITE
CAO
MGO
1 6231RS000167
2 6231RS000168
3 6231RS000169
4 6231RS000170
5 6231RS000171
6 6231RS000172
7 6231RS000173
8 6231RS000174
9 6231RS000175
10 6231RS000176
11 6231RS000177
12 6231RS000178
13 6231RS000179
14 6231RS000180
15 6231RS000181
16 6231RS000182
17 6231RS000183
18 6231RS000184
19 6231RS000185
20 6231RS000186
21 6231RS000187

3. Retrograde metamorphism

The amphibolite grade assemblages retrogressed to lower temperature assemblages in several stages. The process occurred between 1700 Ma and 1450 Ma and coincided with events D2, D3 and D4 in the tectonic evolution of the Jade Province (Parker, 1981). Chemical changes consequent on the replacement of one mineral assemblage by another involved the movement of constituents but again the overall composition of rocks probably varied little on a scale of a few metres.

An apparent association between the formation of nephrite and zones of relatively intense deformation was reported by Nicol (1974, p.23) but was considered by Parker (1981, p.13) not to be a direct genetic link but to provide a mechanism for facilitating the transfer of SiO_2 and $CaCO_3$ into and out of the massive dolomites. This relates to the prograde rather than retrograde transformations and rules out an original silica content in the carbonate sediments. Calcium rejected during the alteration of diopside to tremolite is often restored to the rock as a late stage replacement as carbonate, zeolite or fluorite and the net movement may be minimal. Silica required for the same reaction may be obtained from the alteration of mica to chlorite. Most of the fine grained nephrite in the specimens examined here does not exhibit an oriented fabric but some nephrite in some of the specimens is preferentially oriented.

Mineral assemblages produced during the retrograde alteration are listed below.

a) Marble. Recrystallisation of purely carbonate assemblages is evident only in bands of finer grains, often along the margins of coarser crystals, which are probably the product of stress. Disruption of regularly banded textures into zones dominated by either calcite or dolomite is also an indication of the strain associated with renewed tectonism during a regime of falling temperature.

b) Silica bearing marbles in which olivines had been developed by the prograde episode were altered to ophicalcite or serpentine marbles during retrogression. Low silica parageneses are characterised by individual ovoid pseudomorphs of either antigorite or chrysotile, often retaining textures simulating olivine. Higher silica assemblages contain bands of serpentinite in which the original granular texture may not be retained.

c) A relatively rare assemblage for which the controls of formation are probably moderate silica and high magnesium consists of an amphibole which is probably a high magnesium cummingtonite (kupfferite) and a magnesian member of the series norbergite-chondrodite-humite-clinohumite which might be described as hydrated olivines. The optical identification of both these phases requires confirmation.

Further retrograde alteration of this assemblage produces the magnesian orthorhombic amphibole anthophyllite.

d) Tremolite-nephrite. The moderately silica and calcium-rich diopside rock alters to the tremolite-nephrite assemblage. Alteration is progressive and may ultimately be reversed to some extent. In the first stage diopside alters to massive tremolite at the margins and along cleavages. The second stage is a coarse grained assemblage of tremolite crystals. Isochemical alteration of tremolite to nephrite occurs progressively in several stages of finer and finer grain sizes. The best jade consists of a felt of very fine acicular to feathery grains which appears to replace slightly coarser, often radiating, prisms as an integral mass with relatively sharp contacts. On textural evidence the jade appears to be either a mobile phase in itself or to have formed by replacement of coarser amphibole in place but under the influence of a volatile phase. Nephrite also appears to replace other silicates such as epidote. Even if the whole nephrite phase is mobile the viscosity of the fluid must be high. The grain size of solid precipitating from a fluid depends on the rate of precipitation and the viscosity of the medium. A fine grained precipitate forms rapidly in a medium of high viscosity. Slow precipitation and low viscosity promote high grain size. Most hypotheses on the genesis of nephrite jade attribute the fine grain to physical comminution through tectonic stress (Nichol, 1974; p.16). This appears to be unnecessary, particularly in fabrics without preferred orientation. Rapid cooling in a viscous medium appears adequate to ensure fine grained precipitation. It is possible that tectonic stress may contribute to the rapid cooling by causing sudden loss of a volatile component through fracturing but there is no evidence of a direct effect of stress by comminution. The major loss of volatiles involves CO_2 during prograde metamorphism.

Textural evidence indicates that, while some coarse grains of tremolite are relict fragments only partially replaced by nephrite, other coarse grains have grown at the expense of fine nephrite. The first type is embayed and invaded along cleavages by nephrite, the second merges with acicular nephrite surrounding it. Regrowth of tremolite and the occurrence of tremolite in late veins may take place after, possibly some time after, the regional metamorphic episode and will be mentioned again below.

e) Wollastonite. It is not clear from the sparse evidence available whether wollastonite is an alteration product of a calcium-rich pyroxene or a primary mineral formed during the prograde metamorphism of siliceous but magnesium-poor limestone. It is listed here because the balance of textural evidence suggests that it is a secondary mineral.

f) Epidote-clinozoisite-zoisite alteration assemblages. The epidote produced from carbonate rock rich in silica and calcium is also progressively altered during retrograde episodes. The low iron content of the original epidote appears to be lost to convert the mineral to clinozoisite. This in turn is replaced by orthorhombic zoisite which often occurs in discordant veins. The zoisite often contains enough manganese to colour it pink. Regular bands of epidote tend to be disrupted during the retrograde metamorphism.

g) Chlorite is often pseudomorphous after mica, assumed to be phlogopite, and forms scattered grains and irregular patches. It is also seen to replace both tremolite and nephrite. Chlorite is also present as a massive rock in which it is the only phase. This type of occurrence is usually associated with late discordant veins. Three types of chlorite are distinguished on optical properties and may represent the alteration products of three parental minerals. Some variation on the other hand may be the result of the type of alteration process rather than the parental mineral. The chlorite field in the paragenetic diagram is not satisfactorily related to observed assemblages. More data are needed to resolve its occurrence.

4. Late alteration processes

As mentioned above, some of the alteration of both prograde and retrograde metamorphic phases may date from after the end of the retrograde metamorphic process. Some alteration may be completely unrelated to regional tectonism, and, particularly where volatiles such as fluorine, phosphorous and water are involved, may be of contact metamorphic type related to post-tectonic granitoid intrusions.

The products of this type of alteration are partly disseminated through the fabric of the rocks and partly the filling of veins which are discordant to all other elements of the fabric. The regrowth of coarsely crystalline tremolite from nephrite may have been catalysed by the permeation of the rock by volatiles. Scattered coarse grains of fluorite in cavities almost certainly produced by dissolution of silicates are indications of the overall penetration of the rocks by volatile solvents at a late stage. Apatite is another mineral disseminated through some of the rock specimens and originating probably in reactions between volatiles containing dissolved phosphorous and fluorine and calcium from carbonate or silicate phases. It is possible that some chlorite originated in alteration dating from this time.

Chlorite is also an important constituent of alteration associated with mobile phases, probably aqueous solutions, moving through discordant fractures. Other minerals also precipitated from these solutions are zeolites, carbonates and even diopside and tremolite. The latter two phases are possibly redeposited from constituents leached from the same two minerals located elsewhere in the rock.

A diagram has been prepared using the same method as for the prograde assemblages to show the stable assemblages in retrograde alteration, recalculated to refer to SiO_2, MgO and CaO. This is figure 2.

Figure 2 Hypothetical paragenetic fields in retrograde metamorphism referred to system SiO_2-CaO-MgO. Inferred from observed mineral associations in DDH14 at Cowell.

KEY:

━ Field of analysed samples.

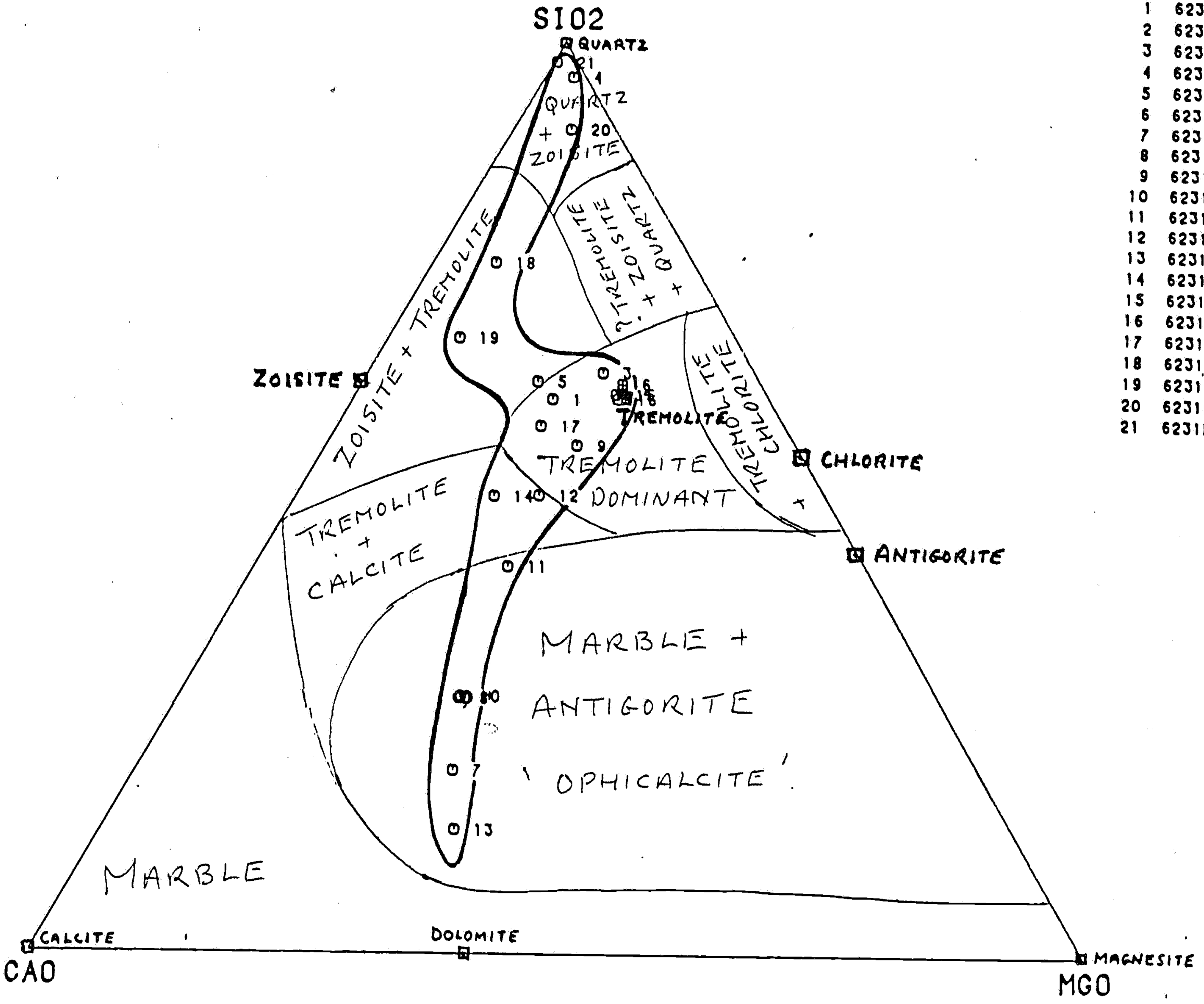
─ Inferred paragentic boundaries.

ZOISITE ▣ Mineral compositions.

▢ Sample compositions.

NOTE: Field boundaries are shown as identical to those of the prograde assemblages. In practice they probably vary. More data are required to elucidate this and also to delineate the fields of chlorite-bearing assemblages. Most samples contain more than one mineral assemblage and equilibrium may not have been reached in any of them. For this reason the boundaries are approximate and some specimens appear not to be in the appropriate fields.

FIGURE 2



1	6231RS000167
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3	6231RS000169
4	6231RS000170
5	6231RS000171
6	6231RS000172
7	6231RS000173
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19	6231RS000185
20	6231RS000186
21	6231RS000187

c. Conclusion

Nephrite jade is composed of very fine grained, felted tremolite. At Cowell it is formed by the metamorphic reconstitution of dolomitic limestone. The alteration occurred during the regional deformation of a siliceous and carbonate sedimentary sequence and the jade formed during a sequence of retrogressive episodes. Tectonic stress may have contributed indirectly to the formation of jade but the fine grain cannot be attributed directly to shearing.

Some mobility of constituents is evident but regional metasomatism is not believed to be a significant factor. A late stage alteration may promote the redevelopment of coarse grained tremolite from fine grained nephrite.

When silica exceeds about 50%, epidote occurs with the tremolite of the prograde assemblage and is altered to clinozoisite and zoisite in the retrograde alteration.

With less silica than about 40% SiO_2, magnesian silicates are formed which alter retrogressively to serpentinite. This produces an ophicalcite which may in itself be valuable as an ornamental stone for building, if not a semi-precious stone for jewellery.

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BIBLIOGRAPHY

Barnes, L.C., Conor, C.H.H., Crettenden, P.P., Daly, S.J., Harris, R.J., Johnson, P.D., McCallum, W.S., Nicol, D., Pitt, G.M., Scott, D.C., Wildy, R.L. and Young, D.A., 1980. Some semiprecious and ornamental stones of South Australia. Dept. Mines and Energy, S.A.

Nicol, D., 1977. Nephrite jade deposits near Cowell, Eyre Peninsula. Min. Resour. Rev. S. Aust. 141:11-26.

Parker, A.J., 1981. Structural and metamorphic controls on the origin of nephrite jade near Cowell, South Australia. Rept. Bk. 81/114. D.M.E.