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PETROLOGY OF BASEMENT ROCKS FROM THE SOUTHWESTERN MARGIN OF THE MURRAY BASIN, SOUTH AUSTRALIA

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CONTENTS PAGE

ABSTRACT 1

INTRODUCTION 1

BASEMENT AND SUPERFICIAL DEPOSITS 2

SAMPLING 2

PETROGRAPHY 2

Yumali DDH Y2 2
Y3 5
Y4 10
Y5 10
Y6 18
Y7 23
Y8 25
Y9 26
Coonalpyn DDH C1 30
C2 32
C3 37
C4 38

Tailem Bend DDH DT4 42

Mason Lookout DDH 1 43

Blind Creek DDH 2 46

DISCUSSION 50

1. Metabasalts 50
2. Metadolerites 51
3. Picritic Metabasalts 51
4. Trachyandesites 52
5. Sediments 52
6. Gabbro 53
7. Granite 53
8. Amphibolites and Feldspathic Gneisses 53

CONCLUSION 53

REFERENCES 55

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Petrology of Basement Rocks from the Southwestern Margin of the Murray Basin, South Australia

M G Farrand

Drilling and sampling of basement intersections by CSR Ltd and the Department of Mines and Energy have revealed an igneous domain in the basement of the southwestern Murray Basin. The most abundant rocks are altered and soda-enriched basaltic lavas and tuffs of spilitic type. Less abundant volcanics are picritic metabasalts and trachyandesites. Intrusive rocks include metadolerites and unaltered gabbro and granite. Sediments are rare and mainly consist of recrystallised silica and chlorite probably derived from corrosion of the basalts in place, together with very rare distal terrigenous clastics, mainly micas and clays. Tectonic deformation is localised rather than regional. The dominantly igneous domain contrasts with terrigenous clastics of the Kanmantoo Group on the northwest and the Glenelg River Complex on the southeast. The extent of the province in other directions is not known. If subsequent drilling indicates a wide area of submarine volcanics the province may be a back arc basin but the volcanics examined were intersected on the Padthaway Ridge which may have been a tensional or transcurrent tectonic feature at the time of eruption. The area is of high ore-forming potential, particularly for pyritic copper-zinc deposits and it is suggested that further drilling should be targeted on zones of strong alteration and tectonic disruption within the volcanic rocks.

INTRODUCTION

Basement of the Murray Basin in South Australia is almost completely concealed beneath sediments of mainly Tertiary age. Marine transgression in the Tertiary reached as far as what are now the Menindie Lakes (Carter 1985). Cover is shallow along the western margin of the Basin east of the Adelaide Fold Belt and occasional inliers of basement outcrop. A corridor of shallow basement with scattered inliers is also formed by the Padthaway Ridge. The latter structure was explored by CSR Ltd (Gidley 1983b, Tonkin and Curtis 1986) with an extensive drilling programme. One aim was to calibrate various types of aeromagnetic signature, another was to examine in detail an area of high total magnetic intensity in the vicinity of Yumali. Previously Thiess Bros (Dredge 1979, Gidley 1983a) had drilled a long linear aeromagnetic anomaly from Tailem Bend southwards to the Coorong east of Lakes Alexandrina and Albert. Amphibolite at Tailem Bend was drilled by the Department of Mines in DDH DT4 (Morris and Nichol 1974). Brief petrographic descriptions were provided by Central Mineralogical Services Pty Ltd (Fander 1985) and chemical analyses were performed by Commonwealth Laboratories Pty Ltd (in Tonkin and Curtis 1986). The present report is an expansion of the petrology, including additional thin sections of CSR Ltd core. Geochemistry is only used to assist in the identification of samples.

BASEMENT AND SUPERFICIAL DEPOSITS

Basement was intersected by CSR Ltd (op cit) in eight holes drilled within a radius of 7 km near Yumali, four holes spread over 15 km near Coonalpyn and two cored holes (as well as several percussion holes) between Tailem Bend and Meningie. The first hole drilled at Yumali (DDH Y1) was abandoned at 197 m in sediment. In retrospect it seems likely that basement would have been intersected in a few more metres. In other holes depth to basement varied from 49 m (DDH C4) to 209 m (DDH Y3) . Cores averaged about 7 m with extremes of 2 m (DDH Y2) and 12 m (DDH Y5). Localities are shown in Figure 1.

Immediately above crystalline basement in most holes a blue-grey clay containing fragments of quartz and mica probably represents weathered basement of the pre-Tertiary land surface. However at some localities, clays of weathered basement pass upward into Permian clays of glacial origin (N F Alley, pers. comm). Thickness of clay varies in the holes drilled from 85 m in DDH Y3 to nothing in DDH C4 which is close to a present day basement inlier. Apart from such outcrops, depth to basement varies from 88 m to 144 m below the present land surface but when related to sea level most of the pre-Tertiary landscape is relatively flat and about 100 m below present sea level. Early Tertiary sediments are terrestrial, lacustrine and estuarine and the original landscape was probably a swampy plain with residual hills. Later marine incursions resulted more in deposition of new sediment than erosion except of the residual hills.

SAMPLING

Thin sections are essentially point samples while material for geochemical analyses was bulked from chip samples taken over intervals of up to two metres.

Where lithologies vary over short distances the chemical analysis may not be representative of a single thin section.

PETROGRAPHY

Specimen 6826 RS 50
CSR numbers Specimen 189632, analysis 189601, TS 53152
Locality Yumali DDH Y2 161.6m
Rock name Metadolerite
Hand Specimen

The rock is a medium grained mosaic of closely-interlocking, irregular patches of white and greenish grey. Opaque black minerals and patchy scattered pyrite are visible. The specimen gives a weakly ferromagnetic response to a hand magnet. The texture displays no detectable preferred orientation.

Thin Section

Alteration is heavy and widespread throughout the rock but despite this it is apparent that the white patches are composed largely but not entirely of plagioclase and the grey green patches consist of amphibole and chlorite. Epidote and opaque material are widespread.

The plagioclase occurs as subhedral to rare euhedral laths which are closely sized about an average of approximately 2mm in length. The laths tend to cluster in groups which are often radiating in structure. Neither the disposition of individual crystals nor that of the clusters exhibits any detectable preferred orientation.

The crystals are quite strongly altered with a consistent pattern of sericite, or often quite coarse grained muscovite, over the major part of the grain and a thin, almost unaltered rim of plagioclase. The marginal zone is often untwinned and few crystals display a well developed multiple twinning. These are not ideal

circumstances for the determination of composition through the maximum symmetrical extinction of albite twins. However all extinction angles appear to be low enough to fall within the oligoclase range and this is probably the compositional range of the plagioclase laths.

In addition to the micaceous alteration of the plagioclase, frequent fragmentary epidote inclusions are probably products of reaction between hydrous fluids and calcium rejected from a more calcic plagioclase than the present composition of the laths.

Plagioclase laths are not the only constituents of the white patches seen in hand specimen. Interstitial material makes up a large proportion of the felsic component of the rock and consists of myrmekite and quartz. The myrmekite appears to consist of vermicular quartz in a matrix of plagioclase. Interstitial quartz is either highly strained or granulated. In places the granular quartz appears to be in optical continuity with the vermicular quartz of adjacent myrmekite. Chemical disequilibrium between plagioclase laths and interstitial minerals is occasionally exhibited in embayment of the plagioclase margins by both myrmekite and quartz. Occasionally the plagioclase adjacent to granulated quartz is itself granulated.

Neither crystallisation nor recrystallisation textures exhibit preferential orientation except in local relationships to adjacent plagioclase.

The mafic component of the rock is now represented by the grey green patches. These consist mainly of platy minerals including two species of chlorite and a weakly pleochroic, poorly crystalline brown mica. One chlorite is a strongly pleochroic penninite with anomalous birefringence. The other is almost completely non-pleochroic and virtually isotropic. Areas of chlorite are mottled due to the fine grain, but poor definition, of individual crystals.

Relict grains and patches of altered hornblende indicate the presence of amphibole at one stage, but not necessarily the original stage, in the history of the rock.

Tabular, skeletal and irregular patches of an amorphous, brown, translucent to opaque material are probably composed of limonite and leucoxene. They indicate the pseudomorphous replacement of a ferromagnesian mineral possibly distinct from the relict amphibole. This may have been pyroxene or even olivine but too little of the original mineral remains to permit identification.

Fragmented epidote is abundant in the chlorite as well as in the plagioclase and a fine grained mineral of high birefringence which is probably sphene is widely distributed in irregular patches.

Long acicular prisms of apatite are widespread but not volumetrically abundant.

No pyrite was observed in the thin section and, in view of the magnetic response of the hand specimen, the opaque material present is probably a magnetite or ilmenomagnetite. Opaque grains are patchy and often skeletal.

Comment

The rock is identified in the CSR report as a diorite but the composition is partly the product of strong alteration. With the benefit of the assay it is clear that the sample is essentially basaltic. Significant analytical determinations are: SiO_2 49.7%, MgO 4.7%, iron expressed as Fe_2O_3 14.5%, CaO 7.45%, Na_2O 2.6%, TiO_2 1.89% and a moderately high vanadium determination of 240 ppm.

An exact correspondence between analytical determinations and observed mineralogy is unlikely since the assay was carried out on a sampled length of core from 161 m to 163 m and the thin section represents a single point in that length. However, the analysis suggests that, despite the alteration, the rock retains an essentially basaltic composition. Magnesium has been retained in the chlorite and calcium lost from plagioclase and probably from pyroxene has been taken up in epidote, apatite and sphene.

Mineral textures suggest the crystallisation of plagioclase phenocrysts in a magma which may also have contained ferromagnesian phenocrysts possibly including amphiboles. The plagioclase laths appear to have seggregated to a large extent in patches. The texture suggests the crystallisation of a minor intrusive or possibly a very thick lava flow. It is unlikely that there ever was a glassy groundmass.

Specimen 6826 RS 67, TS C 50399
Locality Yumali DDH 2 161.95 m - 162 m
Rock name Metadolerite
Thin section

The rock is medium grained and consists of abundant altered plagioclase closely intergrown with altered amphibole. Medium to fine grains of epidote are mainly included in the plagioclase while the principal alteration product of the amphibole is chlorite. Fragmentary patches of opaque minerals are mainly associated with altered amphibole and are probably also produced by alteration. Both interstitial quartz and myrmekitic intergrowths of quartz with plagioclase are late stage and may be introduced.

Plagioclase grains are anhedral for the most part but subhedral laths are present. No preferential orientation is evident. The plagioclase is fresh enough for symmetrical extinction angles of multiple twins to be measured in some grains. The composition indicated by these tests is close to the boundary of oligoclase and andesine. Abundant epidote inclusions suggest that the present composition may be substantially more sodic than the original intrusive plagioclase however.

Amphibole is extensively altered to chlorite and the outline of the original crystals is frequently obscured. However, a few crystals are recognisably euhedral and it is probable that at least some amphibole crystallised before some plagioclase. It is possible that most amphibole was earlier than most plagioclase. Unaltered amphibole is brown and strongly pleochroic but with progressive alteration towards chlorite the colour becomes greenish and the pleochroism is weaker. While alteration in plagioclase produces discrete grains of epidote included in almost unaltered feldspar, chloritic alteration in amphibole is progressive, pervasive and without sharp boundaries. A few grains of epidote included in chloritic masses may be alteration products of amphibole or may indicate earlier plagioclase inclusions.

Opaque material occurs mainly as diffuse and cloudy patches of fine to very fine grains and granules, usually associated with altered amphibole. The material probably consists of iron and possibly titanium rejected during chloritisation. Occasionally an oriented pattern of opaque grains represents material exsolved from amphibole before the crystal structure was destroyed. Rare euhedral to subhedral fine opaque grains are probably original precipitates from the magma.

Interstitial patches of quartz are quite frequent and are either a product of late stage crystallisation, of early alteration while the magma was not totally crystallised or of introduction by replacement after complete crystallisation. In many places the contact between quartz and adjacent plagioclase is marked by zones and patches of myrmekite. This appears to be the product of reaction between quartz and plagioclase and probably indicates the replacement of the latter by the former. The source of the silica is possibly hot, circulating groundwater.

Acicular and prismatic crystals of apatite are frequent.

Comment

The rock is a minor intrusive in which plagioclase and ferromagnesian minerals crystallised together, or at least with a substantial overlap in periods of crystallisation. Evidence of alteration is abundant and the nature of the original plagioclase and ferromagnesium mineral is uncertain. It is clear that calcium has been rejected from both major phases. The alteration has not imposed an oriented fabric on the rock and is probably deuteric in origin.

The specimen sectioned is the same as that analysed and the analysis corresponds closely with that analysed for CSR Ltd. Significant constituents are : SiO_2 52.7%, MgO 5.2%, Fe_2O_3 12.6%, CaO 5.4%, Na_2O 3.86%, TiO_2 1.92% and V 390 ppm.

Specimen 6826 RS 77, TS C 50400
Locality Yumali DDH Y3 213m - 213.05 m
Rock name Metabasalt
Thin section

The rock consists essentially of fine grained, subhedral to almost euhedral plagioclase laths with interstitial chlorite and opaque grains. Large grains of dolomite are sparsely distributed but finer interstitial grains and inclusions increase the carbonate content. Patchy sphene is abundant and apatite rare.

The abundant plagioclase is slightly altered to platy minerals and is often poorly crystalline so that optical determination of composition is not precise. As far as may be determined the plagioclase is an oligo-andesine. No consistent orientation of crystals is apparent over the whole section but local clusters of laths sometimes display a radial structure.

Interstitial chlorite is formless, green and weakly pleochroic. Between crossed polarisers it is weakly birefringent with an anomalous pinkish purple polarisation colour.

The only directional fabric evident in thin section is a weak bedding in opaque mineral grains. The grains are subhedral to anhedral in form and strongly altered to a poorly crystalline sphene. In detail the grains display a weak tendency to preferential elongation but in aggregate there is a tendency to form irregular bands with a parallel orientation.

Sphene is common as an alteration product of opaque minerals but apatite only occurs occasionally as acicular inclusions in plagioclase.

Fine grains of dolomite occur as inclusions and patchy replacement products in both plagioclase and chlorite. Patches overstep the margins of silicate grains and are irregular in shape.

Coarse grains of dolomite are subcircular in outline and are usually at the centre of subcircular zones in which overall grain size of plagioclase, chlorite and patchy sphene is markedly finer than average. Opaque minerals are usually absent. This evidence of chilling and leaching of iron is a possible indication of the passage of volatiles or the ingress of cold water and hence that the specimen may be at or near the surface of a flow. The passage was later filled with dolomite.

Comment

The finer grain size and absence of early ferromagnesian crystals distinguish the specimen from those identified as metadolerites. The rock is probably an altered basalt from near the surface of a submarine flow. It is similar in essence to the CSR specimen 6826 RS 51 from 214.6 m. Significant analyses are: SiO_2 52.3%, MgO 3.98%, CaO 5.15%, Na_2O 4.9%, Fe_2O_3 12.9%, TiO_2 1.59% and V 310 ppm. The dolomite content is reflected in a high loss on ignition of 5.1%.

Specimen 6826 RS 51
CSR numbers Specimen 189633, analysis 189602, TS 35153
Locality Yumali, DDH Y3, 214.6 m.
Rock name Metabasalt with chilled fragment
Hand Specimen

The rock is fine grained and of a dark green colour without white crystals, in contrast to RS 50. Irregular to subrounded white patches up to 5 mm across are concentrated in two wide bands oblique to the core barrel.

The core has fractured along the same plane as the bands which may indicate a primary fabric. The ends of the core exhibit what appears to be a weak foliation parallel to the length of the core. The specimen responds quite strongly to a hand magnet. The internal sawn surface from which the section has been made exhibits a sharp boundary between dark greyish green and lighter greyish green.

Thin Section

The rock consists of a fine grained mass of plagioclase laths and interstitial chlorite. Irregular to ovoid vesicles are filled with carbonate or platy minerals. A substantial part of the section is much finer grained than the rest and includes crystallites in a glassy matrix. The margin of the fine grained patch is sharply defined when seen both with and without magnification and the material appears to be a fragment of autobrecciated lava, probably from the top of the flow.

Plagioclase laths are about 0.05 mm long and are almost entirely without alteration. Some laths are cracked and even bent, however. All orientations are present but there is a statistical tendency for a preferred orientation along the length of the core. The plagioclase is not strongly twinned but what twins there are can be observed clearly since alteration is limited to a few scattered flakes of sericitic mica. The composition indicated by maximum symmetrical extinction angles is in the andesine range.

Between the plagioclase laths the main mineral is a penninitic chlorite. The mineral is either poorly crystalline or is present as a mass of poorly defined grains. It appears mottled and is almost isotropic. Other interstitial minerals are a fragmentary sphene and a few flakes of a pale biotite.

Opaque material, which is at least in part magnetite, occurs as moderately coarse grains associated with fragmentary sphene and as abundant, very fine granules spread throughout the interstitial material.

Abundant short, thin prisms of apatite are included in many of the plagioclase laths.

The carbonate in the thin section is probably dolomite. It occurs as relatively fine patches of replacement scattered throughout the rock and also as coarse grains in the vesicles. The latter may be primary. At one end of the thin section a thin vein of carbonate connects two vesicles filled with carbonate. A second vein of similar type occurs in the centre of the specimen. Textures frequently indicate the replacement of plagioclase by carbonate.

Most of the vesicular cavities in the lava have been filled with carbonate but some are filled with platy minerals instead of, or as well as, carbonate. Two types of platy minerals are present and may occur together or separately in the amygdales. One is a pale, moderately pleochroic biotite with a khaki brown colour. It occurs in flakes about 0.5 mm long with subhedral to euhedral shape. The other mineral is a pale green, weakly pleochroic chlorite with a low to very low birefringence and a tendency to exhibit anomalous polarisation colours. It is a penninite and varies in grain size from somewhat finer than the biotite to fine grained and interstitial. The fine grained material is almost isotropic and may be poorly crystalline.

There is a tendency for some amygdales to be flattened and with a preferred orientation along the core length but some are more equidimensional.

Comment

The fine grain size indicates a probable extrusive rather than intrusive origin for the rock. The large, fine grained, probably chilled fragment may be the product of autobrecciation at the surface of the flow. Former gas bubbles, now amygdales, are abundant enough to suggest that the specimen may have originated nearer the top than the bottom of a flow. Directional textures such as the flattening of vesicles and a weak preferred orientation in the plagioclase laths may be the product of lava flow. Some laths are damaged by fracturing and bending which also may be due to vigorous flow. However, a second preferred orientation seen in the

hand specimen is almost certainly the result of tectonic forces. Alteration is not oriented and is probably deuteric.

The assay is again that of a basic rock. Significant values are: SiO_2 48.5%, MgO 4.3%, CaO 6.5% Na_2O 4.5%, Fe_2O_3 13.5% TiO_2 1.87% and V 290 ppm. The plagioclase is less altered than that of RS 50 but the abundance of sphene indicates an originally high calcium content.

There is little doubt that the rock is a weakly foliated and somewhat altered basalt flow.

Specimen 6826 RS 52
CSR numbers Specimen 189634, analysis 189603, TS 53154
Locality Yumali. DDH Y3 216.3 m
Rock Name Feldspathic metabasalt
Hand Specimen

A diffuse compositional boundary splits the core longitudinally into two unequal parts. The larger of these is a dark grey green and is strongly ferromagnetic. The second part is a lighter greyish green and shows no detectable response to a hand magnet. Both parts exhibit an oriented texture along the length of the core (but across the length of the thin section). The orientation is manifested by flattened green patches, by fine white veinlets and by a general weak foliation. The overall grain size appears to be fine but the rock is porphyritic. Pyrite is present in patches and thin veins.

Thin section

No clear division between dark and light facies is apparent in thin section. The rock consists of abundant plagioclase crystals, a finely granular matrix or groundmass and patchy chlorite. Carbonate alteration is widespread.

The plagioclase occurs mainly as laths which vary in size but average about 0.5 mm long although individually they are up to 1 mm long. It also occurs in large, poorly defined, irregular interstitial plates and as finely granular interstitial intergrowths. Twinning is developed in some of the laths, permitting the determination of a composition in the andesine range, but is absent from many laths and from all plates and mosaics. It is possible that more than one generation of plagioclase are present. The directional texture apparent in the hand specimen is not a reflection of oriented plagioclase. The laths are in random orientations with a tendency to form clusters. Alteration is light but many grains are poorly crystalline from their optical properties.

The interstitial mosaic consists of finely granular minerals of low birefringence. They are untwinned but are probably plagioclase as the assay does not indicate the presence of free quartz.

Chlorite of a penninite type is widespread as an interstitial phase, as medium grained masses which may be pseudomorphous and as amygdaloidal cavity fillings. The latter are often compressed and some are streaked out into thin lenses and schlieren. This texture is one of the causes of the directional fabric observed in hand specimen. Some of the chlorite masses contain fine included flakes of a pale, weakly pleochroic biotite.

The other main cause of a weakly foliated appearance is the distribution of carbonate. This is abundant as veinlets, most of which are parallel to the fabric produced by the chlorite but a few of which are discordant to the dominant foliation. Carbonate is also widespread as fine to medium grained patches with irregular but generally equant shape and also occurs more rarely as the filling of amygdales. The carbonate is dominantly dolomite but some magnesite may also be present.

Fine to coarse patches of a cloudy, amorphous, whitish material are abundant and the material also forms short veins and schlieren, sometimes associated with carbonate. Occasional fragments of highly birefringent inclusions suggest that the material is probably leucoxenised sphene.

Scattered, fine granules of opaque minerals are abundant but more substantial masses occur in irregular form, in skeletal pseudomorphous outlines and as inclusions within the leucoxene. Probably both magnetite and ilmenite are present.

Comment

Because the rock consists to a very large extent of andesine plagioclase, there is some justification for identifying it as an andesite. However, a glance at the assay indicates that an intermediate classification is not appropriate. Significant values are: SiO_2, 42.6%, MgO 5.55%, CaO 9.6%, Na_2O 3.6%, Fe_2O_3 13.6%, TiO_2 2.8%, Cr 200 ppm, V 260 ppm and loss on ignition of 7.85%. The high loss on ignition indicates that carbonate replacement is at least partly responsible for the low silica and high calcium but substantial iron, chromium and vanadium suggest at least a basic affinity, possibly an ultrabasic association.
The present andesitic plagioclase has probably rejected calcium which is now held in leucoxenised sphene and possibly in some of the carbonate. The finely granular interstitial material is possibly derived from devitrified glass, indicating an origin as a lava or tuff.

Alteration has been strong enough to decompose and remobilise the ferromagnesian component of the rock, although the plagioclase has not been altered further than to readjust the calcium - sodium ratio.

Specimen 6826 RS 87, TS C 50401
Locality Yumali Y3, 217.93 m - 217.99 m
Rock name Metabasaltic ash fall tuff.
Thin section

The rock is composed of feldspar both as tabular crystals and as a fine grained mosaic, of chlorite as interstitial material and as lenticular pods and of abundant opaque minerals. A pervasive carbonate alteration makes dolomite a major constituent. Biotite is a minor component associated with chlorite. Lenticular pods, some dolomite lenses and much of the opaque material produce an oriented fabric.

Some of the feldspar is readily identifiable as plagioclase and from symmetrical extinction of twin sets appears to be of andesine composition. Much of the feldspar is without detectable twinning and composition is uncertain. Feldspar in interstitial patches of fine grained mosaic is not identifiable. Tabular crystals are at best only subhedral in shape, largely because of extensive corrosion by carbonate. Orientation is not consistent.

Interstitial chlorite and associated biotite tend to occur in linear aggregates with a preferential orientation even outside the lenticular pods. Within the pods the orientation is generally consistent with the length of the pods. The relative proportions of chlorite and biotite vary between the extremes of virtually all biotite and virtually all chlorite. However, overall chlorite is the more abundant. Chlorite is green, weakly pleochroic and weakly birefringent with an anomalous pinkish purple polarisation colour. Biotite is a pale greenish brown and weakly pleochroic.

Dolomite is widely distributed as irregular patches overstepping the margins of plagioclase grains and massed flakes of platy minerals. Dolomite also occasionally forms lenticular patches of similar dimensions to the lenses of platy minerals. In lenses and in the matrix dolomite tends to take up a preferential orientation.

Opaque minerals are of two types. One type is of fine grain size, of poor shape and of wide distribution. It is associated with chlorite as an interstitial mineral. The second type of opaque material occurs as large, well shaped grains closely associated with lenticular patches of platy minerals, particularly when rich in biotite.

Sphene is a frequent alteration product of opaque minerals (presumably ilmenite) and also forms independent grains. Much of the sphene is leucoxenised.

Comment

Lenticular patches of hydrous, platy minerals possibly indicate original vesicles in a material of volcanic origin but with a low resistance to flattening. This suggests that the rock originated as a pyroclastic rather than a lava. The composition may have been very similar to that of a lava initially but has subsequently been modified by substantial carbonate replacement. Significant analyses are : SiO_2 42.6%, MgO 5.65%, CaO 11.4%, Na_2O 2.28%, Fe_2O_3 13.7%, TiO_2 2.34%, Cr 660 ppm, V 290 ppm and loss on ignition 9.5%. The latter high value, and the high lime content, are reflections of the extent of carbonate replacement, as are probably the relatively low silica and soda. The analysis correlates well with that of an adjacent CSR sample (189603) which has also been dolomitised but less well with a sample (189604) which is less altered.

Specimen 6826 RS 53
CSR numbers Specimen 189635, assay 189604, TS 53155
Locality Yumali, DDH Y3, 218.15m
Rock name Sheared metabasalt
Hand specimen

The fine grained grey basalt is traversed by many fine fractures which are marked by green and white minerals. Fragments between fractures are mainly separated but not otherwise moved by the fracturing but some fragments are seen to be of differing lithologies and are probably brecciated clasts mixed with the fragments in place. The fractures are partly parallel to and partly discordant to the length of the core.

The specimen gives a strongly ferromagnetic response to a hand magnet.

Thin section

The major part of the rock consists of thin plagioclase laths with a strong tendency towards a preferred orientation in a fine grained groundmass composed of chlorite, biotite, sphene and abundant round granules of opaque mineral, presumably magnetite. Patches of carbonate are frequent. Grain size variation occurs between some fragments separated by fractures but the composition does not differ significantly.

The plagioclase laths are certainly phenocrysts in a much finer grained groundmass. They measure up to 1 mm in length in the coarser fragments. Twinning is rare and imperfect but the assay indicates a higher sodium content than the other specimens described. The preferred orientation is the product of flow, as is the occasional damage seen in bent and fractured laths.

Chlorite occurs in the groundmass and, usually with mica, in the fracture system. It is not as abundant as in the other specimens examined and appears to grade into the more abundant micaceous phases.

A transition between chlorite and biotite is represented by a range of intermediate phases. Low potash in the assay indicates that true biotite is probably rare. The most common phase is a greenish brown mica with a rather weak pleochroism and moderately high birefringence. The mica occurs in the groundmass, in fractures and the walls of fractures and in scattered patches which are probably poorly developed amygdales.

Carbonate occurs as scattered patches, in fractures and in rare amygdales. It is probably dolomite.

The rock interstitial to the plagioclase laths is densely packed with very fine magnetite granules.

What appears to be a leucoxenised sphene occurs in scattered crystals, generally fine grained and fragmented.

Comment

The basalt is somewhat less mafic than the rocks described above and is particularly richer in soda. The significant determinations are: SiO_2 46.6%, MgO 3.15%, CaO 7.3%, Na_2O 5.40%, Fe_2O_3 13.0% and TiO_2

3.0%. Compositions such as this used to be referred to as 'spilitic' and were generally believed to indicate sea floor basalts. The specimen is from a chilled and brecciated surface of a lava and is quite possibly submarine. If seen as a large hand specimen it might prove to be a lava pillow.

Specimen 6826 RS 54
CSR numbers Specimen 189636, assay 189608, TS 53156
Locality Yumali, DDH Y4, 204.4 m
Rock name Amygdaloidal metabasalt
Hand specimen

The rock is fine grained, green and amygdaloidal. There is a tendency for amygdales to be flattened in a plane oblique to the length of the core. At the ends of the core section a weakly foliated texture is visible. Fine grained pyrite is distributed through the rock. There is no detectable response to a hand magnet.

Thin section

The dominant mineral present is plagioclase which occurs as a close-packed mass of laths in which all orientations are represented but a very weak preferred orientation is detectable. A smaller proportion of chlorite is interstitial to the plagioclase.The plagioclase laths vary in length between about 0.5 mm and 1 mm and are closely grouped around the groundmass average with almost no tendency towards a porphyritic texture. Despite a weak development of twinning it is possible to determine the composition as that of andesine. Crystallinity is not always well marked but very little alteration has taken place.

A green, weakly pleochroic, almost isotropic chlorite is ubiquitous in the interstices between plagioclase laths.

Sphene is rather patchily distributed as a second interstitial phase while broken prisms of apatite are a third. Scattered flakes of a poorly crystalline, greenish brown mica are also present.

Carbonate is widely distributed in patches and as filling in the amygdales. It is probably dolomite.

Pyrite is rare in the thin section and a few subhedral grains of limonite occur as clusters in a few amygdales.

Comment

The specimen is similar to RS 52 in the high proportion of plagioclase. The chemistry of the basalt is again of spilitic type. Significant assay determinations are: SiO_2 44.8%, MgO 4.35%, CaO 7.7%, Na_2O 3.8%, Fe_2O_3 13.4% and TiO_2 2.8%.

Specimen 6827 RS 70,, TS C 50402
Locality Yumali Y5 150.96 m - 150.99 m
Rock name Amphibolite (meta picrobasalt)
Thin section

The specimen represents a distinctly different type of basalt. The major part of the rock consists of closely-intermeshed, fine grained, feathery prisms of amphibole with minor epidote and poorly-crystalline, dusty, semi-opaque material. Superimposed on the fine grained host are abundant patches between 1 mm and 3 mm across, which vary in shape between subspherical and polygonal with the highest abundance in ovoid to lenticular shapes. Some of these contain coarse grained epidote in a matrix of chlorite and dolomite and are probably amygdales. Others are clearly altered phenocrysts, often with relict fragments or skeletal patches of the original mineral. No preferred orientation is evident in the crystals but many of the flattened amygdales are consistently aligned.

The amphibole is weakly pleochroic from colourless to very pale green and is relatively low in refractive index. It is biaxial negative with 2 V = 40, strong dispersion but weak birefringence. Extinction angles are

up to 22. Most of the properties are those of tremolite but the small 2V suggests that the amphibole is somewhat sodic. It may be a richterite or soda-tremolite but the ragged shape and mottled birefringence of the crystals indicate probable imperfect crystallinity and heterogeneous composition. Only a little sodium is indicated by the assay.

A few of the relict phenocrysts are identifiable as the same amphibole as occurs in fine grains of the groundmass. The phenocrysts are largely replaced by chlorite, sometimes with dolomite.

Minor epidote in the groundmass occurs as anhedral fragments but by far the major form of epidote is euhedral to subhedral prisms in large patches which were probably vesicles. A few patches containing epidote may have been plagioclase phenocrysts. In amygdales epidote is accompanied by chlorite and often by dolomite.

An abundant but unidentifiable constituent is a cloudy, semitranslucent material which is partly interstitial and partly a replacement product of the amphibole. At highest magnification some finely granular particles are resolved but much of the material remains cloudy and formless. Optical properties are not distinct enough to identify the material but a high loss on ignition (4.98%) suggests that more carbonate may be present than that identified in the vesicles. The formless material may be amorphous carbonate, probably dolomitic.

Very rare opaque grains are anhedral.

Comment

The mineralogy and chemical composition of the rock are distinct from those of the spilitic basalts. No feldspar is identifiable, although epidote in amygdales may originally have been plagioclase. The mineralogical composition is that of an altered ultramafic rock with early phenocrysts of original pyroxene and the chemical analysis endorses this identification. Significant analyses are : SiO_2 44.5%, MgO 14.7%, CaO 10.4%, Na_2O 0.71%, K_2O 0.12%, Fe_2O_3 13.4%, TiO_2 1.6%, Cr 660 ppm, Ni 520 ppm and loss on ignition 4.98%. The characteristics of a picritic basalt are particularly exemplified by the high magnesium and low silica. Chromium and nickel are higher than in the spilites.

Abundant, slightly flattened amygdales and well shaped phenocrysts in a fine grained groundmass probably indicate a lava but the evidence does not exclude a pyroclastic flow. Orientation of amygdales may indicate flow but may be the result of slight flattening under gravity. No evidence of flow is seen in the orientation of amphibole prisms and there is an equal lack of indications of a metamorphic fabric.

Specimen 6827 RS 71, TS C 50403
Locality Yumali Y5 151.35 m - 151.4 m
Rock name Metabasaltic amphibolite
Thin section

The specimen is essentially similar to RS 70 with a fine grained amphibolitic groundmass, relict phenocrysts and epidote, chlorite and dolomite in amygdales. A minor difference is the presence of mica in both groundmass and relict phenocrysts.

The mica is olive green and weakly pleochroic with low relief and moderate birefringence. It is approximately uniaxial but with a somewhat imperfect crystal structure and imprecise extinction. It is probably a magnesium-rich, iron-poor biotite rather than a true phlogopite. Potash amounts to 0.44% in the assay.

The amorphous material in this specimen is darker than that in RS 70.

Comment

The specimen was intersected less than 0.5 m below RS 70 in DDH Y 5 and differs only marginally from the latter rock. The presence of a micaceous alteration product is reflected in a potash content which, although low, is almost four times higher than that of RS 70.

Significant analyses are: SiO_2 43.0%, MgO 14.6%, CaO 8.4%, Na_2O 0.95%, K_20, 0.44%, Fe_2O_3 14.4%, TiO_2 1.74%, Cr 1000 ppm, Ni 600 ppm and loss on ignition 5.75%. High magnesium, chromium and nickel with low silica are again more typical of a picritic than a spilitic basalt.

Specimen 6827 RS 46
CSR numbers Specimen 189637, assay 189609, TS 53157
Locality Yumali, DDH Y5, 152.3 m
Rock name Metabasaltic amphibolite tuff
Hand Specimen

The rock is lithologically similar to RS 70 and 71. In a groundmass or matrix of slightly greenish, medium grey there are two distinct types of coloured inclusions ranging from about 1 mm to about 1 cm in diameter. One of these types is a dark greenish grey, often with a fibrous texture, and the other a pale brown colour with a patchy texture. While some of both kinds of inclusion are ovoid to subovoid in shape, others are sharply rectangular in outline. This indicates that some at least of the inclusions are altered phenocrysts rather than amygdales. Others may be clasts. Fine grains of sulphide are occasionally visible.

The specimen does not respond to a hand magnet. As noted below, the assay underlines the distinctive nature of the rock.

Thin section

Under magnification the rock is seen to consist of a wide variety of coarse grained inclusions in a fine grained material which is dominantly composed of a prismatic amphibole in the tremolite-actinolite series. From the diversity of the inclusions the rock is probably pyroclastic and the fine grained amphibole may be said to constitute a matrix rather than a groundmass.

The amphibole forms an almost completely continuous felted matrix of interlocking, slightly ragged and irregular prisms. It is a weakly pleochroic, monoclinic, optically negative amphibole with a large optic axial angle. It is mostly colourless but some larger grains exhibit a pale green pleochroism. It is identified with reasonable confidence as tremolite with a moderate iron content and, as the main mineral present, largely accounts for the high calcium, magnesium and iron determinations in the assay.

The only other mineral present in the matrix is a sparse and poorly-defined, amorphous material of neutral colour which is probably leucoxene.

The inclusions consist largely of fine grained products of alteration but in some of them relict minerals extend in skeletal form but in optical continuity through the whole inclusion and indicate that these are indeed phenocrysts. The relict minerals are plagioclase and tremolite. It is possible that the tremolite is pseudomorphous after pyroxene or even olivine.

The alteration products in the inclusions consist of epidote, secondary amphibole, a little pale mica, four types of chlorite and a pale, rosy brown carbonate.

Epidote is the most abundant alteration product and occurs by itself or with chlorite in fine to medium grained, fragmentary, pseudomorphous masses. In some inclusions it is visibly replacing plagioclase but is not necessarily confined to this parent mineral. The calcium in pyroxenes could be taken up by epidote during alteration.

Secondary amphibole forms networks of rather poorly crystalline material in the fractures and cleavage planes of earlier phenocrysts. It is a colourless, monoclinic amphibole with low birefringence but includes some material with apparently straight extinction. The mineral is probably a somewhat amorphous tremolite but may include some anthophyllite. The parent mineral may again have been pyroxene or olivine.

The mica is a highly birefringent but weakly pleochroic type, changing from colourless to a pale brown. It is probably a phlogopite. It forms patches and tufts of fine flakes associated with both amphibole and chlorite.

The most common chlorite is pale green and weakly pleochroic. It is low in birefringence. It forms dense masses of fine flakes with both random and ordered orientation. It is straight extinguishing and may be termed a prochlorite or ripidolite.

Penninite is not as common but is moderately abundant in the pseudomorphs. It is distinguished by anomalous birefringence but grades into an isotropic form. The mode of occurrence is similar to that of the prochlorite. It is often associated with secondary amphibole.

Completely isotropic, very pale green chlorite may not be a crystallographically distinct species but a poorly crystalline variety of both prochlorite and penninite. However, it is included since it is optically distinct.

A species which is more distinct, although rare, is a cloudy, brownish green, non-pleochroic mineral with a low to moderate birefringence. It occurs in patches in areas where amphibole is altering to chlorite and is probably an intermediate, poorly crystalline phase which is more chloritic than amphibolitic.

The carbonate which is moderately abundant both as pseudomorphous alteration in phenocrysts and in short, discontinuous veinlets is very high in refractive index and birefringence and is distinct from any carbonate examined previously in these specimens. It is faintly to strongly coloured in shades of brown, often with a reddish tint. In the hand specimen the mineral appears pinkish brown. It is probably a sideritic magnesite or possibly an ankeritic dolomite with a composition which certainly includes magnesium and iron but may include calcium also.

Comment

A magnesia content of 15.7% MgO is the most distinctive feature of the assay of this rock. The high magnesium is due not only to the dominant amphibole of the matrix but also to the chlorite and carbonate that have replaced the phenocrysts. There is no petrographic evidence that the magnesium for any of these phases has been added during alteration and the assumption is made that the present composition differs little from that prior to alteration.

Other significant determinations in the assay of the rock are: SiO_2 42.2%, CaO 9.2%, Na_2O only 0.43%, total iron as Fe_2O_3 14.7%, TiO_2 1.67% Cr 780 ppm and Ni 280 ppm. On the evidence of moderately high chromium and nickel and of the strictly bimodal grain size distribution, it is further assumed that the rock is of igneous origin rather than a calc-silicate derived from a former dolomite. A comparison with the magnesium content of hypothetical rocks composed entirely of diopside (about 5% MgO) and forsterite (about 30% MgO) indicates that the original paragenesis probably combined both minerals. From petrographic evidence a little plagioclase certainly occurred as phenocrysts, more may be represented by totally epidotised phenocrysts and there is a possibility that plagioclase may have been included in the matrix.

From these considerations the most appropriate classification for the original rock appears to be a picritic basalt. From the diversity of the inclusions, it is suggested that the eruption was pyroclastic and the rock may be classified as a tuff.

Specimen 6827 RS 47
CSR numbers Specimen 189638, assay 189610, TS 53158
Locality Yumali, DDH Y5, 154.05 m
Rock name Metabasalt.
Hand specimen

The rock consists of a patchy alteration of fine grained dark grey and pale green minerals. Two distinct vein systems cut the rock at an angle to the length of the core. One of these is filled with a vitreous green mineral, the other, which is a branched system, is filled with a mineral altered to a limonitic material. The rock responds with moderate strength to a hand magnet. A few grains of pyrite are present.

Thin section

The rock is relatively coarse grained for a basalt. It is felsic with dominant plagioclase and abundant amphibole. Epidote, chlorite and carbonate are frequent alteration products.

The plagioclase forms a closely-interlocked mesh of lath-shaped crystals which are mainly about 0.5 mm to 1.0 mm long but measure up to 2 mm in rare instances. Simple twinning is more common than multiple twinning and many grains are not twinned. However, what measurements can be made indicate a composition in the andesine range. The feldspar is little altered but is often replaced at the grain margins by epidote. Some plagioclase appears to have been substantially recrystallised.

Rather ragged prisms of amphibole are widespread though less abundant than the plagioclase. Grain size is between 0.5 mm and 1.0 mm and the amphibole is more iron-rich than that of RS 46. It is a green, pleochroic actinolite. Replacement by chlorite is advanced and much of the actinolite is poorly crystalline.

Of the replacement phases, epidote is the most common and intensifies the overall green colour of the specimen. It occurs as fragmentary, irregular masses throughout the rock. Epidote is also present as a vein filling and in this situation forms a mosaic of closely interlocking subhedral to anhedral crystals about 1.0 mm in maximum diameter. A rectangular cleavage is well developed. The vein also contains quartz.

The carbonate, which is mainly iron-bearing and is probably ankerite, is similar to epidote in that it occurs both disseminated and concentrated in veins. The carbonate veins, which also contain epidote, are more branching and diffuse than those of epidote and quartz. Carbonate without iron staining also occurs in the veinlets and may be dolomite or magnesite.

Chlorite is widely distributed as an interstitial phase and appears to be largely, if not entirely, a product of the alteration of amphibole.

The occurrence of quartz in the epidote veins has been mentioned. The abundance is low but the individual crystals are large, though interstitial. Quartz in optical continuity extends discontinuously in the plane of section over 3.3 mm. In the immediate vicinity of the epidote vein a little quartz has been introduced to the wall rock as an interstitial phase. Away from this zone quartz is absent.

Fine grained opaque minerals are widely distributed and, since these are presumably responsible for the magnetic susceptibility of the rock, are either magnetite or a magnetic ilmeno-magnetite.

Comment

In contrast with specimen RS 46, alteration in this rock has not been isochemical. On petrographic evidence both epidote and ankerite have been introduced. The relatively high magnesian content of 7.6% MgO has been enhanced by introduced dolomite but despite this indicates a mafic basalt. From a slightly enriched potash content of 1.0% K_2O it is possible that some of the untwinned feldspar is orthoclase. The thin section may not be entirely representative of the whole length of core assayed and the assay may include two rock types.

Significant determinations are: SiO_2 49.5%, MgO 7.6%, CaO 5.0%, Na_2O 2.35%, K_2O 1.0%, Fe_2O_3 12.6%, TiO_2 1.46% and Cr 130 ppm.

Specimen 6827 RS 79, TS C 50404
Locality Yumali Y5 154.15 m - 154.2 m
Rock name Spilitic metabasalt
Thin section

The mineralogy of the specimen indicates a distinct change in lithology involving a return to a spilitic basalt type. Plagioclase laths are abundant and the ferromagnesian component is represented by interstitial mica and chlorite with some prismatic amphibole. Opaque minerals are abundant. Epidote and dolomite are minor constituents. A carbonate vein cuts the section obliquely.

The plagioclase consists of a felt of very fine laths without distinct optical properties which may be subsolidus devitrification products of poor crystallinity. Porphyritic plagioclase crystals are between 0.1 mm and 1 mm in length and are mainly prismatic but some tabular forms are present. Multiple twinning is distinguishable in some phenocrysts and from symmetrical extinction angles appear to be sodic andesine with about 34% anorthite. No consistent preferred orientation is apparent in the plagioclase.

The most abundant ferromagnesian material consists of closely intergrown and largely interstitial patches of an olive green, weakly pleochroic mica, a pale green, isotropic chlorite and a pale green to olive brown pleochroic monoclinic amphibole. From the close intergrowth the minerals may be associated alteration products of an earlier ferromagnesian mineral, possibly pyroxene. The patches display a weak tendency to preferential orientation. Independent prisms of amphibole are disseminated through the rock as grains in the same size range as the non-porphyritic plagioclase.

Widespread and abundant opaque minerals are of fine to very fine grain size and of euhedral to subhedral shape.

Irregular patches of epidote and of dolomite are dispersed through the rock. Many of these patches are oriented at high angles to the weak fabric outlined by elongated ferromagnesian patches.

The dolomite vein cuts the core at about 60 to its length. The carbonate is fine grained and partly of poor crystallinity.

Comment

The lithological change is underlined by analytical values, particularly substantially lower magnesium and chromium with higher silica and sodium. Significant values are : SiO_2 51.1%, MgO 7.05%, CaO 4.46%, Na_2O 5.4%, K_2O 0.73%, Fe_2O_3 12.2%, TiO_2 1.15%, Cr 30 ppm, Ni 160 ppm and loss on ignition 3.8%. The rock is probably a basalt lava with strong sodium metasomatism and weak potash metasomatism.

Specimen 6827 RS 82, TS C 50405
Locality Yumali Y5, 155.45 m - 155.50 m
Rock name Spilitic metabasalt
Thin section

The rock is similar to RS 79 but contains more plagioclase and less amphibole. Mica is not present. Epidote and chlorite are more evenly distributed. Grain size is somewhat coarser overall and the distinction in grain size between phenocrystal and groundmass plagioclase is not as wide. The rock contains small pods and stringers of quartz. Opaque minerals are concentrated in irregular, altered and skeletal patches. Carbonate is rare.

No preferential orientation is evident in the rock.

Plagioclase consists mainly of closely interlocked crystals of tabular rather than prismatic shape. Small laths such as those in RS 79 are absent and no grains are distinctly porphyritic. A few crystals are bent and fractured. Multiple twinning is poorly displayed and appears to indicate a composition in the oligoclase rather than the andesine range.

Ragged prisms of strongly altered and poorly crystalline amphibole are widely distributed but not highly abundant. The main alteration product is chlorite. No mica is associated with chlorite as it is in RS 79.

Chlorite is also closely associated with highly fragmented epidote. These alteration products are widely distributed interstitially and occasionally form irregular patches.

Mosaic patches of strained and irregular quartz grains are lenticular or form short, irregular veinlets and stringers. A brownish carbonate is associated in places with the quartz and also forms thin veinlets without quartz.

Opaque minerals are distinct from the fine, well shaped grains of RS 79. Alteration to sphene and leucoxene is well advanced and indicates an original ilmenite rather than magnetite. The opaque and semitranslucent material is concentrated in highly irregular and skeletal patches with a rather uneven distribution.

Comment

The high plagioclase content is reflected in an alumina concentration of 16.7% Al_2O_3 and the absence of mica in a lower potash content of 0.34% K_2O. Other values are: SiO_2 49.2%, MgO 7.10%, CaO 5.45%, Na_2O 3.82%, Fe_2O_3 12.1%, TiO_2 1.29%, and Cr 30 ppm, Ni 170 ppm. Loss on ignition is 4.34%, possibly due as much to water content as to carbon dioxide. The rock represents a typical spilitic basalt. It differs in some respects from the spilite intersected 1.3 m higher in the hole and may be a distinct flow.

Specimen 6827 RS 84, TS C 50406
Locality Yumali Y5 156.46 m - 156.49 m
Rock name Fractured and altered spilitic basalt or dolerite
Thin section

The specimen is a plagioclase-rich, medium grained mafic rock which has been subjected to enough stress to fracture the crystals but not to displace the fragments. It has also been subjected to strong replacement by epidote, chlorite, quartz and, particularly, by a pale brown carbonate which is either ankerite or siderite. The main fabric does not display a preferential orientation but the introduction of carbonate has taken place in a plane subparallel to the length of the core barrel and that of quartz at a low angle to that plane.

Plagioclase crystals are often in contact without any intervening groundmass and are of a similar grain size. The texture may be that of a thick lava flow which cooled slowly in the centre but is more likely to be that of an intrusive dolerite. The crystals are frequently fractured but the broken fragments are rarely displaced more than enough to disrupt optical continuity. Some crystals are bent without fracturing. The stress has not imposed a preferred orientation on the fabric and may have been internally generated by pressure changes in the last stages of cooling. Multiple twinning is not well developed and composition appears to be that of an oligoclase.

Pale green chlorite is frequent as an interstitial mineral but also forms patches which replace plagioclase.Epidote is superimposed on the plagioclase as a replacement product in euhedral crystals and as large patches of fragmented grains. It is abundant and is often associated with carbonate and with quartz.

Carbonate is concentrated in irregular veins as a mosaic of small grains but is also widespread as a patchy replacement of plagioclase. The composition is iron-rich.

Quartz occurs as veins and patches both with and separate from carbonate veins.

Opaque material is patchy and closely associated with sphene and leucoxene.

Comment

The rock is more strongly altered than the others examined from DDH Y5, possibly because of the extent of fracturing. Neither stress nor alteration have imposed a regional fabric on the rock and it can be assumed that both are of local origin. Concentration of stress in a rock which may be intrusive possibly implies that the application of the stress postdated the extrusion of basalts which form the country rock. Alternatively the stress may have been internally generated during cooling of the intrusive magma. Significant analyses are: SiO_2 52.8%, MgO 5.4%, CaO 4.1%, Na_2O 2.08%, K_2O 1.69%, Fe_2O_3 15.2%, TiO_2 0.95%

Specimen 6827 RS 48
CSR numbers Specimen 189639. No assay. TS 53159
Locality Yumali DDH Y5 157.05 m
Rock name Metabasalt
Hand specimen

The rock is greenish grey, medium to fine grained and without a directional fabric except for a thin green vein parallel to the length of the core. Fine grains of sulphide are present but rare. The specimen is quite strongly ferromagnetic.

Thin section

The rock consists of abundant plagioclase laths with interstitial chlorite, relict amphibole and epidote.

The plagioclase is in the andesine range and little altered. The laths are randomly oriented and vary little from an average of about 1.0 mm in length.

The chlorite is pale green and weakly pleochroic. It is low in birefringence but contains ragged, irregular patches of higher birefringence and darker colour which are relict amphibole. Much of the chlorite appears to be a product of the alteration in place of amphibole.

Epidote occurs in irregular and fragmented grains which are partly interstitial and partly replace plagioclase laths.

Opaque material is abundant and forms large, irregular grains and clusters of fine granules.

Comment

The rock may be a coarse grained basalt or a minor intrusive. In composition it tends towards the felsic rather than the mafic but lies well within the range of variation already encountered in these rocks.

Specimen 6827 RS 86, TS C 50407
Locality Yumali Y5, 158.25 m - 158.28 m
Rock name Spilitic metabasalt
Thin section

The rock is similar to RS 79 in that it combines a fine grained, chilled groundmass with weakly porphyritic plagioclase laths. It is also similar in a high content of mica as an alteration product. Epidote and carbonate are replacement products and quartz occurs as short, irregular veinlets. Opaque minerals are sparse, patchy and associated with sphene and leucoxene.

Plagioclase includes tabular crystals, probably phenocrysts, and fine grained laths. It has undergone a great deal of replacement.

The main replacement product is an olive green to pale brown pleochroic mica which occurs in fine flakes aggregated to form large, irregular patches. This makes up a large proportion of the rock.

Epidote and carbonate are distributed widely as separate irregular grains and together as patches and veins of coarse, euhedral to anhedral crystals. Quartz is partly associated with these replacement products and also forms short lengths of veinlet by itself or with opaque material in patches.

Opaque minerals are mainly scattered grains associated with semitranslucent material which is partly sphene and partly leucoxene.

Comment

Strong alteration conceals the original nature of the rock but it is almost certainly a spilitised basaltic lava. Much of the alteration is a potash metasomatism. Significant values are: SiO_2 49.6%, MgO 5.75%, CaO 5.85%, Na_2O 3.48%, K_2O 3.38%, Fe_2O_3 10.5%, TiO_2 1.15%, Cu 390 ppm and loss on ignition 5.1%.

Specimen 6827 RS 88, TS C 50408
Locality Yumali Y6, 136.54 m - 136.58 m
Rock name Recrystallised ? hybrid
Thin section

The rock is essentially a mosaic of closely intergrown feldspar with minor quartz, chlorite, mica, opaque minerals and semitranslucent material. The assemblage has been fractured, strained, granulated and partially annealed before the introduction of carbonate by replacement.

The feldspar is partly cloudy and full of opaque grains and granules and partly clear. The two types form distinct areas and possibly consist of two distinct generations, one strongly recrystallised and possibly mobilised. Most of the feldspar is recognisably plagioclase although the multiple twinning is irregular and discontinuous and, in places, spindle shaped. Some grains display an irregular cross-hatched twin pattern. Much of the irregularity is due to strain but some grains are distinguished by a small optic axial angle which indicates a composition of anorthoclase.

Quartz displays strong undulose extinction from strain which has not been annealed. It is closely intergrown with the feldspar.

Chlorite is partly an alteration product of dark mica but is also associated with euhedral opaque grains and with carbonate. It may be partly introduced.

Both dark and light mica are present. The dark mica is a poorly crystalline and partly altered olive brown biotite. It is associated with poorly shaped opaque and semitranslucent material. Muscovite is partly ragged and associated with the biotite but some flakes appear to be well crystallised and associated with carbonate.

Opaque material is partly anhedral, altered and associated with cloudy feldspar, biotite and some chlorite. It is often concentrated round the margins of areas of fresh feldspar. A second type of opaque material consists of euhedral to subhedral grains which appear to be associated with carbonate and new chlorite.

Carbonate is interstitial, invades feldspar along fractures and cleavages and replaces many grains entirely. It also forms thin veins cutting the whole fabric. There is no distinction in replacement of cloudy or fresh feldspar.

Comment

Most minerals occur in two distinct forms and suggest that the rock may be a hybrid of two origins. One may have been the basaltic rocks which are the most common lithology in the basement of the Yumali region and the other a more potassic type. The latter may have consisted of a volatile fraction only and may have merged with solutions carrying dolomite, new chlorite and new opaque minerals. Significant analyses are: SiO_2 50%, MgO 5.4%, CaO 1.81%, Na_2O 7.8%, K_2O 0.41%, Fe_2O_3 9.75%, TiO_2 2.08% and loss on ignition 4.14%.

Specimen 6827 RS 49
CSR numbers Specimen 189640, assay 189611, TS 53160
Locality Yumali, DDH Y6, 138.15 m
Rock Name Hybrid ? contact rock
Hand specimen

The rock is quite distinct from the basaltic specimens examined so far and is from the most northerly hole drilled. It contains pink feldspar in relatively coarse grains, up to 8 mm long in a band on one side of the core and oriented along the length of the drill hole. The rest of the core consists of irregular and poorly defined patches of white, grey and dark greenish grey. The darker part of the specimen is quite strongly ferromagnetic but the pink feldspathic band exhibits no response to a hand magnet.

A cross section of the core exhibits a poorly defined, irregular and discontinuous compositional banding across the section. The dark material is fine grained in comparison with the feldspathic part of the specimen.

Thin section

The section has been cut at a point where very little of the pink feldspar is included and the thin section is probably not fully representative of the analysed sample. Both dark and light facies of the specimen have been strongly stressed, granulated, annealed, restressed and altered. The texture is mylonitic but ovoid patches of granulated feldspar are outlined by bands of amorphous opaque to weakly translucent material and local changes of overall composition are detectable.

Plagioclase is the most readily recognisable mineral present, although it occurs in uncharacteristic forms. It forms finely granular patches, feathery, curving fronds and sheaves and closely intergrown, irregular patches with a roughly radiating texture. In these occurrences the feldspar is unaltered but a formless matrix of feldspathic material is permeated by a felt of sericite.

No discrete potash feldspar is recognisable but it is possible that much of the feldspar is anorthoclase or cryptoperthite. The abundance of sericite suggests a substantial potash content.The sericite felt is divided into ovoid domains by dark, ropey bands of what appears to be limonitic leucoxene with fine opaque inclusions which are probably ilmenite.

Occasional ovoid patches consist, instead of sericite, of a pale green chlorite, sometimes with inclusions of fine, pale brown mica flakes. The latter may be of phlogopite. Pale biotite and phlogopite are also distributed through the sericite felt.

Fine opaque grains are widespread are quite abundant in the sericite - biotite - chlorite mesh. The grains are often euhedral with square outlines and are probably magnetite.

Irregular patches of a carbonate with high refractive indices but no iron staining are common in the corner of the section which is largely feldspathic but also occur within the more mafic parts of the specimen. The carbonate is probably a dolomite.

Comment

The dual composition of the specimen is underlined by the assay, in which one group of elements indicate a felsic rock and another group a mafic rock. Determinations characteristic of a felsic rock are: K_2O 2.7%, Ba 820 ppm, Na_2O 3.0%, CaO 2.45%. Those characteristic of a mafic rock are: SiO_2 41.8%, MgO 6.0%, Fe_2O_3 16.6% TiO_2 4.5%, V 155 ppm. The variations appear too extreme to be combined in any single basaltic type.

The combination of two extremes of composition, together with considerable grain size variation across the core section, suggests the presence of two rock types which have partially merged. It is suggested that the rock is a hybrid formed at the contact of basic rock, possibly volcanic, and a highly alkaline plutonic rock, probably an undersaturated syenite. The extreme cataclasis is the product of concentrated stress either at the margin of an intrusion or at a shear zone or fault plane.

Specimen 6827 RS 89, TS C 50409
Locality Yumali Y6 139.03 m - 139.07 m
Rock name Recrystallised ? hybrid
Thin section

The rock is essentially similar to that in RS 88 but recrystallisation is less advanced. The major part of the rock consists of a granulated and cloudy mosaic of indeterminate feldspar, chlorite and opaque and semitranslucent material.

A band of chlorite, opaque material, poorly crystalline mica and abundant semitranslucent material cuts the section diagonally as an undulating band. Carbonate is rare in this specimen.

Recrystallisation has taken place in scattered domains with subcircular outlines emphasised by concentrations of opaque material. The domains consist largely of fresh feldspar but fine, euhedral grains of opaque minerals and patches of chlorite are also included in some areas. Less distinct domains of recrystallisation consist of euhedral cubes of opaque minerals in a matrix of well crystallised chlorite.

Comment

A less advanced stage of recrystallisation exemplified by this specimen has not involved the introduction of any material. The recrystallisation is initiated at scattered centres and later merges to produce larger, more irregular areas. This is a common devitrification texture of glassy rocks. At this early stage the minerals involved are feldspar, chlorite and opaque minerals. The origin of the cloudy feldspar is not clear but it was not derived directly from a basaltic source. Strong granulation and strain polarisation are indications of local tectonic stress. More than one episode of alteration may have taken place. Significant analyses are: SiO_2 50%, MgO 4.04%, CaO 1.34%, Na_2O 6.75% K_2O 0.73%, Fe_2O_3 12.0%, TiO_2 3.46% and loss on ignition 3.38%.

Specimen 6827 RS 50
CSR numbers Specimen 189641, no assay, TS 53161
Locality Yumali, DDH Y6, 139.4 m
Rock name Feldspathic metabasalt
Hand specimen

The rock is a dense, fine grained, green grey basalt with green and brown veinlets. Pyrite is present as scattered groups of grains. The rock responds strongly to a hand magnet.

Thin section

The rock is a fine grained, feldspathic basalt with fine grained phenocrysts and a preferred orientation due to flow. Platy minerals are interstitial to groundmass plagioclase. Abundant fine grains of magnetite are responsible for the ferromagnetic response. Coarser grain sizes are evident at one end of the section.

Plagioclase phenocrysts are thin laths up to 1 mm long. Groundmass plagioclase averages about 0.02 mm in length. The phenocrysts are not exclusively aligned but exhibit a definite preferred orientation. Groundmass plagioclase is less affected by flow but rotation of the stage between crossed polarisers produces a point of general maximum illumination when the phenocrysts are in the 45 position, indicating a degree of preferential orientation even in groundmass plagioclase laths. Twinning is too poorly developed to permit optical determination of composition.

Interstitial spaces are sparse and are filled by two platy minerals. One is a very pale green, weakly pleochroic, almost isotropic chlorite. The other is a very pale brown, weakly pleochroic mica which is probably phlogopite. The two minerals also occur in patches which are too small and irregular to constitute amygdales and in fractures parallel to the flow direction.

The opaque minerals occur as euhedral to subhedral disseminated grains and as irregular patches, some of which are sulphides. The cubic form of the euhedral grains and the high magnetic susceptibility of the rock indicate that the main opaque phase is magnetite.

Abundant very fine prisms of very high refractive index are probably rutile and tend to be associated with chlorite and phlogopite.

A carbonate which is probably dolomite occurs as small patches dispersed through the rock and as the filling of a vein trending along the length of the thin section, at an angle to the flow direction.

At one extreme end of the section, which is also the end of a section of core, a narrow zone of the rock is distinguished by three features. One is a series of thin, sub-parallel fractures with the approximate trend of the flow direction. The fractures are filled with an amorphous, semi-translucent film, probably of limonite and leucoxene. Occasionally carbonate is also present. Between the fractures the basalt is very fine grained and without phenocrysts but contains abundant chlorite and mica flakes with a preferred orientation oblique to that of the plagioclase. The third feature is a development between some fractures at the extremity of the specimen of coarser grained feldspar, mica and coarser magnetite than in the basalt. The feldspar is strongly fractured.

Comment

The basalt is either a thin intrusive sheet such as a dyke or an extrusive lava. From the evidence of flow the latter is probably the more likely. The coarser grained material against an apparent chilled margin in the basalt is possibly the contact of the flow where it is chilled against a coarser grained rock. Alternatively, the drill may have penetrated a pillow structure in a submarine lava flow.

Specimen 6827 RS 51
CSR numbers Specimen 189642, assay 189612, TS 53162.
Locality Yumali, DDH Y6, 141.0 m
Rock name Metadolerite
Hand specimen

The rock is medium grained, green and white with a marked preferential orientation in the fabric. There is a strong response to a hand magnet. Pyrite is present in fine and medium grains.

Thin section

The rock is a uniform intergrowth of medium grained plagioclase with chlorite, mica, epidote and dolomitic carbonate as alteration products and abundant magnetite. Preferential orientation is not prominent under magnification. A little quartz is present.

Plagioclase crystals are tabular and euhedral crystals are rare. Because plagioclase is abundant, many grains impinge on each other and anhedral grains are the most frequent. The feldspar is more strongly altered than

that in the basalts and the central parts of the crystals are obscured up to a narrow marginal zone. Many crystals are untwinned and are probably of poor crystallinity. Most extinction angles measured gave compositions in the oligoclase range.

Alteration products of plagioclase consist of sericite flakes, chlorite, epidote and carbonate.

Scattered patches of irregular and fractured quartz are present interstitially to the plagioclase.

The mafic component is represented by interstitial chlorite and by abundant magnetite but iron and magnesium are also contained in mica, epidote and dolomite which occur frequently as interstitial alteration products.

Rare, fine grained prisms of apatite are present.

Comment

The dolerite is probably intrusive and compositionally is more feldspathic and siliceous than many of the extrusive rocks in the collection. The thin section may not be representative of the analysed sample.

Significant analytical determinations are: SiO_2 46.5%, MgO 4.75%, CaO 7.75%, Na_2O 3.0%, Fe_2O_3 13.6% TiO_2 2.1% and V 260 ppm.

Specimen 6827 RS 52
CSR numbers Specimen 189643, no assay, TS 53163
Locality Yumali, DDH Y6, 145.65 m
Rock name Metadolerite
Hand specimen

The specimen is a medium grained rock consisting of closely interlocked pale grey and dark greenish grey crystals. A white vein up to 1 cm wide with an internal zone of green material cuts the core obliquely to its length. A finer veinlet of the same material branches at a high angle from the main vein. Other fine veinlets are faintly visible, subparallel and perpendicular to the core barrel. Fine, disseminated pyrite is visible. The rock responds strongly to a hand magnet.

Thin section

The rock is highly feldspathic, somewhat coarser grained than RS 51 and contains pyrite. Otherwise the samples are almost identical.

The plagioclase is mainly tabular although lath shapes occur locally. It is intergrown and well shaped crystals are rare. Alteration is moderate and consists of relatively coarse grained sericite and fragmentary epidote. The composition is in the oligoclase range. No preferred orientation is evident. Patches of fractured quartz occur interstitially.

Chlorite occurs interstitially but also appears to replace plagioclase. It occurs as a mosaic of relatively coarse flakes in an inner zone of the dolomite vein and interstitially to some of the dolomite crystals.

Dolomite occurs in the vein system and disseminated through the rock.

Medium grained, subhedral to anhedral magnetite is abundant.

Apatite occurs as long, thin prisms which are locally frequent but not abundant overall.

Comment

The rock is another example of a highly feldspathic, soda-rich dolerite in which the ferromagnesian mineral has been altered to chlorite. Other alteration products are sericite, epidote, carbonate and apatite. Most of these minerals are calcium - bearing and it is clear that several stages of alteration are represented. The net effect is to add silica, sodium and potassium but to fix the calcium displaced from both original plagioclase and pyroxene. The vein system indicates, however, that calcium and magnesium are mobile.

Specimen 6827 RS 60
CSR numbers Specimen 189667, no assay, TS 53183A
Locality Yumali, DDH Y7, 152.3 m
Rock name Tuffaceous sediment
Hand specimen

The specimen consists of flame-like intergrowths of fine grained dark green, pale green and grey lithologies. Elongation of the intergrowths is approximately parallel to the length of the core. The magnetic response of the specimen to a hand magnet is patchy. The green areas tend to be weakly responsive but the grey areas are generally not responsive.

Thin section

The flame-like texture is produced by the interfingering of lensoidal and discontinuous bands of dark green mica, pale green chlorite and yellow green epidote which form the green masses, with quartz and dolomite which makes up the grey lithology. Felsic material of low birefringence and fine grain size which occurs with the mica and epidote is probably at least partly plagioclase although no twinning of any kind is evident.

Epidote and green mica occur together in various proportions and form a thinly laminated deposit. Magnetite and amorphous leucoxene are abundant in these lithologies and tend to reinforce the bedded nature of the sediment. Some quartz is present even in the green coloured rock. Chlorite tends to form lensoidal patches of monomineralic rock which appear pale green in hand specimen. Some chlorite also occurs with the mica and epidote crystals are coarse grained but fragmented.

Quartz bands are composed of a quartz mosaic somewhat coarser grained than the green lithologies. If there were originally any laminar structure, it has been obliterated by recrystallisation. The quartz is intergrown with, and partly replaced by, thin bands and large patches of dolomite which varies between fine grain size in the bands to quite coarse grain size in patches. A little dolomite occurs in the green lithologies but by far the greatest proportion is confined to the cherty lithologies.

Comment

The rock is probably made up of pyroclastic basalt material and cherty silica from colloidal precipitation. The distinguishing characteristic of this specimen is the dolomite component. This has probably been precipitated as a chemical deposit in a similar manner to the chert. The complex structure of the sediment is possibly due to tectonic forces rather than to deposition or soft sediment slumping.

Specimen 6827 RS 53
CSR numbers Specimen 189644, assay 189613, TS 53164
Locality Yumali, DDH Y7, 155.1 m
Rock name Sheared metabasalt
Hand specimen

The rock is fine grained and dark green with pale green ellipsoidal patches about 2 mm long. A diffuse microveining imparts a directional fabric along the length of the core. A few fine, white, crenulated veinlets

are oblique to this direction. The broken end of the core specimen displays a distinct foliation. A few fine, scattered grains of sulphide are present. The specimen responds quite strongly to a hand magnet.

Thin section

The texture of the rock indicates severe tectonic disturbance which produced a marked foliation. The section was cut across the core and the foliation is oblique to the section. The orientation of the foliation is an acute angle to the core barrel which is nominally vertical. The paragenesis consists mainly of a mass of alteration products, principally epidote and dolomite, but relict plagioclase and bands of abundant magnetite are evidence of the original mineralogy.

Relics of the felsic component are generally too granulated and too poorly crystalline for identification but fragments of multiply twinned plagioclase are recognisable.

The whole rock is permeated with grains, fragmented masses and discontinuous bands of epidote and dolomite, both together and separately. The pale green patches seen in the hand specimen are also composed of these minerals. The foliation bends around the patches, suggesting they were present before the deformation and that they may have originally been amygdales in the basalt.

Pale green chlorite and pale, weakly pleochroic, brownish mica represent the original ferromagnesian component of the basalt but have been mobilised by the deformation into bands and lenses as part of the foliation.

Magnetite has not been altered by the deformation but formation of bands of alteration products, particularly epidote and dolomite, has concentrated the opaque grains into irregular and open aggregates along the foliation planes.

Comment

Despite alteration severe enough to make identification of the rock by optical mineralogy extremely uncertain, the nature of the original lithology is clear from the assay. The abundance of major elements indicates a composition very close to the average of the dolerites and basalts collected by CSR Ltd. Mobility of constituents is surprisingly small considering the major recrystallisation. The main components are: SiO_2 45.8%, MgO 5.25%, CaO 8.35%, Na_2O 2.2%, K_2O 1.38%, Fe_2O_3 12.2%, TiO_2 2.3%, V 180 ppm and Cu 145 ppm. Some of the sulphide grains may be of chalcopyrite.

Specimen 6827 RS 54
CSR numbers Specimen 189645, no assay, TS 53165
Locality Yumali, DDH Y7, 155.9 m
Rock name Altered, cherty, basalt tuff
Hand specimen

The rock is fine grained and a greyish green in colour. The short (50 mm) length of core is cut by three oblique, discontinuous lenticular and branching veins of white carbonate and chlorite. The chlorite is partly disseminated but in one vein two marginal zones 5 mm thick consist of chlorite concentrated in a large number of en echelon fractures. A few grains of sulphide are visible in the veins and associated fracture zones. No magnetic response was detected.

Thin section

The green part of the rock consists of a fine grained mosaic of pale chlorite and material with low birefringence which is probably quartz but may also contain feldspars. The grain size is too fine for optical tests to be diagnostic.Superimposed on the quartz-chlorite mass are granular lenses and schlieren of epidote and dolomite.

Euhedral to anhedral magnetite grains form clusters with an elongation along the foliation.

The oriented fabric is produced by chlorite, dolomite, epidote and magnetite.

The white veins consist of coarse crystals of dolomite drawn out into ellipsoidal grains and closely intergrown in a mosaic. Fine grains of quartz often occur in interstitial spaces and chlorite and pale biotite occur in the edges of the veins and in the walls of the veins where schlieren of platy minerals are parallel to the foliation.

Comment

This sample was not analysed and is too fine grained for the full use of optical techniques of mineral identification. However, it seems clear that fine grained ferromagnesian material was deposited with fine grained siliceous material, probably largely quartz. The fabric appears to be sedimentary although probably modified by alteration under stress. The typical oceanic association of greenstone and jasper or chert apparently occurs in one rock. It is possible that fine, basaltic ash was spread on the sea floor where colloidal silica was also being precipitated. A terrigenous, detrital origin for the chlorite appears most unlikely. Much dolomite was introduced along bedding planes but both dolomite and chlorite were mobilised into veins which are discordant to the main fabric although showing evidence of considerable deformation themselves.

Specimen 6827 RS 55
CSR numbers Specimen 189646, no assay, TS 53166
Locality Yumali, DDH Y8, 128.0 m
Rock name Recrystallised chert, quartzite and siltstone.
Hand specimen

The specimen is a pale grey, fine grained, densely veined rock. The veins are filled with a white mineral. A little fine, crenulated bedding is visible in places. No magnetic response was detected.

Thin section

Quartz is very much the dominant mineral in the rock. Grain size varies from coarse to very fine but in much of the rock this is more the result of varied degrees of recrystallisation than of sedimentation. The large grains consist of coarse mosaics of quartz and are randomly distributed in a matrix of finer grains which are often in contact along simple boundaries with 120° junctions. Very fine grains of quartz form interstitial patches and are often associated with sericitic mica. This facies may possibly represent the original sediment before recrystallisation but a high degree of deformation is evident in a contorted quartz veinlet and the finest grain size may be the product of granulation. The extent of recrystallisation is such that little evidence of the original sediment remains. An indication that it is at least partly derived from terrigenous detritus is the presence of a few scattered tourmaline grains of generally rounded shape and a fine to medium grain size. A cherty origin for much of the quartz remains possible.

In the centre of the section a band of micaceous quartz siltstone shows less evidence of recrystallisation but displays stress in the crenulation of bedding planes accentuated by dark, opaque matter. The dip of the bedding planes is about 70° to the length of the core. The sericitic mica displays a very strong preferred orientation. A much weaker bedding of a similar orientation is apparent in the coarse grained sandstone. Some elongation of grains, grain size variation and lenticular patches of amorphous dark material are responsible for the oriented fabric. Many of the mineralogical features are randomly oriented.

Comment

On petrographic evidence the specimen is a distal sediment but a contribution from locally precipitated colloidal silica, and possibly clay or mica, appears probable. The extent of the contribution cannot be assessed because of the strong recrystallisation and it may be considerable. The fabric of the rock appears to be

essentially sedimentary bedding but a superimposition of deformational textures is evident and much of the recrystallisation of silica has been randomly orientated.

Specimen 6827 RS 56
CSR numbers Specimen 189647, no assay, TS 53167
Locality Yumali, DDH Y8 130.6 m
Rock name Deformed micaceous chert
Hand specimen

The rock is fine grained and finely banded in dark and light greys. The bands are crenulated and microfaulted on a fine scale. A few irregular grains of sulphide are present. No response was detected with a hand magnet.

Thin section

The rock consists almost entirely of quartz, which forms the light grey bands, and sericitic muscovite, which forms the dark grey bands. A pale chlorite and opaque minerals are the only other constituents. The bands are oriented at an angle of about 30 to the length of the core.

The siliceous bands consist of recrystallised quartz in grain sizes between a few microns and about 0.5 mm. The coarser grains are less abundant than the finer grains and tend to be in patches of strongly recrystallised mosaic. The finer and more widely distributed grains are also recrystallised with equilibrium grain boundaries. Some strongly recrystallised patches are lenticular and preferentially oriented, particularly when surrounded by mica, but most patches in quartz bands are randomly oriented.

The abundance of mica varies from a few flakes between quartz grains in the siliceous bands to closely packed and virtually continuous flakes in mica bands. Strong preferred orientation is evident in the mica flakes but the foliation is crenulated in the mica bands and exhibits three planes of foliation in the more siliceous bands. Microfaulting is common.

Microfaults are emphasised by the presence of opaque material and in places with a pale, non-pleochroic chlorite. Finely granular opaque grains are abundant in the mica bands and larger, more irregular grains occur in the siliceous bands.

Comment

The origin of the sediment is probably terrigenous in part but a substantial proportion of at least the quartz may have been precipitated locally as colloidal silica. The mica may have been original but alternatively may have been transported as clay in suspension from a distal source, to be metamorphosed to sericitic mica. This recrystallisation occurred under the influence of stress and produced several intersecting planes of foliation, possibly including the original bedding direction. Some of the crenulation was probably the result of tectonic forces but some may have been produced by intraformational slumping of a soft, colloidal sediment. The steep dip of the sediment is probably tectonic in origin.

Minor sulphide mineralisation is possibly of the pyritic copper type which is typical of oceanic crust.

Specimen 6827 RS 57
CSR numbers Specimen 189648, no assay, TS 53168
Locality Yumali, DDH Y9, 148.7 m
Rock name Altered, dolomitic, siliceous, feldspathic basalt tuff
Hand specimen

The rock is divided both compositionally and structurally into three lithological types. A fine grained, pale green lithology is in contact with a coarser grained grey green lithology along a complex, lobate boundary.

The third lithology is white and occurs in veins along the length of the core and as ovoid patches. All three zones give a weak response to a hand magnet.

Thin section

The colour variations are due to varied proportions of chlorite and dolomite. Minor components, also in varied proportions, are opaque minerals, quartz, plagioclase, biotite and leucoxene.

The pale green lithology consists of chlorite with minor opaque minerals, leucoxene, quartz and dolomite. The latter occurs in scattered ovoid patches with a strict preferential orientation. Most of the chlorite itself is strongly oriented in masses of fine pleochroic flakes which all change colour together in plane polarised light and extinguish together on rotating the stage between crossed polarisers. Both opaque minerals and patches of leucoxene tend to be elongated with a common preferred orientation. Only the quartz forms a fine grained mosaic without detectable orientation. Some of the oriented fabric appears to be bedding but many features are due to recrystallisation.

The grey green lithology is distinguished by a coarser grain size in the quartz, more abundant opaque minerals, the absence of leucoxene, the presence of scattered biotite flakes and, above all, by the dominance of dolomite. The latter forms long, discontinuous, en echelon bands in strict orientation. Chlorite and biotite occasionally form small lensoid patches of relatively coarse flakes.

To some extent the grey green lithology is transitional to the white since the latter is composed almost entirely of dolomite. However, the white lithology is also structurally distinct in that dolomite forms the filling of discordant veins.

Some of the minerals of low birefringence are recognisable as plagioclase and much of the fine grained mosaic may be feldspathic.

Comment

The specimen has not been assayed but, apart from a high loss on ignition, it is doubtful whether the analyses would differ greatly from those of the basalts. The possibility that the lithology is that of a terrigenous sediment appears remote and the origin of the high chlorite and iron oxide contents appear much more compatible with a basaltic source. The sedimentary features may be ascribed to a pyroclastic origin. The extensive recrystallisation may be partly or wholly due to tectonic deformation but the specimen does not exhibit the crenulated foliation seen in RS 56. Although some carbonate has clearly been mobilised into veins, the major part of the alteration appears to have been virtually isochemical.

Specimen 6827 RS 58
CSR numbers Specimen 189649, assay 189616, TS 53169
Locality Yumali, DDH Y9, 150.65 m
Rock name Metabasalt tuff and distal sediment
Hand specimen

The rock is fine grained and sharply divided into light green and dark green lithologies. The light green portion is finely laminated in a plane subparallel to the contact. The dark green lithology is also laminated but on such a fine scale that it appears massive at first sight. The contact between the two lithologies is a straight line on the cut surface and is oriented about 15 off the length of the core. A fine vein is filled with white carbonate material and cuts the dark green lithology in a straight line about 5 to the long axis of the core. Neither lithology responds to a hand magnet. Very fine grains of sulphide occur in the carbonate veins.

Thin section

The fine laminations appear to be sedimentary features and at least part of the sediment is of terrigenous origin. Variation between dark and light rock is due to a sharp change in the proportions of quartz on one hand and chlorite plus iron oxide on the other. The essential components of the rock are the same as those of RS 57 but the carbonate is much less frequent.

The siliceous part of the specimen, which is light green in hand specimen, is composed mainly of a fine to medium grained mosaic of quartz and plagioclase. The varied grain size is the product of recrystallisation, particularly of the quartz, which has produced an oriented fabric through the elongation of grains and lenticular clusters. Recognisable plagioclase is sparse but substantial fine grained, untwinned feldspar must be present on the evidence of the assay.

The rather weak preferred orientation due to the quartz is strongly reinforced by mica, dolomite and chlorite. Sericitic muscovite forms loose bands of en echelon schlieren. Dolomite occurs as conformable veins, lenses and grains which are probably not original but formed from calcium rejected from plagioclase and magnesium from ferromagnesian minerals early in digenesis.

Most of the mafic component of the rock is now represented by chlorite. This is interstitial and is strictly oriented in the plane of foliation which is close to, but not exactly coincident with, the original bedding. A few coarser flakes of biotite occur with the chlorite.

The iron content of the basaltic material is now present as opaque grains. The absence of ferromagnetism and the occasional presence of leucoxene suggests that the opaque mineral is ilmenite or haematite.

Rare, fine grains of tourmaline and zircon indicate the presence of distal terrigenous clastic material.

The dark green part of the rock is composed very largely of chlorite which forms a mass of fine green grains. Consistent orientation is indicated by optical continuity of pleochroic absorption.

Interstitial felsic material may be quartz, plagioclase or probably, both minerals. It is very fine in grain size generally but contains occasional coarser grains.

Fine dolomite lenses and grains are frequent and are texturally conformable with the chlorite.

Opaque minerals are finer grained but much more frequent than in the light green part of the rock.

The dolomitic veins (two are present in the thin section) are mainly monomineralic. However, patches of fine quartz mosaic and relatively coarse grains of sulphide occur within the veins and thin zones containing chlorite and leucoxene in separate bands form the walls of the veins.

Comment

Four types of material are included in the specimen. Two of these are, respectively, felsic and mafic basaltic material which must originally have been in the form of fine ash. The proportions of plagioclase and ferromagnesian material vary markedly between two ash falls which are divided by a sharp bedding plane. Carbonate is an alteration product of both types of ash and is also mobilised into veins.

The two other components of the specimen are both non-volcanic sediments but one is a chemical precipitate and the other is of possibly terrigenous clastic origin. The difference between felsic and mafic basalt is enhanced by the greater proportion of quartz in the felsic part. This indicates the more prolific precipitation of colloidal silica while the feldspathic basalt pyroclastic material was being erupted. The terrigenous material is composed mainly of fine flakes of mica. These appear to be more abundant in the felsic tuff but tend to

merge with the chlorite in the mafic tuff. Minor tourmaline and zircon also indicate a probable terrigenous source for some of the sediment.

The assay probably does not relate directly to the petrographic sample as it represents a greater length of core. However, it probably covers both varieties of basalt tuff and the range of non-pyroclastic sediment. A high ilmenite content is indicated by the titanium dioxide assay but the potash content of mica seen in thin section may be understated by an assay which includes other material. Relevant determinations are: SiO_2 48%, MgO 5.2%, CaO 7.05%, Na_2O 2.9%, K_2O 0.4%, Fe_2O_3 13%, TiO_2 2.8% and Cr 105 ppm.

Specimen 6827 RS 59
CSR numbers Specimen 189650, assay 189617, TS 53170
Locality Yumali, DDH Y9, 154.3 m
Rock name Metabasalt tuff and siliceous sediment
Hand specimen

Three colour divisions are evident in this specimen but in the basaltic lithologies appear to be more the product of varied quartz contents than of different types of basalt. About half the core consists of fine grained grey rock with a weak green tint. The other half is similar to the chloritic material of specimen 6827 RS 58 but is greyer in colour. The white carbonate occurs in thin, discontinuous lenses and schlieren and as large ovoid patches. Sulphide grains are relatively abundant and occur in the sediment as well as the carbonate veins. A very weak ferromagnetic response was obtained from the grey rock but not from the green part.

Thin section

Quartz is by far the most abundant mineral in the grey part of the specimen and forms a similar fine to medium grained mosaic as in RS 58, displaying a similar weak preferred orientation. Plagioclase is a component of this but the relative proportion is uncertain. Lenses of mosaic quartz and sulphide are sparsely distributed.

Chlorite is the next most abundant mineral and forms a tenuous, interstitial mass with a consistent optical orientation.

Carbonate is mainly confined to the veins and patches. It occurs sparsely as scattered grains in the rock.

Mica appears to be absent from this lithology but other terrigenous minerals such as rare, fragmental tourmaline and zircon are present.

Ilmenite and leucoxene are moderately abundant as very fine grains.

Chlorite is abundant in the greenish part of the rock but more quartz and plagioclase are present than in the chloritic part of RS 58. The dark colour is as much due to the abundance of very fine ilmenite as to the chlorite.

Square outlines of pyrite grains coarser than the ilmenite are relatively common. The pyrite often occurs in lenticular patches with biotite in relatively coarse flakes and minor mosaic quartz. The biotite is partially chloritised.

Biotite flakes are also scattered abundantly throughout the rock usually with bands of chlorite and with a strong preferred orientation.

Thin dolomite lenses en echelon within the foliation are more abundant in the dark than the light part of the rock. Distribution of the lenses tends to be patchy.

The felsic part of the rock consists of a fine mosaic of grains with low birefringence. Twinning is not detectable but, from the assay, a moderate amount of plagioclase is certainly present and probably occurs as untwinned grains.

The thin section does not contain the large white patches of carbonate which are seen in hand specimen but several carbonate veins are present. One of these follows the contact between the two types of rock. Dolomite is the main mineral present and is much coarser grained than in the rock. Quartz is also present and is quite abundant in some veins. Chlorite also occurs in some veins. Some of the carbonate is pale brown in colour and is probably ankerite. Occasional grains of sulphide occur in the veins.

Comment

The rock is a sediment with a substantial content of silica, much of which is probably colloidally precipitated. Recrystallisation has produced coarse grains. The other major component is pyroclastic material of basaltic composition. The proportions of these components vary reciprocally. The contact between the quartz-rich and the basaltic sediments is sharp enough to fracture and make place for carbonate veins.

The analysis is again an average of various rock types but does indicate the greater importance of silica in this rock than in the other similar mixtures of chert and basaltic tuff. Relevant values are: SiO_2 71.4%, MgO 2.6%, CaO 1.78%, Na_2O 2.6%, K_2O 0.86%, Fe_2O_3 6.4%, TiO_2 1.23% and Cr 120 ppm.

Specimen 6826 RS 55
CSR numbers Specimen 189651, assay 189618, TS 53171
Locality Coonalpyn, DDH C1, 144.5 m
Rock name Gabbro
Hand specimen

The rock is coarse grained with an average grain size of about 5 mm. It consists of whitish, lath shaped plagioclase, in which multiple twinning is visible with a hand lens, and bronze coloured pyroxenes of poor shape. Scattered, large, poikilitic plates of biotite are prominent when they reflect the light. The plagioclase displays a strong orientation at about 60 to the length of the core. The rock is strongly ferromagnetic. There is no greenish tint which would have indicated the chloritic alteration prevalent in the other basic rocks intersected in the CSR drill holes.

Thin section

Three minerals dominate the composition of the rock: plagioclase, pyroxene and an opaque mineral which is strongly magnetic. Biotite, chlorite and apatite are less abundant.

The plagioclase occurs as almost completely unaltered euhedral to subhedral tabular crystals up to about 6 mm in length. From the maximum symmetrical extinction angles the composition is that of a sodium-rich labradorite at the centres of the crystals. A weak compositional zoning identifies the marginal zones as andesine. The plagioclase crystals exhibit a strong preferential orientation at an angle to the length of the core which varies between about 60 and 80. The orientation is not rigidly consistent and many grains lie outside even the broad limits quoted. The fabric is probably produced by flow of the magma from which the rock crystallised. There is no evidence of later metamorphic re-orientation and the absence of alteration, particularly with the retention of compositional zoning, indicate the improbability of any significant recrystallisation.

The pyroxene grains are mainly augite but a few display optic axial angles somewhat smaller than is typical of augite and may tend towards a pigeonitic composition. The crystals vary from rare subhedral prisms to irregular, interstitial masses the shape of which is determined by the other phases. The pyroxenes are more strongly altered than the plagioclase but range from very little affected to completely replaced by alteration products. The latter also vary quite widely. The least altered pyroxene includes small patches of brown hornblende, a pleochroic green to brown amphibole and, in places, biotite along cleavages and at the margins

of the pyroxene. More altered grains are partly or entirely replaced by a highly birefringent amphibole which is probably grunerite. Small patches of chlorite were probably an originally magmatic ferromagnesian mineral. The chlorite is not abundant enough to tint the rock green. Some highly birefringent minerals of very fine grain size may be products of a further stage of alteration in which highly magnesian material has become platy silicates such as phlogopite and talc.In thin section the abundant opaque material is seen to be coated in places with leucoxene. The opaque mineral may be, at least in part, an ilmenomagnetite and the highly ferromagnetic response of the hand specimen may be due to the abundance of iron oxides rather than the strength of magnetic response of individual grains. The opaque material occurs in large, highly irregular and largely poikilitic patches up to 3 mm across. Occurrences are almost entirely limited to areas of ferromagnesian minerals.

Some occurrences of biotite are too large, too well crystallised and too independent of pyroxenes to be alteration products. Patches in optical continuity over 4 mm with a poikilitic habit are almost certainly primary crystals precipitated at a late magmatic stage, which may have coincided with the minor replacement of pyroxene by biotite.

A few thick and often irregular prisms of apatite are also primary crystals but may have resulted from the rejection of calcium by plagioclase at a late stage to maintain equilibrium with the melt at the lower magmatic temperature prevailing.

Comment

The specimen is distinct from the other basic rocks examined not only in the coarse grain size but, more significantly, in the low level of alteration. Petrographically it is similar in many respects, particularly in the flow alignment of plagioclase and in the presence of poikilitic biotite, to the Black Hill Norite. Since, from the absence of metamorphism, it is presumably post-Delamerian in age, it may well be related to that intrusive, suggesting a more extensive distribution of the suite of gabbroic intrusives than had been revealed by the drilling carried out by North Broken Hill Pty Ltd in the area between Long Ridge and Mannum. At 60 ppm the chromium content of the Coonalpyn gabbro is higher than that determined for the outcrop of the Black Hill Norite. The level in the intrusion exposed by pre-Tertiary erosion and now penetrated by the drill may be lower than that exposed in the Black Hill intrusion. The biotite content of the Coonalpyn gabbro is lower than that of the Black Hill intrusion. Nickel has not been determined but the contents of copper and cobalt are low at 26 ppm for both elements. The abundances of iron, titanium and vanadium are high.

Significant analytical determinations are: SiO_2 44.2%, MgO 5.7%, CaO 10.4%, Na_2O 2.7%, K_2O 0.47%, Fe_2O_3 17.3%, TiO_2, 4.3% and V 320 ppm.

Specimen 6826 RS 56
CSR numbers Specimen 189652, no assay, TS 53172
Locality Coonalpyn, DDH C1, 148.4 m
Rock name Gabbro
Hand specimen

The rock differs very little from 6826 RS 55. There is more pyroxene and a little more biotite in it. The flow alignment of plagioclase is almost perpendicular to the length of the core. The magnetic susceptibility is possibly a little lower but tests with a hand magnet are at best semiquantitative. A few grains of sulphide are present.

Thin section

The similarity between the two gabbro samples is confirmed in thin section. The rock consists of fresh plagioclase and pyroxene which is less altered than in RS 55. The opaque minerals are somewhat finer grained than in the latter sample but do not appear to be less abundant. Biotite is more abundant.

Plagioclase grains are smaller, less well shaped and less abundant than in RS 55. Preferential alignment is evident but is somewhat less accentuated than in the latter specimen and is close to perpendicular to the length of the thin section.

The lighter alteration in the pyroxenes permits straight extinction and a very faint pleochroism to be detected in a few grains, which are probably hypersthene. Some pyroxene grains are zoned and others contain inclusions of differing pyroxene composition. Alteration products are less abundant but include a little biotite, chlorite and at least two amphiboles, hornblende and grunerite.

Opaque minerals tend to be finer grained and of better crystal shape than in RS 55 but patches of irregular shape are still common. Opaque minerals are closely associated with pyroxene clusters.

Biotite is more widely distributed but of finer grain size than in the section from 145 m.

Rare short, wide and slightly rounded prisms of apatite are present, mainly in ferromagnesian clusters.

Comment

The specimen represents a minor compositional and textural variant of a substantial gabbroic intrusion. The presence of hypersthene suggests that there may be noritic variants and possibly ultramafic differentiates at depth. The rock is not dynamically metamorphosed and seems likely to be part of the same post-Delamerian suite as the Black Hill Norite.

Specimen 6826 RS 97, TS C 50410
Locality Coonalpyn C 2, 122 m - 122.05 m
Rock name Porphyritic metabasalt
Thin section

The rock is altered too strongly for detail of both mineralogy and fabric to be identifiable. However, it is clear that plagioclase phenocrysts up to 5 mm in length are contained in a groundmass which includes fine plagioclase laths less than 0.5 mm long. Interstitial areas are filled with fine grained material of indeterminate optical properties. Alteration products such as epidote, amphibole and mica are superimposed on the original fabric. Quartz occurs in small patches of mosaic. Opaque and semitranslucent material is abundant. No preferential orientation is apparent.

Twinning is not well displayed by the phenocrysts but as far as may be determined the plagioclase is oligoclase. Crystals are tabular. Alteration consists of small flakes of sericitic muscovite.

Epidote occurs mainly in the groundmass but often encroaches on plagioclase crystals. Most grains are fragmented and patchy but a few are euhedral prisms. The latter occur in association with small patches of quartz and sometimes form radiating clusters.

Amphibole occurs as fine, acicular prisms, mainly in the groundmass.

Muscovite flakes occur with quartz in grain sizes considerably coarser than the sericite flakes.

Many of the abundant opaque grains are euhedral and independent of alteration products or other opaque grains. The major part of the opaque material occurs in groups of grains and as patches, often skeletal, surrounded and partially replaced by a semitranslucent material, probably leucoxene.

Comment

A porphyritic basalt has been spilitised and further altered by siliceous and potassic fluids. Significant analyses are: SiO_2 51.8%, MgO 4.68%, CaO 8.3%, Na_2O 3.32%, K_2O 0.6%, Fe_2O_3 9.3% and TiO_2 1.29%.

Specimen 6826 RS 57
CSR numbers Specimen 189653, assay 189620, TS 53173
Locality Coonalpyn DDH C2, 123.1 m
Rock name Porphyritic, amygdaloidal, feldspathic metabasalt tuff.
Hand specimen

The rock is mainly fine grained and grey coloured but contains small patches of green minerals and occasionally pale grey minerals. From the elongation of the green patches a directional fabric is oriented along the length of the core but a stronger fabric is oriented at 45 to the core barrel and provides the planes along which the rock fractures. The rock displays a strong ferromagnetic response to a hand magnet.

Thin section

Under magnification the rock is seen as a chaotic mass of acicular amphibole, fragmentary epidote, mosaic quartz, relict feldspar and contorted bands of fine cubic grains of magnetite with leucoxene. The green patches consist of chlorite but there is little of this in the matrix of the rock.The amphibole is green and pleochroic and tends to form fans and rosettes of radiating needles. It also forms a reticulated network of very fine prisms across relict feldspar phenocrysts. The mineral is probably actinolite.

Epidote occurs in shapeless masses of fragmented grains and scattered independent grains throughout the rock. It has grown as a random replacement of the original rock, consisting mainly of feldspar from the assay, without a pseudomorphous habit or any systematic texture.

Quartz is moderately abundant and may have been introduced. It makes up formless patches of fine mosaic either in relict feldspar or as a general matrix replacement.

Feldspars occur in two forms. The most common is as feathery laths which are probably original matrix crystals. These form the major component of the rock. More rarely the imprecise outlines of large tabular crystals are relict phenocrysts in which the shadowy outlines of polysynthetic twins are still detectable. The phenocrysts display a weak preferred orientation but the matrix feldspar laths appear to be random in orientation.

The main structural element in the rock is provided by contorted bands of well-shaped magnetite crystals in a linear matrix of amorphous leucoxene. These bands are oriented overall at right angles to the length of the thin section (and to that of the core) but at any one point may take any direction.

Green patches seen in hand specimen consist largely of chlorite but often include mosaic quartz and acicular actinolite. The grey patches seen in hand specimen are largely porphyritic plagioclase crystals but some consist of plagioclase and quartz in a relationship which suggests the replacement of the former by the latter.

Comment

Two elements of the fabric are not entirely chaotic even though the minerals involved are strongly altered. These are the plagioclase phenocrysts and the bands of iron oxides, from which titanium has been removed as leucoxene. The two elements impart a roughly consistent directional fabric which could be the bedding of a tuff or flow lines in a lava. The contorted form of the oxide banding appears on balance to be more indicative of a tuff than a lava. The rock most compatible with the evidence appears to be an ash flow tuff.

The chemical composition indicates a silica-rich, feldspathic basalt. Significant determinations are: SiO_2 49.8%, MgO 4.1%, CaO 8.75%, Na_2O 2.95%, K_2O 0.87%, Fe_2O_3 10.2%, TiO_2 1.25% and V 185 ppm.

Specimen 6826 RS 99, TS C 50411
Locality Coonalpyn C2 124.3 m - 124.35 m
Rock name Porphyritic metabasalt ? tuff.
Thin section

The rock is less markedly porphyritic than RS 97 but exhibits the same spilitisation, siliceous and potassic alteration. Little carbonate is present. There are no consistently oriented textures. From sharp boundaries between some mineral assemblages the rock may contain pyroclastic components.

A few corroded plagioclase phenocrysts are present and measure up to about 2 mm in length. Almost no feldspar remains in recognisable condition in the groundmass. Alteration is too heavy for composition to be identified.

Most of the rock consists of a fine grained mass of felted sericite, fragmentary epidote, feathery amphibole, chlorite, nondescript material of low birefringence and abundant semitranslucent, amorphous material which obscures large areas. The distribution of these mineral components is patchy and, while most of them are present in any field of view, one is usually dominant.

Patches of mosaic quartz, often with radiating clusters of feathery amphibole, are probably introduced but may possibly represent original amygdales.

Opaque minerals are abundant as grains and patches but are strongly subject to alteration, probably to leucoxene, which forms extensive patches of semitranslucent, amorphous material.

Comment

The specimen is essentially similar to RS 97 but is somewhat more strongly altered. Significant analyses are: SiO_2 50.5%, MgO 3.82%, CaO 10.3%, Na_2O 3.2%, K_2O 0.91% Fe_2O_3 19.2%, TiO_2 1.28%.

Specimen 6826 RS 58
CSR numbers Specimen 189654, assay 189621, TS 53174
Locality Coonalpyn. DDH C2, 126.1 m
Rock name Basaltic ash flow tuff.
Hand specimen

The rock is complex in structure and composition. It consists largely of fine grained dark grey minerals with coarse grained pink, white and pale grey patches up to 7 mm long. Superimposed on the grey rock are flame like extensions of green to yellow green minerals passing out from a mass in one corner of the specimen. A band of finely laminated grey and white rock cuts the core from the centre of the yellow mass in one corner to the opposite corner. This directional fabric is the basis to a less precise degree, of the other lithologies and the general preferred orientation makes an angle of about 20 with the length of the core. The rock is fairly strongly responsive to a hand magnet in the grey parts but unresponsive in some of the green parts.

Thin section

The great complexity of the lithology is due to several factors. Rock fabric itself varies from porphyritic to glassy and possibly includes lithic fragments. Identification is hampered by strong alteration of several types. Alteration products include epidote, actinolite, chlorite, quartz, dolomite and leucoxene. A weak potash metasomatism appears to have affected the feldspars to the extent of producing the pink patches seen in hand specimen. A thin vein has introduced quartz and potash feldspar while another is filled by dolomite. The rock appears to be an ash flow tuff but heavy alteration makes the identification uncertain.

The tuff consists of a fine grained matrix with abundant tabular plagioclase phenocrysts up to 4 mm long and elongated amygdales full of epidote and bladed actinolite. The matrix is devitrified glass and is mainly

feldspathic but contains abundant fine grains of opaque minerals, probably magnetite. Opaque grains in a matrix of leucoxene also form undulating bands which mark flow lines in the tuff. Small patches of alteration products are also drawn out in the same directional fabric. The feldspar phenocrysts are not strongly altered and appear from a moderately well developed multiple twinning to be oligoclase. Many of the phenocrysts are preferentially oriented. A few are bent. Large masses of opaque material and actinolite with straight edges may be pseudomorphous after original ferromagnesian phenocrysts. Occasional patches of untwinned feldspathic minerals may be made up of orthoclase.

The finely banded zone is formed by lines of alteration following fine fractures. The fine structures are outlined by very fine granules of opaque minerals but are accentuated by patchy carbonate, abundant epidote and occasional actinolite.

The flame like features are concentrated at one end of the thin section, which is cut across the width of the core. The flames consist of lines of epidote crystals with patchy actinolite and relict plagioclase. Some patches of these alteration products are bounded by straight lines, suggesting that they may represent pseudomorphous replacement of phenocrysts or possibly of lithic fragments. Patches of mosaic quartz may have been produced by the recrystallisation of chert fragments.

Comment

The rather chaotic structure may be the product of the submarine eruption of a pyroclastic flow or possibly of the explosive disruption of a submarine lava. Well developed flow lines indicate the proximal flow of disrupted fragments which may have been produced by either process. The original magma contained relatively coarse grained plagioclase phenocrysts and possibly porphyritic ferromagnesian minerals.

A rather weak potassium metasomatism appears to have affected the rock and may be responsible for the presence of orthoclase both in the tuff itself and in fine veins. This may be the product of granitic intrusions in the vicinity or of convective circulation of sea water within the volcanic pile driven by the heat of the basaltic magma itself. Relevant analytical determinations are: SiO_2 51.8%, MgO 3.45%, CaO 5.7%, Na_2O 3.75%, K_2O 1.63%, Fe_2O_3 12.6% and TiO_2 1.41%.

Specimen 6826 RS 59
CSR numbers Specimen 189655, no assay, TS 53175
Locality Coonalpyn, DDH C2, 126.5 m
Rock name Feldspathic ash flow tuff
Hand specimen

The rock is similar to but less altered than specimen RS 58. Pale grey phenocrysts up to 8 mm long are contained in a fine grained, dark grey ground mass. A few dark green crystals up to 1 mm long may be pseudomorphs after ferromagnesian phenocrysts. Green schlieren are diverted around phenocrysts and mark a corrugated foliation about 15 from the length of the core. A moderate ferromagnetic response is uniform throughout the specimen.

Thin section

The rock is the same as that intersected 40 cm higher up the drill hole. The only difference lies in the alteration. A little epidote is present but the main alteration product is a pale khaki mica with a rather weak pleochroism. It is probably a form of biotite and appears to have been introduced rather than forming part of the original pyroclastic. Quartz is moderately abundant and also appears to have been introduced. Other alteration products are chlorite, often associated with the biotite, and a little zoisite with the more abundant epidote.

The rock is highly feldspathic and most of the feldspar is porphyritic. Some phenocrysts consist of a cluster of individual crystals and some coarse grains are possibly lithic fragments. Most phenocrysts are plagioclase but twinning is not strongly developed and the nature of some feldspars is not clear.

Comment

Although the alteration is not as heavy as in RS 58, evidence of the original nature of the rock is somewhat obscure. It is clearly an ash flow tuff and was probably similar in composition to the other basaltic rocks sampled. However it is now more siliceous and potassic, probably due to alteration related to convective groundwater circulation.

Specimen 6826 RS 101, TS C50412
Locality Coonalpyn C 2 128.05 m - 128.1 m
Rock name Metabasaltic lapilli tuff
Thin section

The rock consists of flattened domains up to 12 mm long. The domains are distinguished by grain size and by mineralogy within the range of assemblages encountered in the basaltic rocks. Margins of the domains are rounded rather than angular and the extent of flattening appears greater than that expected under gravity alone. The rock is probably a product of eruption from a proximal vent of fragments hot enough to remain plastic when deposited. Movement in a steep cone of pyroclastic debris probably squeezed and streaked out individual fragments to form a welded tuff of ash bombs or lapilli.

The variety of lithologies in the lapilli includes highly porphyritic basalts with plagioclase phenocrysts up to 5 mm long, rocks composed almost entirely of epidote, fine ash with no phenocrysts and the kind of lithology encountered in Yumali Y6 consisting of coarse grained, closely interlocked, highly strained plagioclase.

Comment

The range of lithologies displayed in the tuff fragments as well as the specimens RS 97 and 99 includes the same rock types as are intersected in the drill holes at Yumali. It is a reasonable assumption that the magnetic anomalies which are continuous between and beyond the two areas drilled, indicate a continuous occurrence of submarine basalts. The extent of spilitisation and of silica and potash metasomatism varies from place to place but, apart from the picritic type, the basalts are essentially similar. Significant analyses are: SiO_2 55.4%, MgO 3.56%, CaO 3.82%, Na_2O 4.76%, K_2O 0.97%, Fe_2O_3 12.1% and TiO_2 1.45%.

Specimen 6826 RS 60
CSR numbers Specimen 189656, no assay, TS 53176
Locality Coonalpyn, DDH C2, 131.15 m
Rock name Silicified porphyritic metabasalt.
Hand specimen

The major part of the rock is fine grained and grey with occasional green schlieren. Spheroidal, lensoidal and irregular white to pale grey patches are frequent and up to 15 mm long. Rare green patches are up to 10 mm long. Green schlieren and the elongation of grey and green patches produces an oriented fabric about 10 to the length of the core. The specimen displays a moderate response to a hand magnet.

Thin section

The specimen is a highly feldspathic porphyritic basalt which is much less strongly altered than the tuffs intersected higher in DDH C2. On the other hand it is more strongly silicified, particularly in the amygdales.

Plagioclase occurs both as phenocrysts and as laths in the fine grained groundmass. The phenocrysts are oligoclases on the basis of extinction angles. Crystals are subhedral but display the results of strain in

microfaults and bent tablets. Plagioclase laths in the groundmass are about 0.5 mm long. They also are bent occasionally but are fresh enough to display multiple twinning in many crystals, indicating an oligoclase composition. Neither phenocrysts nor groundmass laths are preferentially oriented. Both are weakly replaced by epidote.

The epidote occurs as scattered and fragmented grains in both phenocrysts and groundmass. Distribution is patchy and some compositional variation is apparent. A little zoisite is present. Other alteration products are very rare flakes of pale biotite and abundant leucoxene associated with fine grains of opaque minerals. Opaque minerals and leucoxene are widely distributed but do not form the flow lines seen in the tuffs.

The frequent grey patches seen in hand specimen to be preferentially oriented are composed of quartz mosaic. The patches were originally vesicles but some replacement of the basalt has also occurred. Fine grains of quartz are also distributed sparsely through the basalt outside the mosaic patches.

Comment

The basalt and the tuffs intersected in DDH C2 are essentially similar to but in some respects, distinct from others in the region. The magma is highly feldspathic and contains large plagioclase phenocrysts. Specimens 6826 RS 57, 58, and 59 represent submarine pyroclastic eruptions or possibly the explosive destruction of the surface of a lava flow while RS 60 represents the interior of a lava sheet in which flow was not pronounced. Even the interior of the flow was subject to silicification, however, although both retrograde alteration in place and metasomatism affected the lava much less than the tuffs.

Specimen 6826 RS 61
CSR numbers Specimen 189657, assay 189619, TS 53177
Locality Coonalpyn, DDH C3, 128.5 m
Rock name Porphyritic microcline granite
Hand specimen

The most prominent features of the specimen are pink porphyritic feldspars up to 8 mm across. Grey, interstitial quartz and scattered black flakes of mica are less abundant. The rock is sharply different from the dominantly basic suite already examined. Magnetic susceptibility is very weak.

Thin section

The dominant pink colour of the feldspars in hand specimen is somewhat misleading. Although microcline is the dominant feldspar, plagioclase is also present and is equally pink. Some coarse grained quartz is present but the major part of the quartz occurs as a mass of fine grains. Biotite is strongly altered to chlorite. Opaque minerals, zircon and a carbonate with high refractive index are also present.

The microcline occurs as euhedral to subhedral grains up to 8 mm long. It is strongly to moderately perthitic and lightly sericitised. Simple Carlsbad twins are common. Finer and more irregular microcline also occurs in the interstitial groundmass.

Plagioclase phenocrysts are slightly smaller and less well shaped than the microcline and plagioclase is more abundant as fine grains in the groundmass. Twinning is rarely well developed but a tendency to almost straight extinction is detectable and indicates an oligoclase composition. Many grains are clearly zoned. Alteration is light and sericitic. Patches of myrmekite are common near contacts with microcline. Rarely plagioclase rims occur around microcline and around older plagioclase crystals.

Quartz occurs in two distinct habits in this rock. Some quartz grains are about 2 mm across and form phenocrysts in a fine grained groundmass of plagioclase and other quartz. The groundmass quartz forms a fine grained mosaic which is largely interstitial but also invades the margins of coarser grains of feldspar and even of earlier quartz. The mass of fine quartz mosaic between phenocrysts is quite distinctive.

Scattered flakes of pale brown biotite about 1 mm across are strongly altered to green chlorite. Some flakes are completely altered.

Many biotite flakes include large prisms of zircon, irregular patches of opaque material and patches of a carbonate which is probably dolomite.

Opaque minerals, which are ferromagnetic, occur as independent patches as well as inclusions in biotite.

Comment

The absence of any metamorphic alteration or fabric and the retention of zoning in plagioclase indicates a post-tectonic origin for the granite. The separation of late quartz from the main stage of crystallisations of the rock, with reaction and replacement of the latter by the former, is reminiscent of the Long Ridge Granite. Analyses of the two granites are similar and it is likely that they are of similar age and affinity. Relevant analytical determinations are: SiO_2 74.1%, MgO 0.14%, CaO 0.75%, Na_2O 2.65%, K_2O 5.15%, Fe_2O_3 3.5%, TiO_2 0.14% and Rb 260 ppm.

Specimen 6826 RS 103, TS C 50413
Locality Coonalpyn C4 49 m - 49.05 m
Rock name Flow banded trachyandesite
Thin section

The rock is very fine grained and strongly flow-banded with few feldspar phenocrysts about 1 mm long. Much of the groundmass is not identifiable optically owing to fine grain size and a light red-brown staining. However, a green amphibole occurs as subhedral prisms and sericite flakes are common. Opaque grains are profuse. Free quartz occurs in patches.

Some of the phenocrysts are multiply twinned and therefore plagioclase but many are untwinned and may be either plagioclase without twinning or orthoclase. The abundance of sericite indicates a substantial potassium content.

The amphibole is actinolite with a green to yellow brown pleochroism. It is patchy in distribution and abundant in places.

Sericite flakes occur in the groundmass as well as in phenocrysts as alteration products. Possibly there is potash feldspar in the groundmass.

Very fine grains and granules of opaque minerals are widely distributed in great profusion. Irregular patches of opaque material are also present, usually associated with amorphous alteration.

Minor quartz occurs in patches around which flow lines are diverted. The quartz may be original but may be replacing a mineral present while the lava was still flowing.

Comment

Chemical analysis is more informative than optical examination as far as the composition and identification of the rock are concerned. Significant values are: SiO_2 59.3% MgO 1.84%, CaO 3.78%, Na_2O 4.1%, K_2O 3.08%, Fe_2O_3 8.2% and TiO_2 1.04%. From the high silica and low magnesia contents the rock is clearly intermediate rather than mafic. From the high soda and potash it is trachytic but with moderately high lime as well it has been identified as trachyandesite. The amount of free quartz does not justify classification as an acid rock since some or all may be introduced.

Specimen 6826 RS 104, TS C 50414
Locality Coonalpyn C4, 51.4 m - 41.45 m
Rock name Flow banded trachyandesite
Thin section

The specimen originated about 2.5 m below RS 103 in the drill hole but is almost identical in lithology. It is fine grained, strongly flow banded and contains a few small irregular and fragmented phenocrysts of twinned and untwinned feldspars. Blue-green to pale yellow brown pleochroic actinolitic amphibole is abundant in bands alternating with more feldspathic bands. Flow bands are diverted around phenocrysts and patches of altered feldspar and mosaic quartz. Opaque material is abundant both as profuse fine granules and as larger patches, often associated with amorphous, semitranslucent material which is probably leucoxene.

A system of thin, branching veinlets is filled with epidote.

Comment

Analysis underlines the essential similarity between specimens RS 103 and 104. The only difference is slightly more lime and potash and less soda in RS 104 relative to 103. Significant values are SiO_2 59.9%, MgO 1.66%, CaO 4.94%, Na_2O 3.88%, K_2O 3.46%, Fe_2O_3 7.75% and TiO_2 1.02%.

Specimen 6826 RS 105, TS C 50415
Locality Coonalpyn C4 53.8 m - 53.85 m
Rock name Andesite
Thin section

The rock is texturally and compositionally slightly different from intersections higher up the drill hole. It displays a weak preferential orientation in discontinuous patches of very fine and of coarser grain sizes but lacks the prominent flow banding evident in RS 103 and 104. It is more markedly porphyritic than the latter two samples with more and larger plagioclase phenocrysts and a few rectangular to rhomboidal outlines up to 3 mm across now filled with epidote and leucoxene. This type of altered phenocryst may originally have been pyroxenes.

The groundmass consists mainly of a very fine grained mosaic of minerals with low birefringence, probably plagioclase, and fine, scattered acicular prisms of actinolitic amphibole. Opaque minerals are profuse as fine granules and common as larger patches.

Bands of coarser grain size contain, in addition to phenocrysts, patches of mosaic quartz, epidote, actinolite and amorphous leucoxene. The quartz grains may be introduced but may be, like the other minerals, alteration products of mafic minerals.

A vein of amorphous to fibrous haematite cuts the section with a disseminated mineral in the walls which may be jarosite.

Comment

The analysis confirms the mineralogical differences relative to RS 103 and 104. The lime content is higher while the potash content is lower in RS 105. Significant values are : SiO_2 60.9%, MgO 1.02%, CaO 5.15%, Na_2O 3.86%, K_2O 2.32%, Fe_2O_3 8.35%, and TiO_2 0.95%.

Specimen 6826 RS 62
CSR numbers Specimen 189658, assay 189624, TS 53178
Locality Coonalpyn, DDH C4, 54.25 m
Rock name Banded trachyandesite
Hand specimen

The main part of the rock is fine grained and grey. A diffuse, pale yellow banding is almost parallel to the length of the core. A branched system of fractures carries a core of red brown mineral about 3 mm across. The walls of the fractures are pale yellow and the veins, together with altered wall rock are about 8 mm across. Streaks of brown mineral and patches of yellow mineral are common. The magnetic response of the rock is moderate.

A test with sodium cobaltinitrite indicates that irregular and discontinuous bands in the fine grained grey part of the rock consist almost entirely of potash feldspar.

Thin section

The fine grained lithology is the dominant rock type in a specimen which contains many compositional variations. The weak banding seen in hand specimen consists of fine compositional laminations which appear to be caused by flow. Flow lines are diverted round lenticular patches which may be altered phenocrysts. The fracture systems are superimposed on the fine grained fabric and consist of a zoned paragenesis which is possibly unrelated to that of the host rock.

The fine grained lithology consist largely of minerals with low birefringence and of fine granules of opaque minerals. Some bands contain short prisms of actinolite and scattered epidote grains. Other bands contain finer flakes of sericite. The staining produced by sodium cobaltinitrite confirms the evidence of the sericite and indicates that a considerable proportion of the finely divided minerals of low birefringence consists of potassium feldspar. This accounts for 3.25% K_2O in the assay. The assay also includes 3.5% Na_2O which suggests that plagioclase is another substantial component of the fine grained material. None of the grains are twinned. Relatively high calcium (4.7% CaO) is accounted for by the substantial amount of epidote, carbonate and actinolite but may have originated, at least in part, from earlier plagioclase. Quartz is also a component of the fine grained rock.

Opaque minerals are widely distributed but in places are concentrated into thin bands. It is these bands which produce the most prominent evidence of crenulated flow banding. The bands are often reinforced by leucoxene, either surrounding opaque grains which are probably now magnetite or forming independent bands. Most of the crenulation is due to flow around obstacles but it is possible that tectonic stress may also be involved.

The coarse grained veins are partly concordant with the flow banding but partly discordant to it. This discordance, with the apparent introduction of epidote into the wall rock from the veins, suggests that the veins are not immediately related genetically to the fine grained rock. The veins consist of a central zone of quartz, limonite and a yellowish garnet which is probably grossular. Minor zoisite and epidote are also present. The marginal zones of the veins are marked by a high concentration of epidote and the alteration of wall rock visible in hand specimen is seen to consist of the introduction of epidote and a little quartz. As noted above, the calcium rich paragenesis appears to have been introduced from elsewhere.

Some of the patches noted in hand specimen consist of quartz, with or without limonite, and are part of the introduced material. Other patches which are distinguished by the diversion of flow lines are part of the original paragenesis. They consist largely of epidote but often contain relict feldspar. Rare occurrences display enough relict twinning to indicate that the feldspar was plagioclase but other examples where sericite flakes are present and no twinning is evident may have been orthoclase. The patches are both lenticular and spherular and probably represent feldspar phenocrysts affected not only by magma flow but also by regional metamorphism.

Comment

The assay is indicative of an iron-rich andesite but the petrographic evidence indicates that the composition is hybrid. The original rock is highly feldspathic with phenocrysts of both orthoclase and plagioclase and a groundmass which contains orthoclase, plagioclase, a little quartz and a large amount of ilmenite. The rock is tentatively identified as a trachyandesite but the amount of potash in the assay may justify the term of trachyte if the high lime is accepted as largely introduced. Identification is tentative as the degree to which potash has been introduced is not known. Relevant analytical determinations are: SiO_2 60.1%, MgO 1.65%, CaO 4.7%, Na_2O 3.5% K_2O 3.25%, Fe_2O_3 9.25%, TiO_2 0.97% and V 135 ppm. The presence of a third, non-volcanic sedimentary component is possible but most of the rock appears to be of volcanic origin.

Specimen 6826 RS 106, TS C 50416
Locality Coonalpyn C4 55.3 m - 55.35 m
Rock name Trachyandesite
Thin section

The specimen resembles RS 103 more closely than RS 105 although, from the analysis, it is more andesitic than the former specimen. The groundmass is very fine grained with a very fine banding due largely to variation in the abundance of an actinolitic amphibole as well as to grain size variation. Phenocrysts are small (up to about 1 mm long) and consist of recognisable plagioclase and strongly altered feldspar without twinning which is probably orthoclase. Sericite is the main alteration product.

Fine grained bands consists mainly of a mosaic of minerals with low birefringence which are probably feldspars. Very fine flakes of biotite occur in some bands. Coarser grained bands include phenocrysts and patches of probable alteration products containing quartz, sericite, chlorite, opaque minerals and amorphous leucoxene. Biotite, amphibole and mosaic feldspar also form lenses around which flow bands are diverted. In places patches of opaque material are drawn out into stringers.

Fine granules of opaque minerals are widespread and abundant.

Comment

Analysis indicates that specimen RS 106 is in some respects intermediate in composition between RS 103 and RS 105. It is included in the classification of trachyandesite mainly on the basis of a moderately high potash content. Significant values are: SiO_2 59.9%, MgO 2.08%, CaO 4.98%, Na_2O 3.78%, K_2O 2.96%, Fe_2O_3a 7.95%, TiO_2 0.98%.

The lavas intersected in drillhole C4 are distinct from those at Yumali and in the Coonalpyn drillhole C2. They are intermediate in composition with a range in the ratio of lime to potash which categorises the rocks as varying between andesites and trachyandesites. Data are not completely definitive but petrographically the alteration appears to be isochemical and the rocks are genetically distinct from the basaltic suite. The fine flow banding is typical of more silica rich and more viscous magmas than the basalts. Free quartz appears to be the product of alteration but the silica involved was probably an original component of the rock.

Specimen 6826 RS 63
CSR numbers Specimen 189659, no assay, TS 53179
Locality Coonalpyn, DDH C4, 55.35 m
Rock name Banded trachyandesite
Hand specimen

The specimen is very similar to specimen RS 62. The fine grained grey rock is virtually identical but the coarse grained veins are much less developed. The rock is moderately responsive to a hand magnet. Staining with sodium cobaltinitrite indicates a content of potash feldspar somewhat lower than that of RS 62.

Thin section

The section confirms the similarity between the two specimens from DDH C4. Specimen RS 63 is somewhat less altered than RS 62. It is possible to determine from relatively well preserved plagioclase twinning that some of the phenocrysts are oligoclase. Others are orthoclase. A few lenticular patches contain quartz and a poorly defined band with patchy limonite in it may consist of introduced material.

Comment

The lower potash feldspar content suggests that andesite is closer than trachyte to the composition of the rock. However, identification of the rock as a complete unit can only be tentative where the two specimens examined display a strong compositional banding. The essentially volcanic origin of the sediment is indicated by the phenocrysts but some sediment of other than pyroclastic origin may be present.

Specimen 6827 RS 62
CSR numbers Specimen 189631, no assay, TS 53183
Locality 6 km ESE of Tailem Bend, SADME DT4, 11.25 m
Rock name Amphibolite
Hand specimen

The specimen displays weak banding determined by the grain size and abundance of dark green prismatic minerals and light coloured, pinkish brown crystals. Grain size varies from about 5 mm at one end of the small (8 cm) slab of drill core to about 2 mm at the other end. Banding and a preferred orientation of both minerals dips about 45 to the length of the core. The specimen does not respond to a hand magnet.

Thin section

The rock consists mainly of coarse grained (up to 8 mm maximum diameter) amphibole, plagioclase and quartz. A little leucoxenised sphene, opaque minerals and very minor mica and limonite are present. Bands of granulated quartz, plagioclase and some amphibole cut through the major grains and indicate post-crystallisation processes.

The amphibole occurs as coarse prisms up to 8 mm long with a slightly ragged and often fragmented shape but apart from this a frequently subhedral to euhedral habit. The mineral is strongly pleochroic from green to pale brown with a high birefringence and is probably a hornblende tending towards a gruneritic, high iron, composition. The prisms tend strongly towards a preferred orientation and tend to cluster in bands and groups. A little amphibole occurs in the groundmass but most is porphyritic.

Plagioclase occurs almost equally as porphyritic crystals up to 5 mm across and in the groundmass. In composition it is now andesine but may have been more calcic originally. In some grains a concentric zoning is marked by bands of inclusions but no compositional difference remains. Some plagioclase is obscured by a cloudy alteration but much is almost unaltered. Twinning is often poorly developed. Plagioclase is particularly prone to shattering and is abundantly represented in the interstitial bands of granulated material.

Quartz occurs as scattered grains in the fine grained, interstitial material where it often replaces plagioclase. It also occurs as a mosaic on a large scale in leucocratic bands conformable to the gneissosity and on a smaller scale in fine fractures cutting original coarse grains of both plagioclase and amphibole. The quartz appears to be partly or wholly introduced as a late phase.

Sphene partly altered to leucoxene is moderately abundant as irregular, fragmented grains which tend to form elongated patches with a preferred orientation, usually associated with amphibole.

Opaque minerals are rare and are also associated with amphibole. Limonite is present as stains along fractures.

The mica is a brown biotite and occurs as rare scattered, fine grained flakes which appear to be a product of primary crystallisation rather than of alteration.

Comment

The present composition of the rock is that of a diorite but the evidence of granulation and silicification suggests that it is altered and may originally have been a gabbro. The presence of biotite may indicate a similar original composition to that of the Black Hill intrusive to the north-northeast. However, metamorphism of the amphibolite indicates that, if it is part of the Black Hill suite, that suite must have been intruded over a period extending from before or during the Delamerian Orogeny to after the end of that Orogeny. An alternative possibility is that the amphibolitisation and other alteration may be local phenomena of Post Delamerian age. The Tailem Bend area is at the intersection of a strong north-south tectonic fabric with the NNW-SSE fabric of the Padthaway Ridge. This junction is still subject to stress relating to the opening of the Southern Ocean which was initiated in late Jurassic times.

6726 RS 238, TS C 55644
Locality Mason Lookout DDH 1 159.95m.
Rock Name Plagioclase - mica gneiss.
Hand Specimen

The rock is medium grained and banded in dark and light shades of grey. Mica flakes are widespread but are more abundant in the darker bands.

Thin Section

The major constituent of the rock is a closely interlocked mosaic of plagioclase. Mica and quartz are minor components and trace minerals include amphibole, sphene and zircon.

Plagioclase is fresh, well twinned and relatively uniform in a grain size of about 0.5 mm. Composition from symmetrical extinction angles is oligoclase. Grains are anhedral and equant without any appreciable preferred orientation.

Quartz occurs as individual anhedral, equant grains intergrown with the oligoclase and as small patches of interlocking mosaic.

The mica is a pale brown, weakly pleochroic type, possibly close to phlogopite in composition. It occurs as fine flakes with a preferred orientation parallel to the banding. The concentration of mica is the major control of the shades of grey of the bands.

A rare constituent of the dark bands is an almost colourless, weakly birefringent mineral with a prismatic to acicular structure and a ragged, fragmented habit. Refractive indices are moderate and extinction is oblique. The mineral is probably tremolite.

Sphene and zircon are frequent accessory minerals and tend to be concentrated in, but not restricted to, the darker bands.

Comment

The gneiss is weakly banded due to varied concentration of mica and accessory minerals but it is composed essentially of sodic plagioclase. The banding and, particularly, the preferred orientation of mica suggest metamorphic recrystallisation and the extent to which metasomatic changes accompanied this process is uncertain. This uncertainty extends to the ultimate origin of the rock.

6726 RS 237, TS C55643
Locality Mason Lookout, DDH1 158.5m.
Rock Name Intermediate, weakly banded gneiss.
Hand Specimen

The rock is coarser in grain size than RS 238 and banded texture is more weakly developed. The overall colour is light grey but some of the light coloured grains are pinkish. The dark minerals are greenish. Fine grains of pyrite are disseminated through the rock.

Thin Section

Oligoclase is the most abundant constituent in this sample but albite is also present. Quartz is more abundant than in RS 238 but mica is less abundant. Tremolitic amphibole is the main ferromagnesian mineral. Scattered accessory minerals and opaques, sphene and zircon. No feldspar is identified as potassic and the pink colour is probably in albite.

Oligoclase grains are of coarse to medium sizes, anhedral although generally equant. Grain margins are often granulated. No preferred orientation is detectable.

Quartz grains tend to be of fine size but include coarser patches of partially annealed mosaic. It is distributed throughout the rock in interstitial positions. No preferred orientation is evident.

Biotite occurs as fine flakes sparsely distributed with a preferred orientation at about 45° to the weak banding seen in hand specimen. The mineral is pleochroic from very pale brown to colourless.

The dark green ferromagnesian mineral seen in hand specimen is a tremolitic amphibole with a very pale green tint in thin section. Pleochroism is from very pale green to colourless, refractive indices are very low and extinction very low angles to almost straight in some sections. Birefringence is weak. The mineral is either an amphibole variety with some characteristic of anthophyllite or is structurally imperfect, possibly due to submicroscopic chlorite alteration. Crystal habit is fragmented with ragged outlines. Prismatic and acicular fragments in optical continuity are the main basis of the weak banding seen in hand specimen. However some amphibole is similar in orientation to the biotite and a few grains are composite, partly mica and partly amphibole.

Opaque grains consist of fine, black euhedral to subhedral crystals and irregular patches of sulphide.

Sphene is not abundant but several medium sized, subhedral greenish brown grains are present.

Zircon grains are rare and often associated with sphene.

Comment

Differing orientation of mica and amphibole indicate that directional textures originated in two processes. These may be original magmatic banding and a tectonic episode which may have included metasomatism. The highly sodic composition of the plagioclase may not be original.

6726 RS 236, TS C55642
Locality Mason Lookout, DDH1 156.6m.
Rock Name Amphibolite and plagioclase-amphibole gneiss.
Hand Specimen

The specimen consists of a greenish black, coarse grained portion and a speckled green-black and pinkish white, medium grained portion separated by a vein-like, pinkish band with fine dark spots.

Thin Section

The three lithologies are distinguished by different proportions of ferromagnesian and felsic minerals. The dark lithology consists mainly of amphibole with minor opaque minerals and very minor plagioclase, quartz, biotite and carbonate. The speckled lithology consists mainly of interlocking amphibole and plagioclase with minor opaque minerals and quartz and accessory zircon. The pinkish band consists of plagioclase with minor quartz and opaque minerals and with traces of quartz, mica, amphibole and carbonate. Sphene and chlorite are present in a thin vein.

The amphibole is hornblende with a pleochroic scheme of blue green to green to yellow brown. Grains are up to 7mm long and closely intergrown with anhedral shape. The core of many crystals is darkened by fine grains of opaque minerals, often along cleavages, while a paler margin to the crystals is of different composition and lacks opaque inclusions. A preferred orientation is evident but every crystal does not conform.

Irregular patches of opaque material up to 8mm long but skeletal in structure occur interstitially to amphibole but in close intergrowth with the host mineral.

Quartz, plagioclase, carbonate and biotite also occur interstititially to and as fine grained inclusions in the amphibole.

In the speckled lithology very anhedral hornblende and somewhat sericitised plagioclase are closely intergrown with minor opaque minerals and quartz. Very minor biotite and zircon are present. The latter, in unusual habit, is anhedral and intergrown with opaque minerals.

The pinkish band is composed partly of lithology similar to the speckled rock but with abundant quartz and very minor hornblende and opaque minerals. Interstitial carbonate, biotite, chlorite and sphene with rare zircon are present. Part of the pinkish band consists of a single crystal of feldspar over 13mm long. No twinning is visible but most of the crystal is obscured by a thick felt of sericite. The feldspar may be orthoclase.

Chlorite and sphene are mobile phases and fill a thin vein which cuts the section from end to end.

Comment

The pinkish lithology is almost certainly discordant to the main fabric, suggesting that recrystallisation has disrupted the original rock. The extent that this has occurred is uncertain.

6726 RS 239, TS C55645
Locality Mason Lookout percussion drillhole PH4 18-20m.
Rock Name Plagioclase amphibolite.
Hand Specimen

Drill cuttings are speckled greenish black and yellow.

Thin Section

The cuttings consist of medium grained intergrowths of amphibole, plagioclase, quartz, opaque minerals, sphene and possible monazite.

The amphibole is hornblende with a pleochroic scheme of blue green, green and pale yellow brown. It is anhedral and does not display a detectable preferred orientation.

The plagioclase is partly altered by sericite. In some cuttings it has been granulated into a mosaic, often partly annealed. In other cuttings only grain margins have been granulated.

Quartz occurs as fine grains and as patches of mosaic. It is mainly interstitial to amphibole and plagioclase but in places forms inclusions within grains of both these minerals.

Opaque grains are anhedral and mainly interstitial. In some cuttings they are more abundant than in others.

Sphene is often associated with opaque grains, usually forming zones around their margins. It also occurs as individual grains, chains of grains in fractures, and patches of mosaic.

A relatively rare mineral with high refractive indices and biaxial positive optical sign with a very small 2V is possibly monazite.

Comment

The cuttings represent a lithology similar to that intersected by diamond drilling at 156.6m and described as the speckled lithology. Recrystallisation is strong.

6726 RS 235, TS C55651
Locality Blind Creek DDH2 125.6m.
Rock Name Oligoclasite.
Hand Specimen

4The rock consists of coarse grained grey to pink crystals strongly fractured and intruded by a reticulated system of green and black veinlets.

Thin Section

The rock is mainly composed of plagioclase in random intergrowth. Fractures within and around the plagioclase grains and on a larger scale through the whole fabric contain either amphibole or biotite or both. Minor quartz and opaque minerals are mainly interstitial and carbonate fills thin fractures. Sphene is an alteration product of opaque minerals. Apatite and zircon are accessories.

Plagioclase crystals are up to 7 mm across. Multiple twinning is well developed and maximum symmetrical extinction angles indicate a composition of calcic oligoclase. Grains are anhedral, mainly equant and without apparent preferred orientation. Contacts between grains are simple and junctions of grain boundaries are often at equilibrium angles of 120°. However, grain boundaries, cleavages and twin planes have often been invaded by other phases.

Amphibole is the most abundant interstitial mineral. It is pale green, weakly pleochroic and, probably of actinolitic type. Grains are fine, fragmented and mainly anhedral. Chloritic alteration is common. Amphibole also occurs as fine grains in a system of thin veins filling fractures. In this type of occurrence the actinolite displays a preferred orientation along the fracture.

Biotite also fills thin fractures, both alone and with amphibole. In the vicinity of these veins biotite is also present along grain boundaries and minor fractures within plagioclase crystals. It is less abundant than amphibole.

Fine grained quartz is also a component of the vein system, as individual grains and as mosaic patches.

Opaque grains occur mainly in the veins but occasionally form inclusions in plagioclase. Opaque material is often surrounded by alteration haloes of sphene.

Rare carbonate is present in thin veins.

Apatite and zircon are present as inclusions in plagioclase.

Comment

The main component is oligoclase in an equilibrium or near equilibrium mosaic. Recrystallisation may be responsible for the state of equilibrium but in this specimen there is no evidence of directional stress having been applied. The fracture system is reticulate rather than directional in orientation.

6726 RS 234, TS C55650
Locality Blind Creek, DDH2 123.95m.
Rock Name Amphibole plagioclase gneiss.
Hand Specimen

The rock is banded in dark green and pinkish grey. The green bands consists of fine grained minerals. The pinkish grey bands consist of coarse grained pink minerals and grey minerals. The bands are undulating and appear to have been displaced by fracturing.

Thin Section

The fine grained green mineral is hornblende, the coarse grained grey mineral is quartz and the pinkish mineral plagioclase. Biotite, opaque minerals, chlorite, carbonate and sphene are minor and trace components.

The amphibole is mainly fine grained but very irregular masses in optical continuity over 7mm suggest that some at least may have initially been coarse grained and that the fine grain size is possibly the product of recrystallisation. The coarse grained relict amphibole displays a preferred orientation in which individual crystals are curved. Fine grained hornblende is also preferentially oriented at an angle to the plane of banding, but not all grains conform to the orientation. The pleochroic scheme is blue green, green and very pale yellowish brown. Much of the amphibole is continuous but individual grains and mosaic patches of both quartz and plagioclase are irregularly distributed through the green bands.

Coarse grained quartz occurs in a vein which is subparallel to the banding. A thinner vein is subparallel to the preferred orientation of the amphibole.

The major part of the plagioclase is calcic oligoclase but a few grains are optically positive and are probably albite. Grains are coarse, up to 5mm across, but many are fractured. The broken fragments have not separated but remain within the outline of the original crystal. In addition to fracturing, strain in the crystals is shown by flexure of twin planes and the development of finely granular material along the margins of grains and in interstitital spaces. The latter are often 2mm wide. Thin bandls of granular material occasionally occur along fractures within plagioclase grains.

Most of the intergranular recrystallisation consists of mosaic plagioclase but both biotite and hornblende also occur within the granulated bands. Opaque grains and associated sphene occupy similar spaces. Chlorite and carbonate are less abundant but occur in the same manner.

Comment

Evidence of strain in this specimen is undoubted although much of the interstitial recrystallisation may be the product of chemical rather than physical granulation. Distortion of the coarse grained plagioclase must be of physical origin. Mobility of amphibole and biotite is evident but large scale metasomatism is only evident in the quartz. A regional penetrative deformation is probably responsible for foliation in the amphibole oblique to the original compositional banding of the rock but distortion of the plagioclase does not appear to be related the same plane of foliation. A second deformation may be responsible for this, for interstitial granulation and for a limited amount of metasomatic activity. These indications could form the basis for further work.

6726 RS 233, TS C55649
Locality Blind Creek, DDH2 121.1m.
Rock Name Plagioclase, amphibole, biotite gneiss.
Hand Specimen

The specimen consists of a funnel-shaped mass of pinkish white lithology between a green and white lithology and a black and white lithology.

Thin Section

Oligoclase is the most abundant phase in all three of the lithologies distinguished in hand specimen. Amphibole is the green mineral and biotite the black mineral. Sphene, opaque minerals, quartz, carbonate, chlorites, rutile and zircon are minor and accessory minerals.

The oligoclase is anhedral, fractured and bent. In the central, funnel shaped, pinkish white lithology granulated material occurs along fractures and grain boundaries and in interstitial spaces. In the speckled lithologies amphibole and biotite are present interstitially and in fractures instead of, and in places as well as, granulated feldspar.

The amphibole is most abundant in, but not entirely restricted to, the green and white speckled lithology. In thin section the mineral is extremly pale in colour and weak in birefringence. On this evidence it is tremolitic rather than actinolitic. However, birefringence is low and the mineral is probably poor in crystal structure. It forms anhedral to subhedral-prismatic crystals. Chloritic minerals may be alteration products. Fractures across the section are filled with amphibole.

Biotite is pale brown and moderately pleochroic. It tends to be better shaped than the amphibole, some flakes are of euhedral shape. It is mainly interstitial to plagioclase but appears to invade adjacent crystals as a replacement of the feldspar.

Sphene occurs interstitially and as fracture filling. Irregular patches are up to 4mm across. It also occurs as alteration haloes around opaque grains.

Fine grains of quartz and carbonate occur both interstititally and as inclusions in plagioclase.

Rutile and zircon form fine grains within plagioclase crystals.

Comment

Preferred orientation is not apparent except in a rough parallelism of large fractures. Strain textures in the feldspar are random in direction. Mobility of constituents on the scale of the thin section is apparent in amphibole, biotite, sphene and possibly opaque minerals. The funnel shape of light coloured rock in hand specimen is possibly additional evidence of local mobility.

6726 RS 232, TS C55648
Locality Blind Creek, DDH2 117.3m.
Rock Name Plagioclase, biotite gneiss.
Hand Specimen

The rock exhibits a somewhat indistinct banding of mainly white and speckled black and white lithologies.

Thin Section

The banding is produced by variation in the concentration of biotite in a mosaic of plagioclase. Minor quartz, very minor sphene and chlorite and accessory opaques, rutile and zircon are present.

The plagioclase is a calcic oligoclase. Some grains display bending of twin planes and some marginal granulation is evident. However the evidence of strain is less than that in the specimen from 123.95m. No preferred orientation is apparent.

Biotite is mainly interstitial but also occurs in short bands, some parallel but others oblique, in which flakes display a preferred orientation. A weak preferred orientation of biotite in interstitial positions is apparent but no single orientation is exclusive.

Quartz occurs as interstitial grains and as fine grains included in plagioclase.

Sphene is widespread but quantitatively minor. It is interstitial and mainly associated with biotite.

Chlorite is rare, interstitial and associated with biotite. Fine grains of rutile, zircon and opaque minerals occur bhoth interstitially and as inclusions in plagioclase.

Comment

The rock is similar to that intersected at 159.95m.

6726 RS 231, TS C55647
Locality Blind Creek, DDH2 116.8m.
Rock Name Plagioclase - biotite gneiss.
Hand Specimen

The specimen consists of a pinkish white lithology and a black lithology. The boundary between the two is sharper than that between the bands in specimen RS 232.

Thin Section

The pinkish white lithology consists of lightly sericitised plagioclase. Plagioclase is also the major constituent in the black lithology. The colour is due to interstitial biotite covering the plagioclase grains. Pale green amphibole, quartz, chlorite, rutile and sphene are minor constituents of both lithologies. Zircon and carbonate are accessory minerals.

Plagioclase grains are fractured, bent and separated by zones of fine granules which also form large interstitial patches in both lithologies.

Biotite is interstitial to plagioclase in the black lithology and occasionally occurs in fractures within plagioclase grains.

Amphibole and chlorite are mainly associated with biotite but occasionally occur in the pinkish white lithology.

Chlorite, quartz and carbonate occur in fractures within plagioclase grains as well as in interstitial granular material.

Rutile, sphene and zircon are mainly interstitial but also occur as inclusions in the crystals of major phases.

Comment

A set of thin fractures in approximately parallel array imparts a directional fabric to the rock. A fabric of greater strain producing extensive distortion and granulation appears to be without preferred orientation. Analysis of the fabric of rocks intersected in drillholes DDH[1] and DDH[2] requires oriented specimens which are not available. Evidence of a consistent preferred orientation is sparse but that of strong thermal recrystallisation is plentiful. The main thermal events associated with the Delamerian Orogeny occurred late

in the episode when substantial intrusive activity was prevalent. The age of intrusion of the amphibolites presumably predates this episode which was probably responsible for amphibolitisation and alteration of the felsic assemblages. It is possible, but not conclusive, that the intrusion reponsible for the linear magnetic anomaly south of Tailem Bend was a differentiated, layered mafic dyke. Present compositions are largely the result of metasomatic changes associated with a recrystallisation which appears to be of thermal rather than tectonic origin.

6726 RS 230, TS C55646
Locality Blind Creek, PH2, 43-49m.
Rock Name Limestone and metasandstone.
Hand Specimen

Cuttings from a percussion drillhole consists of Murray Basin sediments and a Palaeozoic sandstone.

Thin Section

The most abundant cuttings consits of bioclastic limestone. One cutting is a micritic limestone and one is a fine metasandstone consisting of angular quartz and biotite clasts supported by an argillaceous and sericitic matrix. Minor reaction between framework and matrix is evident.

Comment

The sandstone has undergone minor recrystallisation without a directional fabric and is probably Cambrian in age and located within the thermal aureole of an Ordovician intrusion. The limestones are probably Tertiary in age.

DISCUSSION

1. Metabasalts

The altered basalts and basaltic tuffs sampled by CSR contain plagioclase phenocrysts in which twinning is not always well enough developed to be used to estimate composition and which are often poorly crystalline, although not usually altered very strongly. The best estimate of composition is that of oligoclase but zones at the margin of some crystals are untwinned and may be more sodic.

The ferromagnesian component of the main type of Yumali basaltic rocks is now represented almost exclusively by abundant chlorite, both interstitial and pseudomorphous after phenocrysts, and an opaque iron oxide which is usually magnetite and accounts for the strongly anomalous magnetic signature of the basement. In a few specimens the opaque minerals are not susceptible to a hand magnet and are probably ilmenite. Titanium is also contained in sphene, much of it leucoxenised.

The term 'spilite' is less common in the literature today than it was when Amstutz (1974) edited a symposium on spilites and spilitic rocks. The concept of basalt alteration by water convecting through the pile is still useful however, and certainly applies to the altered basaltic rocks sampled near Yumali.

The assumption of most authorities is that the sodic plagioclase composition has been changed from a more calcic plagioclase by reaction with sea water or a saline pore solution derived from sea water convecting through a rock mass, driven by the heat of magma before, during and after extrusion. Calcium displaced from the plagioclase is largely incorporated in epidote, apatite, sphene and carbonate. These minerals are abundant in the Yumali rocks although all four do not necessarily occur in any one specimen.

The alteration of ferromagnesian minerals occurs through the agency of the same brine solutions as produced a sodic metasomatism in the plagioclase. The active agent is the water of the brines rather than the soda.

Hydrous alteration continues at lower temperatures to produce a dolomitic carbonate and to introduce quartz, probably as colloidal silica. Most of this is apparently precipitated within the rock.

It is clear from petrographic evidence that, on the scale of the thin section, calcium, magnesium and silica are mobilised to the extent that dolomitic carbonate and silica appear in veinlets and amygdales. The distance over which these components travel, the proportion of the total which becomes mobile and the extent to which they are lost from the volcanic pile as a whole are minor enough to preserve the main chemical and textural characteristics of the rocks as altered basaltic volcanics.

Spilitisation has not proceeded to the limit in the plagioclase as the most sodic phase identified is oligoclase. However, a potassium enrichment has occurred in some of the spilites, particularly in those from DDH C_2.

Brown mica is not uncommon as an accessory mineral. It is usually associated with chlorite and is often poorly crystalline. Some of the mica is dark brown and pleochroic, some is light brown and poorly to non-pleochroic. It is possible that both biotite and phlogopite are present but the most common phase is probably transitional between mica and chlorite.

Hellingwerf (1987) has recently published a model in which the mineralogy and chemistry of Proterozoic sea-floor metabasites in Saxa, Sweden, have been modified by two hydrothermal alteration processes operating simultaneously at different depths. Spilitisation was produced by downward movement of cool (250 - 400C) solutions dominated by sea water while potassic alteration was superimposed at greater depth by rising, hot (300-550C) solutions with a high metal content. Both soda and potash metasomatism were associated with base metal sulphide mineralisation but the richer and more diverse ores were produced by the potassic solutions.

Although convection can be effected in groundwater throughout a pile of terrestrial volcanics, the abundance of tuffaceous material and of chilled and brecciated basalt fragments, the presence of chemical sediments and the absence of proximal terrestrial clastic sediments suggest spilitic basalts of the Yurrali-Coonalpyn area are of marine origin and may be pillow lavas.

2. Metadolerites

Four specimens of dolerite, two from DDH Y2 and two from DDH Y6, have been sectioned. The rocks are rich in plagioclase which is more strongly albitised than that of the basalts. The most common measured plagioclase composition is oligoclase but much of the plagioclase is untwinned and may be albitic. Sericitisation is more advanced than in the basalts. Quartz has been introduced into the groundmass and in vein systems which also carry carbonate. In one specimen a myrmekitic intergrowth of quartz and plagioclase occurs in the groundmass. The most common alteration product of the ferromagnesian component is chlorite but amphibole is occasionally present.

Apart from the introduction of silica and sodium, the composition of the dykes does not differ significantly from that of the basalts. It is probable that the former are the feeders for the eruption of the latter and are involved in the same metasomatising convective system. The dykes are almost certainly the main heat source which drives the convection.

3. Picritic Metabasalts

Specimens from DDH Y5 contain abundant secondary amphiboles with only minor chlorite as the alteration products of primary ferromagnesian minerals. An iron-bearing tremolite is pseudomorphous after phenocrysts, but is itself altered to anthophyllite. Plagioclase is not abundant but a great deal of epidote is present. Phlogopite and an ankeritic carbonate are moderately abundant.

A basalt intersected two metres deeper in the drill hole is amphibolitic but contains plagioclase in contrast to the specimens described above. The specimens are related and are distinct from the chlorite-rich spilites. They

appear to represent a more undersaturated, magnesium-rich magma crystallising initially as a picritic basalt. Hydrothermal alteration has resulted in amphibolitisation rather than in chloritisation and the original composition appears to have been preserved. The presence of a rock intermediate in composition between the spilites and the picritic basalts may be the product either of fractionisation or contamination.

4. Trachyandesites

Flow-banded pyroclastics from DDH C4 consist of a fine grained groundmass composed of potash feldspar, identifiable only through sodium cobaltinitrite staining, sericite, opaque minerals, leucoxene and minor epidote and actinolite. Coarse patches of epidote with relict oligoclase, and sericite with relict orthoclase represent original phenocrysts as flow lines are diverted around them. Other patches containing quartz and limonite were probably original vesicles.

These rocks appear on petrographic evidence to have contained a relatively high content of potash at the time of extrusion and are probably not metasomatically enriched. They are moderately rich in plagioclase and are classified as trachyandesites. This is somewhat tentative since a vein system containing a garnet of grossular type indicates the introduction of some calcium, possibly derived from the contact metamorphism of carbonate. One specimen is classified as andesite since it appears to be low in potash.

5. Sediments

Because of substantial recrystallisation and some deformation, the exact nature of the sediments sampled is often obscure. From the evidence that is available it appears that at least two sources of sediment are involved, chemical precipitates and terrigenous clastics. It seems likely that the former type of sediment is much more abundant than the latter but the relative proportions are not clear in some samples. The sediments are undoubtedly distal.

The sediments consist principally of combinations of quartz, carbonate and mica (which may originally have been clay minerals). Very rare, very fine grains of tourmaline and zircon are indisputably of terrigenous origin. Volcaniclastic and sedimentary material are frequently interbedded or interfinger in flame-like masses. Pyroclastic material consists largely of chlorite but also includes plagioclase and opaque minerals. The basic components of analysed pyroclastics plot close to those of the basalts.

Petrographic examination of thin sections indicates that silica is mobilised on the scale of a few millimetres during alteration of the basic rocks. It is therefore anticipated that on a larger scale chert beds are likely to be interbedded with lavas and tuffs and that chert and pyroclastic material may have been deposited together. Several of the sediments sampled by CSR consist of fine grained silica of colloidal origin forming typical chert. This occurs with and without incorporated chlorite and other volcaniclastic minerals. In some specimens the quartz forms a recrystallised mosaic which includes quite coarse grains. It is not absolutely certain that none of the quartz is of clastic origin but it appears improbable since the accompanying chlorite is of fine grain size and the quartz mosaic does not exhibit any trace of nuclei resembling detrital grains.

Only where quartz is associated with tourmaline and zircon of clearly detrital origin is there a strong possibility that some, if not all, of the quartz is also detrital.

The same arguments apply to carbonate in sediments. The carbonate is often recrystallised and segregated into patches but probably originated as a fine grained chemical precipitate or a reaction product within rocks of volcanic origin. Calcium, magnesium and iron were mobilised, at least locally, during alteration of the basalts and tuffs and were able to react with any dissolved carbon dioxide.

The origin of the mica is most uncertain. It may have been eroded from a distal land surface or from a land where the climate minimised the production of clastic detritus. It may have originated as clay minerals. Alternatively it may have been produced, as clay or as mica, at or close to the point of deposition during the

alteration of lavas or tuffs. It may have sedimented directly from a cloud of fine, volcanic ash. As with the quartz and carbonate, only the presence of tourmaline or zircon is definitive evidence of a detrital origin.

6. Gabbro

The first hole drilled at Coonalpyn, DDH C1, intersected an unfoliated, relatively unaltered hypersthene gabbro in which the plagioclase crystals retain a compositional zoning. Alteration mainly consists of minor to major replacement of pyroxene crystals by amphiboles with biotite along cleavages. Very minor development of chlorite is in strong contrast with the spilitisation of the basalts. The presence of substantial interstitial biotite invites immediate comparison with the Black Hill Norite and it appears likely that this occurrence may be a member of the same post-orogenic suite of basic to ultrabasic rocks.

7. Granite

The granite encountered in DDH C3 is also virtually unaltered and retains zoned plagioclase. It is assumed to be post-orogenic. The quartz is partly replacive and may indicate a genetic similarity to the Long Ridge Granite which crops out near Sedan, east of the Mount Lofty Ranges.

8. Amphibolites and Feldspathic Gneisses

Amphibolites outcrop at Tailem Bend and were intersected together with feldspathic gneisses, in drill holes between Tailem Bend and Meningie. The rocks were identified as orthogneisses (Morris and Nichol 1974) and as a possible metamorphosed layered mafic intrusion (Gidley 1983). The linear form of the strong magnetic anomaly may indicate a mafic/ultramafic dyke. Amphibolite bands are indicated by intense anomalies due almost certainly to high magnetite contents. The genetic affinity and age of the rocks is still uncertain. Alteration is metasomatic and appears to be post-tectonic.

CONCLUSION

Drilling of basement near the southwestern margin of the Murray Basin has revealed a dominantly magmatic province of both volcanic and intrusive rocks. Minor sediments of fine grained, distal type indicate a probable marine environment. Intersections extend over 40 kms but calibration of aeromagnetic signatures against intersected rocks suggests that these lithologies may extend in a wide band of broadly continuous subcrop for about 200 km in a NNW-SSE direction. At the westerly end of this band the signatures suggest a northerly extension of indeterminate length.

This magmatic domain, tentatively named here the Padthaway Domain, contrasts sharply with coarse grained, terrigenous, clastic metasediments to the northwest and southeast. These are the Kanmantoo Group which outcrops along the eastern slopes of the Mount Lofty Ranges and the Glenelg River Complex just over the Victorian border. Recent drilling by the Department (Rankin *et al.* 1991) suggests from intersections of limestones and coarse grained clastics in the vicinity of Peebinga and Kringin that there may be a shoreline in the northeast, possibly extended from Victoria. However, the northern and southern boundaries of the province are not known.

From the sparse data available the province appears to be linear and hence the most likely tectonic environment is one of tensional rifting. This perception is reinforced by a discrimination plot (Rankin *et al.* 1991) in which the samples appear in the within-plate field. However, the data are biased by the distribution of shallow basement since both the sparse outcrop of inliers and the preferred choice of drill sites are concentrated along the Padthaway Ridge. Drilling of parts of the Murray Basin in which the basement is under deep cover might reveal a wider basin of igneous rocks. Such a basin might be a rhombochasm if small or a back-arc basin if substantial. It has been suggested (Coward 1976) that the Padthaway Ridge marks the trace of a major shear zone along which left lateral movement is responsible for the sigmoidal form of the Adelaide Fold Belt. If this is so, uneven movement on opposite sides of the shear might have resulted in the subsidence of rhomboid segments and the eruption of magma to fill the chasms.

Moderate assymetry in the open Delamerian folding of the Mount Lofty Ranges indicates that stress was applied from the southeast towards the northwest. Since the associated igneous activity occurred east of the Ranges, a subduction model is not applicable unless the Benioff zone is well to the southeast of South Australia. If the volcanic and intrusive rocks prove to be as or more extensive in a broadly N-S direction as they are from NW to SE, it is possible that they may floor a back-arc basin. However, the tectonic model is probably more complex than this since a mantle-tapping structural corridor marked by the Padthaway Ridge cuts obliquely across the supposed basin.

Optical petrography indicates that, as well as *in situ* alteration, such minerals as chlorite, carbonate (both dolomite and ankerite-siderite phases) and silica are mobilised at least on the scale of the thin section. No examination of polished mounts in reflected light was carried out but simple inspection with a hand lens reveals that pyrite and possibly chalcopyrite occur both as fine, disseminated grains and as recrystallised aggregates in the mobilised veins and pods. It is possible that on a larger scale sulphide mineralisation with a gangue of quartz, chlorite and carbonate, individually or together, may be present, particularly in pyroclastic volcanics and in sheared or brecciated rock.

Potassium metasomatism occurs locally, notably in the Coonalpyn metabasalts, superimposed on the regional sodic spilitisation. Mineralogically it is expressed as an olive brown biotite. The highest concentration of copper was recorded in a micaceous metabasalt.

Geochemical analysis did not delineate any sustained anomalies of ore metals apart from a consistently high background of chromium in the picritic metabasalt of DDH Y5 at Yumali. The highest copper value mentioned above is 390 ppm Cu in a micaceous, spilitic, basalt with a potash content of 3.38% K_2O, also from DDH Y5. The specimen is 6827 RS 86 from 158.3 m. The only other copper value above background is 145 ppm Cu in a sheared, microveined, metabasalt (6827 RS 53) from 155.1 m in DDH Y7. Potash content is 1.38% K_2O. Neither of these anomalous values are supported by adjacent high concentrations of copper but may suggest the importance of tectonic disturbance and alteration processes as indications of potential mineralisation. High potash contents in trachyandesites are not due to metasomatism and are not correlated with high copper concentrations.

Zinc concentrations tend to be higher on average than copper while lead values are lower. Variations in concentration are not correlated with any identifiable characteristics of structure or chemistry.

The drilling carried out so far has identified a domain of high economic potential below the sediments of the Murray Basin. The prevailing metabasaltic lavas and pyroclastics are potential hosts for pyritic copper-zinc sulphide mineralisation and the intrusive rocks provide thermal energy to power hydrous convection cycles as well as the potential of their own ore concentrating environments. Mechanisms and environments of ore generation are provided by the metasomatic and mobilising processes apparent from thin section petrology. Further drilling guided by evidence of alteration, brecciation and mobilisation is required to follow up indications of mineralising processes already obtained. The area chosen by CSR Ltd for concentrated drilling has the advantages of shallow basement, the intersection of structural trends, the presence of a gabbro to provide thermal energy, a trend towards undepleted mantle in the picritic basalts and abundant metabasaltic lavas and pyroclastics as the host and source rocks for economic mineralisation.

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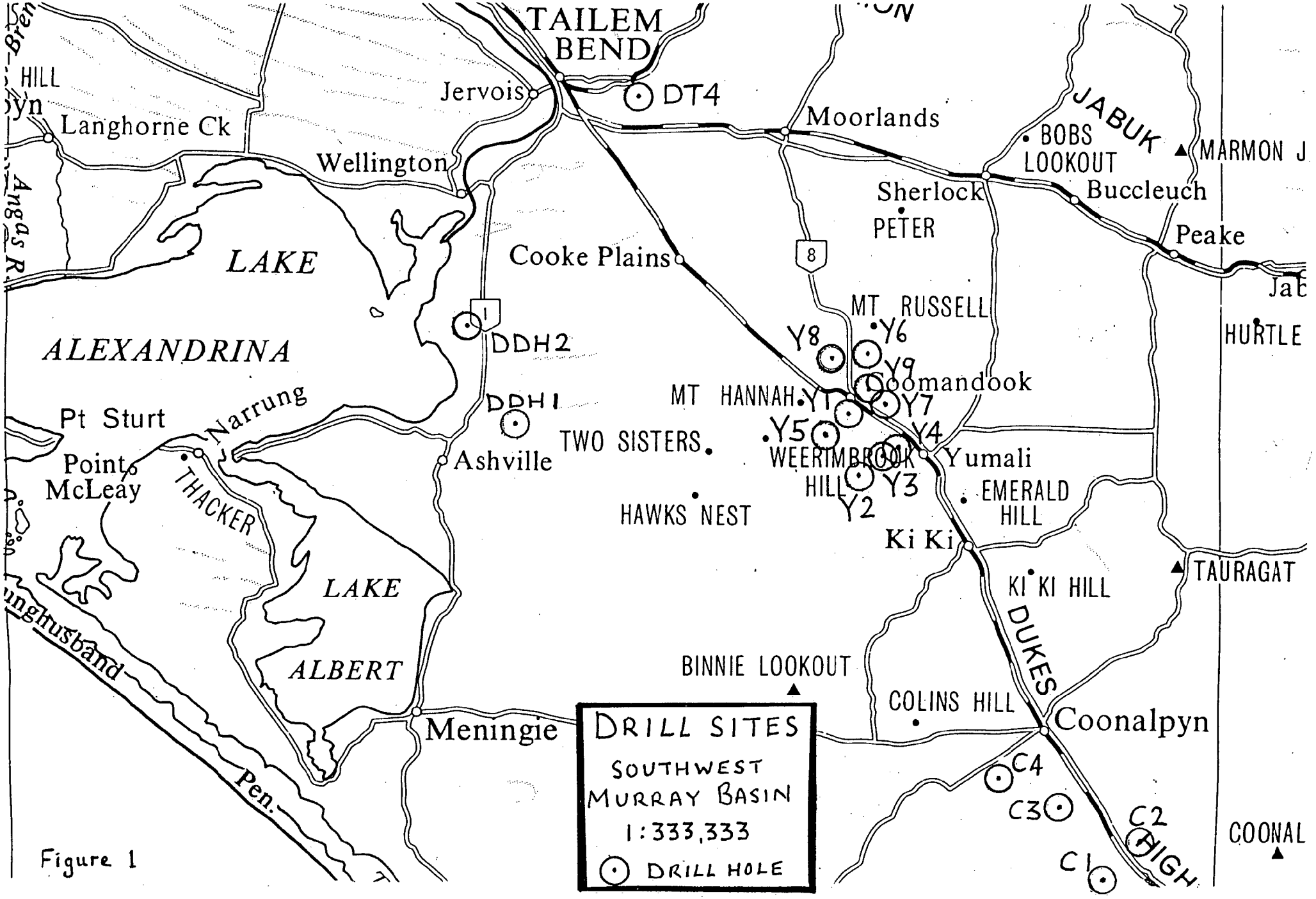
TAILEM BEND
Jervois
DT4
Moorlands
JABUK
BOBS LOOKOUT
MARMON J
Langhorne Ck
Wellington
Sherlock
PETER
Buccleuch
Peake
Cooke Plains
8
LAKE
ALEXANDRINA
1
DDH2
MT RUSSELL
Y8
Y6
Y9
HURTLE
Coomandook
DDH1
MT HANNAH
Y1
Y7
Y5
Y4
Pt Sturt
Narrung
TWO SISTERS
Ashville
WEERIMBROOK
Yumali
Point McLeay
THACKER
HILL
Y3
Y2
EMERALD HILL
HAWKS NEST
Ki Ki
TAURAGAT
KI KI HILL
DUKES
LAKE
ALBERT
BINNIE LOOKOUT
COLINS HILL
Meningie
Coonalpyn
C4
C3
C2
C1
HIGH
COONAL
Pen.
DRILL SITES
SOUTHWEST
MURRAY BASIN
1:333,333
DRILL HOLE

Figure 1