DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT.BK.NO. 84/62

# PETROGRAPHY OF FORTY TWO SPECIMENS FROM WITHIN AND SOUTH OF THE BURRA OPEN CUT COPPER MINE

GEOLOGICAL SURVEY

by

M.G. FARRAND

JULY, 1984

DME.454/82

CONTENTS

PAGE

ABSTRACT 1

INTRODUCTION 1

PETROGRAPHY 2

DISCUSSION 78

a) The depositional environment 79

b) Non-carbonate sedimentation 79

c) Evidence for a pyroclastic contribution 80

d) Carbonate sedimentation and diagenesis 81

e) Metasomatic changes 83

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

SADME Pet Rept 5/84
1:100 000 Sheet 6630

Rept. Bk. No. 84/62
D.M.E. No. 454/82
Disk No. 91

# PETROGRAPHY OF FORTY TWO SPECIMENS FROM WITHIN AND SOUTH OF THE BURRA OPEN CUT COPPER MINE

## ABSTRACT

Petrographic examination of a series of specimens collected at a distance from the ore zone at Burra indicates that only extreme recrystallisation of dolomite may be attributed to metasomatic processes. It is suggested that the form of precipitation in purely dolomitic sediments is controlled by the concentration of carbonate in solution and that the relationship between carbonate and silica in the sedimentation and diagenesis of the dolomite is controlled by the pH and Eh of the fluid medium respectively above and within the sediment. Evidence is put forward that there is a pyroclastic component in much of the non-carbonate sedimentation.

## INTRODUCTION

Rock specimens collected from the open cut copper mine at Burra have been described recently in Amdel Report GS 1/1/271 and in SADME Report Book 83/28 by the present author. A second series of samples was collected by John Drexel and Wayne McCallum of the Mineral Resources Branch to provide additional evidence relating to some of the issues raised in the earlier reports. The present report describes the petrography of these samples as seen in hand specimen and thin section. To facilitate correlation the descriptions are presented in a standardised form. The percentages given for mineral constituents are estimated from visual inspection. No counting techniques have been employed and the values are subjective and at best semi-quantitative. The thin sections have been stained with alizarin red to emphasize the presence of calcite. The chips from which the sections were cut have been treated with hydroflouric acid and sodium cobaltinitrite to assist in the identification of potash feldspar.

# PETROGRAPHY

Specimen B2, 6630 RS 102, TS C41982

Rock name: Dolomite with quartz

Hand specimen:

Medium grained grey quartz is included in fine grained, buff to beige dolomite.

Thin section:

a) Modal estimates Semi-quantitative estimates of mineral percentages are:

| Mineral | % |
|---|---|
| Dolomite | 85 |
| Quartz | 12 |
| Microcline | 1 |
| Opaque minerals | 2 |

b) Textures

Dolomite is closely intergrown as a mosaic of mutually interfering grains of equant but irregular shape and of varied but generally fine grain size. A few euhedral to subhedral rhombs are present as inclusions in both the dolomite mosaic and, rarely, in quartz grains. In plane light the outlines of rounded pelletoids are visible as finer grained patches.

The quartz is highly irregular in shape and of coarser grain size than the dolomite matrix. Grain margins are deeply embayed. Quartz distribution is patchy.

The rare microcline was also originally coarse grained but consists now of highly corroded remnants.

The opaque material is partly fine subhedral cubic grains and partly irregular patches.

c) Alteration

1) Dolomitic replacement of quartz and microcline is evident.
2) Patches of quartz are probably introduced.
3) A little evidence of potash metasomatism (as microcline) is still preserved.

4) Much of the opaque material was probably originally euhedral pyrite cubes.

5) No evidence of kaolinisation remains.

d) Origin

Petrographic evidence suggests that the rock originated as a chemically precipitated carbonate sediment, probably of dolomitic composition at the time of precipitation. The abundance of the dolomite and the fine, though varied, grain size of the close packed, anhedral grains are typical of normal Skillogallee Dolomite. Intraformational pelletoids, evidence of which has survived the recrystallisation of the specimen, are common features of the carbonate facies of the Skillogallee Dolomite.

Recrystallisation of the dolomite has had only minor effects on the main fabric but has produced substantial replacement of the margins of quartz and microcline grains. Complete replacement of these minerals may have occurred to an extent that is not possible to estimate.

The grain size of quartz and microcline is too coarse for these minerals to have been deposited with the fine chemical sediment and they are almost certainly the product of subsequent introduction, probably in low temperature solutions. The inclusion of dolomite within the quartz suggests the later date of the latter.

The opaque grains now consist of limonitic iron oxide but were almost certainly pyrite when first deposited. It is not possible to conclude with certainty the time of precipitation but it is more likely to have been during diagenesis than during any post-lithification process of mineralisation.

Despite its location in the centre of the mineralised zone, the degree of alteration of the specimen is unexpectedly slight.

Specimen B6, 6630 RS 106, TS C41983

Rock name: Silicified dolomite and/or magnesite

Hand specimen:

The specimen has a flinty appearance but is mainly composed of a grey carbonate. On the cut surface a fractured and brecciated structure is seen. The joint surfaces of the specimen are lightly stained with a yellow, probably iron rich, coating.

Thin section:

a) Estimated mode

| Mineral | % |
|---|---|
| Carbonate | 80 |
| Quartz | 15 |
| Microcline | 2 |
| Muscovite | 1 |
| Opaque minerals | 2 |

b) Texture

The carbonate component consists of coherent masses of an extremely fine grained mineral separated by slightly coarser euhedral to subhedral material. The latter carbonate is probably dolomite but the former may be magnesite. Pale grey to white carbonate in rounded masses within a matrix of Skillogallee Dolomite have been tested in the past by X-ray diffraction and have proved to be magnesite. The optical properties of dolomite and magnesite are too similar for reliable identification in thin section.

The fine grained masses in a coarser matrix give the specimen a brecciated appearance but a system of fine fractures is superimposed on both fragments and matrix. Coarse to medium grained quartz and microcline are concentrated along the fractures and in the dolomitic matrix but are not confined to these locations. Scattered grains occur throughout both carbonates. The textural relationships of silicates and carbonates are complex. Inclusions of carbonate are often contained in both quartz and microcline but the margins of grains of both these minerals are often embayed in contact with both of the carbonates. A third relationship is displayed in patches of coarse grained quartz in which quartz grains in equilibrium with each other also appear to be in equilibrium with euhedral to subhedral coarse dolomite. The quartz grains are in contact with each other along simple boundaries which frequently meet in perfect triple junctions. There is very little strain polarisation in the quartz.

The rare muscovite occurs as medium grained flakes in fractures.

The opaque minerals are almost certainly pseudomorphs after pyrite and occur as single cubes and small stringers of subhedral grains which are widely distributed throughout the sample but which are concentrated in both the discordant fractures and in the dolomitic matrix between the fine grained masses.

c) Alteration

1) Remobilisation of carbonate.
2) Introduction of quartz interstitially to fine grained carbonate masses, along fractures and disseminated.
3) Potash metasomatism both as microcline and as muscovite.
4) Introduction of pyrite probably during diagenesis, possibly a redistribution as pyrite into post-lithification fractures, conversion of pyrite to limonite.
5) No evidence of kaolinitisation or other alteration.

d) Origin

The rock originated as a carbonate facies of the sedimentary Skillogallee Dolomite. Despite the distance of this locality from the centre of the ore zone, silicification, potash metasomation, remobilisation of carbonate and the introduction and possible remobilisation of pyrite has affected the specimen.

Specimen B7, 6630 RS 107, TS C41984

Rock name: Siltstone or pyroclastic

Hand specimen:

The specimen is a fine grained, light brown sediment with a strongly bedded structure. The weathered surface is coated with limonite. The surface treated with sodium cobaltinitrite has been stained a uniform yellow, presumably reflecting a high abundance of potash feldspar in the matrix.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Potash feldpsar | 50 |
| Plagioclase | 5 |

| | |
|---|---|
| Quartz | 10 |
| Mica | 20 |
| Clay minerals | 10 |
| Limonite | 5 |

The estimated abundance of potash feldspar is based partly on the extent of the sodium cobaltinitrite stain. Optically identifiable potash feldspar consists of microcline clasts with a modal abundance of about 20%. The matrix of the rock includes much material of low birefringence which may be potash feldspar. However, sericitic mica and some chlorite also retain a sodium cobaltinitrite stain.

The mica listed includes some birefringent flakes but is mainly colourless. With increasingly imperfect crystal structural the mica grades into the clay fraction and the relative abundance of the mica and clay is estimated very approximately.

Limonite is mainly translucent but amorphous.

b) Texture

The fabric is strongly bedded owing to the preferred orientation of the platy minerals and of elongated clasts of quartz and feldspars. The elongation of some of these clasts, and of some mica flakes, is so considerable that post-sedimentation growth is possible. However, even equant clasts are frequently highly angular and abrasion during transport was probably minimal. Chemical decomposition of feldspar clasts was also minimal.

c) Alteration

Apart from possible recrystallisation during diagenesis the rock does not appear to have been altered. If alteration has occurred it probably involved the introduction of potash.

d) Origin

The siltstone is a non-carbonate sedimentary facies of the Skillogallee Dolomite. The freshness of the feldspars, the angularity of the clasts and the high potassium content of the matrix are compatible with a volcanic origin but are not strong enough evidence in themselves to support a conclusive identification of such an origin. An alternative origin is that of deposition of a terrigenous sediment in an environment of constant renewal of water during deposition. In these circumstances the chemical precipitation of carbonate does not take place.

Specimen B8, 6630 RS 108, TS C41985

Rock name: Fractured ?magnesite

Hand specimen:

The specimen is an extremely fine grained, pinkish brown rock of carbonate composition. A network of fractures is outlined by limonite staining and has produced a tectonic breccia rather than the intraformational type exemplified by specimen B6.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Fine grained carbonate | 75 |
| Coarse grained carbonate | 20 |
| Limonite | 5 |

The fine grained carbonate is possibly magnesite but the identification requires confirmation by X-RD. Some of the coarse grained carbonate is dolomite but much of its appears to be recrystallised magnesite.

b) Texture

Faint bands in the fine grained carbonate may indicate a stromatolitic origin. The major textural feature is the discordant fracturing with coarse recrystallised carbonate and amorphous limonite.

c) Alteration

Recrystallisation of carbonate along the fractures is the only evidence of alteration in the specimen.

d) Origin

The rock originated as a chemical sediment, probably influenced by stromatolitic algal growth, deposited as part of the carbonate facies of the Skillogallee Dolomite. The composition of the carbonate is magnesium-rich but it is not possible to distinguish optically between dolomite and magnesite. Fracturing subsequent to lithification brecciated the rock and promoted limited recrystallisation and the introduction of iron along the fractures.

Specimen B11, 6630 RS 111, TS C41986

Rock name: Highly altered sediment

Hand specimen:

The rock is a patchy pink, brown and white, highly friable material with a weakly bedded fabric. Impregnation with epoxy resin for thin section preparation has obscured much of the specimen and may have inhibited staining with cobaltinitrite except in scattered patches.

Thin section:

a) Mode

Estimates of the modal proportions are particularly imprecise because of the diversity and frequent fundamental changes in the lithology over very short distances. The original lithology appears to have included both shale and siltstone and superimposed upon this variation was a wide range of alteration products. One of these appears to vary in optical properties continuously between those of chalcedony and of chrysocolla. The mineral is very fine grained and a scan by X-ray diffraction is advisable to check the identification and the percentages given. Minerals such as quartz and kaolinite are partly sedimentary and partly hydrothermal in origin.

| Mineral | % |
|---|---|
| Quartz | 30 |
| Kaolinite | 30 |
| Chalcedony | 5 |
| Chrysocolla | 5 |
| Microcline | 5 |
| Plagioclase | 5 |

| | |
|---|---|
| Opaques | 10 |
| Limonite | 10 |
| Jarosite | Trace |
| Muscovite | Trace |
| Dolomite | Trace |

b) Texture

In the scattered patches of rock with least alteration a consistent banded fabric is evident which probably represents the original bedding of the sediment. In individual minerals the only textures which may be original to the sediment, albeit to the diagenetic rather than sedimentary stage, are euhedral to subhedral shapes in opaque grains. These may represent pyrite although almost certainly replaced by limonite and jarosite. Quartz grains exhibit textures of considerable marginal corrosion. The grain size of most quartz is too high to be compatible with a sedimentary origin in a shale or siltstone and most of the quartz now present is almost certainly introduced or at least completely recrystallised.

On a mesoscopic scale alteration products such as chalcedony, chrysocolla and jarosite occur as patches and cavity linings of irregular to botryoidal form. Kaolinite of hydrothermal origin often occurs in masses in the form of a cauliflower head. On a microscopic scale these alteration products are fibrous or platy and frequently form a mass of close-packed rosettes.

In the initial stages of alteration a substantial solution porosity was developed.

c) Alteration

1) Very minor dolomite associated with hydrothermal quartz as fine inclusions.
2) Substantial recrystallisation of quartz into coarse grained patches, with the probable introduction of silica in solution.
3) Minor potash metasomatism producing scattered microcline and rare muscovite.

4) There is no evidence that the opaque minerals were copper-bearing and no evidence of carbonate copper. Copper was apparently introduced at a late stage along with kaolinite and colloidal silica as chrysocolla.
5) Kaolinisation and the introduction of colloidal silica with minor copper occurred late in the history of the rock, after the formation of cavities by dissolution of rock which had already been subject to silicification and minor potash metasomatism, in what was probably a low temperature hydrothermal process.

d) Origin

The sediment is another example of the non-carbonate deposition which took place in the dominantly carbonate sedimentation of the Skillogallee Dolomite. The anomalous features of the specimen are the sudden increase in alteration and the introduction of copper mineralisation in a locality remote from the centre of the open cut where the main mineralisation is located. It seems likely that a structural feature, probably a fault, has provided a passage for hydrothermal solutions carrying colloidal silica, some alumina and a little copper from the principal site of the mineralisation. The process may have been a late episode in the main mineralisation or a completely unrelated process at a considerably later date.

Specimen B12, 6630 RS 112, TS C41987

Rock name: Dolomite

Hand specimen:

The rock is hard and fractures with sharp angularity. It is white and fine grained apart from scattered patches of coarser quartz.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 95 |
| Quartz | 5 |
| Plagioclase | Trace |

Red stains along the fractures appear to be the result of penetration by the alizarin red dye and its failure to be removed by washing. It apparently does not indicate the presence of calcite.

b) <u>Texture</u>

The dolomite is a massive intergrowth of fine grains with a few patches of coarse recrystallisation. The only structures displayed are frequent fine fractures which are responsible for the angular surface of the hand specimen. Some of the coarse recrystallisation is associated with coarse quartz but small patches are sometimes isolated from this. Textures indicate a corrosive relationship between quartz and dolomite.

Quartz occurs mainly in patches of coarse crystallisation which are generally elongated in shape and are often seen to be controlled by fractures. Where quartz grains are in contact, the boundaries are simple with junctions close to 120° but most grain contacts have been invaded by dolomite and many quartz grains are reduced to corroded relics with strongly embayed margins. Corrosion by coarsely recrystallised dolomite is particularly severe but even the fine grained carbonate occupies embayments in quartz grains which it encloses.

Plagioclase occurs in rare euhedral crystals completely isolated in surrounding fine grained dolomite.

c) <u>Alteration</u>

1) Dolomitisation is confined to the marginal replacement of quartz grains, presumably during an episode of remobilisation.

2) Silicification has introduced the coarse quartz to what was presumably a fine grained dolomitic chemical sediment.

3-5) There is no evidence of potash metasomatism, ore mineralisation or kaolinisation.

d) <u>Origin</u>

Precipitation of fine grained dolomite was probably chemical, taking place under arid conditions in an evaporating body of enclosed water. The rapid alternation of siltstone and dolomite observed in the sampling traverse across the strike suggests that the time scale for the deposition of the sediments was extremely short, possibly even seasonal. The cycle of flowing water followed by stagnant, evaporating water is probably the result of delicate balance between rainfall and evaporation so that small changes result in the major variation between flushing outflow of water to the sea and a condition of internal drainage with falling water level. The small changes may be seasonal or, if not, may be the cumulative effect of a few years of drought or above average rainfall. In areas of continuous internal drainage the balance may be even more delicate with the concentration of carbonate dissolved in the water varying slightly above and below the saturation point as inflow and evaporation vary.

Silicification appears to affect sediments quite remote from any influence of the solutions involved in the deposition and remobilisation of the copper mineralisation and the presence of coarse grained quartz in this specimen, which is less than 10 m from the location of B12, does not imply the influence of a fault. The fault zone is presumably quite narrow. Post-silicification mobilisation of the earlier dolomite is also more widespread than the copper mineralisation and may be unrelated to it.

<u>Specimen B15, 6630 RS 115, TS C41988</u>

<u>Rock name</u>: Silty dolomite

<u>Hand specimen</u>:

The rock is a finely laminated sediment of a light grey colour. It is coherent enough to ring when struck. Grain size is mainly fine but patches of brown on the weathered surface surround coarser grains of oxidised iron compounds. Green colouration on the weathered surface suggests the presence of copper but the colour does not penetrate the interior of the specimen. A weak yellow stain in some bands may be partly absorbed by clay but probably correlates with the detrital feldspar.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 75 |
| Quartz | 15 |
| Feldspar | 2 |
| Limonite | 8 |

b) Texture

The lamination is less prominent under magnification than it appears in hand specimen. Linear arrays of quartz grains appear through a mass of fine grained dolomite. Slight variation in the grain size of the dolomite occasionally reinforces the bedded fabric but most of the oriented textures are more evident on a wide scale than in the field of view of the microscope.

Bands of detrital silicates are marked by a high concentration of grains rather than a continuous succession. The bands are broken up by dolomite and individual grains are strongly embayed. Where more than one grain of quartz are in contact the boundaries are simple and the few junctions remaining are close to 120°.

Feldspars include plagioclase and microcline and are included in the quartz bands.

Limonite occurs as euhedral pseudomorphs after pyrite. Some limonite has spread from these grains to form the brown stained patches seen in hand specimen.

c) Alteration

1) Dolomitic replacement of silicate grains is widespread.
2) Recrystallisation of the original detrital quartz is evident in the equilibrium textures still visible through the dolomitic replacement.
3-5) There is no evidence of potash metasomatism, ore mineralisation, kaolinisation or other form of alteration. The feldspars appear to be detrital.

d) Origin

The evidence is overwhelming that the specimen is a finely bedded sediment of an original composition probably approximating to that of a quartz siltstone with minor feldspar. The dominant dolomite of its present composition must have been deposited by a replacement process. It is possible that preferential replacement of a clay component accounts for the uneven distribution of relict quartz but eventually the quartz itself was largely replaced. It is also possible that some dolomite, particularly that of a very fine grain size, was a component of the silt during the original deposition of the sediment. However, the evidence that much, if not all, of the dolomite is a replacement phase is inescapable.

The location of specimen B15 is remote from the centre of copper mineralisation and the dolomitisation may be completely unrelated to any mineralisation process. It is possible that the sediment represents the transition of the depositional environment from a chemical system in which dolomite in solution was below saturation and silicate sediment was deposited to one in which evaporation gradually produced a dolomite concentration exceeding saturation. Some dolomite was perhaps precipitated as a chemical sediment but eventually the concentration in the depositional environment, particularly in the pore water of sediment already deposited, became so high that exchange reactions between silicate sediment and the carbonate solution resulted in the replacement of clay, feldspar and quartz by dolomite.

This process implies that the silicification was also diagenetic. Possibly the highly alkaline pH of the pore water promoted the mobility and recrystallisation of the quartz before it began to react with dolomite in solution.

Specimen B17, 6630 RS 117, TS C41989

Rock name: Sandy dolomite

Hand specimen:

The rock is a purplish grey sediment with a densely crystalline texture and bedding traces marked by discontinuous light coloured bands. On the cut surface numerous lenticular cavities are evident, often along the traces of bedding. A few such cavities are visible on the broken faces.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 90 |
| Quartz | 9 |
| Limonite | 1 |

b) Texture

The rock is essentially similar to specimen B15. The only differences are a more complete replacement by dolomite, coarser grain size in the quartz, the absence of feldspar and fewer grains of limonite after pyrite. The cavities are less the result of plucking of quartz during sawing than of the natural dissolution of quartz. A coating of iron oxide on the walls of many cavities suggests that they are natural.

c) Alteration

1) Evidence for dolomitisation is clear.
2) Mosaics of coarse quartz which are still visible are almost certainly the product of recrystallisation.
3-5) No evidence of potash metasomation, ore mineralisation or kaolinisation remains. Production of cavities by dissolution is a probable alteration process.

d) Origin

The same considerations applied to B15 apply to this specimen. The rock probably originated in the same way; by the dolomitisation of a silicified sediment. Again, the implication is that silicification, whether by the introduction of silica or simply by the mobilisation and redistribution of silica already incorporated in the sediment, had taken place before deposition of dolomite by precipitation from solution and by replacement of silicate in the solid state. It is possible that rising pH promoted the mobility of silica and produced solution cavities in quartz lenses as evaporation increased the concentration of carbonate in the water.

Specimen B19, 6630 RS 119, TS C41990

Rock name: Dolomitic limestone

Hand specimen:

The rock is a dense, fine grained sediment with a fine lamination. The lamination is both complete and very regular but with a rather weak definition.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Calcite | 60 |
| Dolomite | 30 |
| Quartz | 9 |
| Limonite | 1 |

b) Texture

The rather weak definition of the laminations is due to the similarity in composition of the minerals making up the bands. Both are carbonates. Calcite is mainly much coarser grained than the dolomite and forms thicker bands. In rare occurrences both calcite and dolomite are closely intermixed in a fine grained band. Calcite also occurs in discordant veins. Dolomite forms thin bands of very fine grains between the calcite laminations.

Quartz occurs as scattered, ragged, corroded grains, mainly in the calcite bands. A few grains occur in the dolomite and one patch of scattered grains appears to be discordant to the bedding.

Limonite occurs as very fine grained pseudomorphs after pyrite.

c) Alteration

The only evidence of alteration is the presence and corrosion of quartz grains. This may indicate that some silicification preceded the deposition of carbonate.

d) Origin

Apart from the rather ambiguous evidence of the quartz, the sediment appears to have been produced by the chemical precipitation of carbonate under rhythmically varying conditions. It is more likely that variation in parameters such as pH and Eh controlled the carbonate phase precipitated than that the concentration of magnesium and calcium in solution fluctuated rhythmically.

Specimen B21, 6630 RS 121, TS C41991

Rock name: Dolomite

Hand specimen:

The rock is fine grained and massive but with a hackly fracture. The grey surface is pocked with small black marks which, on magnification, are revealed as comprising a dark centre surrounded by a white zone and a black, circular rim.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 97 |
| Quartz | 1 |
| Clay minerals | 1 |
| Limonite | 1 |
| Mica | Trace |

b) Texture

The dolomite is fine grained and massive but is cut by a few fractures. Quartz occurs in isolated patches without any obvious structural control. The clay minerals are fine grained and occur within the outlines of coarse euhedral crystals which were either rectangular or hexagonal, possibly hexagonal prisms. Limonite occurs as fine grains probably pseudomorphous after pyrite. A few fine, scattered flakes of colourless mica are present.

c) Alteration

1) Apart from marginal replacement in quartz grains, the dolomite appears to be a primary phase.
2) Coarse quartz was probably introduced.
3) The very minor mica is probably not the product of potash metasomatism.
4) No ore mineralisation is present.

5) Replacement of a coarse grained mineral or minerals by fine clays is evident but this is probably not a process of exogenic origin.

d) Origin

The sediment was probably the product of massive chemical precipitation of dolomite from a stagnant, evaporating body of water. Deposition of silica and replacement of this at grain margins were relatively unimportant. The nature and origin of the mineral or minerals now replaced by clay is uncertain.

Specimen B33, 6630 RS 133, TS C41992

Rock name: Stromatolitic dolomite

Hand specimen:

The rock is a fine grained grey dolomite with finely crenulated bands containing coarse grains of quartz stained with limonite. The structure of the bands is that of an algal reef in which sediment is trapped in mats of organic growth.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 75 |
| Quartz | 20 |
| Limonite | 5 |
| Feldspar | Trace |
| Organic matter | Trace |

b) Texture

Under magnification the fine grained dolomite is itself seen to be faintly banded with variations in the density of a light organic impregnation. The bands visible in hand specimen consist of coarse, interlocking crystals of quartz and dolomite. The quartz forms a mosaic which is not in perfect equilibrium and originated at least in part from a detrital accumulation in hollows on the stromatolite surface. Some patches of quartz transgress the growth bands of the stromatolite and must have expanded by replacement of the original dolomite. The quartz has itself been corroded by dolomite during a later recrystallisation.

Discordant fractures cut the specimen with no visible relationship to the banding. Dolomite has been recrystallised into coarser grains along the margins of some of the fractures.

Limonite occurs as a pseudomorphous replacement of fine euhedral pyrite grains and as a brown amorphous material which penetrates the stromatolite along the coarse grained bands and, particularly, along the discordant fractures. Most of the limonite has been introduced, presumably by solutions, at a late stage in the history of the rock.

A very few grains of both microcline and plagioclase are present as randomly distributed inclusions in the fine grained dolomite.

c) Alteration

1-2) Minor replacement of dolomite by silica and of silica by dolomite has occurred, probably without any substantial introduction of either from outside the chemical system of the sediment, even on hand specimen scale.

3-5) Iron does appear to have been introduced as a hydrated oxide at a late stage, possibly as part of a weathering process. There is no indication that it may be related to the copper mineralisation.

d) Origin

The evidence is convincing that the dolomite originated as a chemical sediment trapped in algal filaments of a stromatolitic reef. At least some of the quartz probably originated as terrigenous sediment deposited during short intervals of current action in hollows in the reef. Minor redistribution of carbonate and silica was followed much later by the introduction of limonite.

Specimen B93, 6630 RS 192, TS C41993

Rock name: Silty shale

Hand specimen:

The rock is fine grained and finely banded with plane laminations and a rather patchy buff colour. One band consists of white, kaolinitic clay and another of dark, coarser grained iron oxide. Part of the mottled colouration is due to a patchy distribution of limonitic staining. The weathered surface of the specimen is coated with a crumbly white deposit. A weak distribution of cobaltinitrite stain appears to be related to discordant fractures and small concretionary structures.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Clay | 50 |
| Quartz | 25 |
| Limonite | 15 |
| Feldspar | 5 |
| Mica | 5 |

b) Texture

The clay and detrital quartz and feldspar make up a finely bedded and strongly oriented fine sediment. Occasional grains exceed the size range for shale and justify the adjective 'silty'. One band consists almost entirely of detrital clay of kaolinite type. This band has been partially replaced by coarsely recrystallised kaolinite and biotite. The term 'mica' includes a range of colourless and coloured micas with varied degrees of crystallinity, and hence of birefringence, grading into clays with low birefringence. Some of the micas are certainly of replacement origin, others may have been original detrital constituents but have probably recrystallised to a coarser grain size.

Scattered sub-spherical patches up to 2 mm across but mainly about 0.5 mm across stand out because iron oxide staining has been removed from them and has been concentrated round their margins. Internally the patches consist of coarsely recrystallised clay and ragged flakes of colourless mica. These are the concretionary patches accentuated in hand specimen by a weak yellow cobaltinitrite stain. Some of the patches lie on late discordant fractures but many appear to be randomly located.

Some discordant fractures carry medium grained quartz interlocked in a mosaic along simple grain boundaries. Limonite has been redistributed along some fractures.

Apart from the latter form of limonite, the mineral occurs as a pervading brown stain throughout the shale but more abundantly as pseudomorphs after pyrite. These are widely distributed through the shale but are concentrated particularly in a few continuous or almost continuous beds.

c) <u>Alteration</u>

1) No dolomite is involved in the sedimentation of, or subsequent processes in, this lithology.
2) Quartz has been introduced along discordant fractures but there is no evidence of recrystallisation of detrital quartz or introduction of diagenetic quartz in the sediment.
3) A weak yellow stain from the sodium cobaltinitrite is seen at the point in the kaolinite band where the penetration of solutions has produced a coarse recrystallisation of the kaolinite followed by an inner zone of pale green, weakly pleochroic biotite. Although no potash feldspar could be identified optically, the sodium cobaltinitrite has revealed with its weak yellow stain a point at which potassium metasomation has been active. The process has been halted, probably by falling temperature or pressure in the invading solutions, at a part-way stage which demonstrates the nature of the process quite explicitly.

   The results of a more cryptic process of potash metasomatism are revealed by the spheroidal spots in which clays are recrystallised and a colourless mica is developed. Penetration of the fabric by solution along fractures may be responsible for the location of some of the metasomatic patches but the factors responsible for other centres of reaction are obscure.
4) No ore minerals were identified in transmitted light.
5) Kaolinite has been recrystallised quite clearly but there is no evidence of introduction of clay from an external source.

d) Origin

The sediment is the product of quiet deposition of fine, terrigenous detritus in virtually stagnant water. It is possible that the detritus may have been an airborn ash but there is no definitive evidence to support this suggestion. The presence of pyrite throughout the specimen with local high concentration indicates a relatively low Eh. It is possible that the pH of the depositional environment was also low enough to prohibit the precipitation of any carbonate.

Specimen B100, 6630 RS 199, TS C41994

Rock name: Micaceous siltstone or pyroclastic

Hand specimen:

The specimen is fine grained with a bedded fabric marked partly by fine banding and partly by lines of oriented solution cavities. The weathered surface is friable and rusty brown in colour. The sawn surface is a pinkish beige colour. The surface treated with sodium cobaltinitrite has taken a strong and uniform yellow stain.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Quartz | 20 |
| Feldspar | 30 |
| Mica | 30 |
| Limonite | 20 |
| Jarosite | Trace |

Estimated percentages of quartz and feldspar are influenced by the strong cobaltinitrite stain on the hand specimen. Many grains are too fine for quartz and feldspar to be distinguished if the feldspar is untwinned. If the strength of the cobaltinitrite stain is largely due to the sericitic mica, the feldspars may have been overestimated. Microcline and plagioclase are both identifiable by the pattern of multiple twinning. However, in some grains it is not clear whether the twinning observed is the complete set of plagioclase twins or one set only of microcline twins. No attempt has been made to estimate relative percentages of the species of feldspar although all feldspar grains are fresh.

The micaceous component includes a few detrital flakes as well as a continuous interstitial mass of fine sericitic mica stained brown.

b) Texture

The bedded texture of the hand specimen is less clearly displayed in thin section. Elongated grains of quartz and feldspar are only imperfectly oriented. There is a tendency to preferred orientation in the fine grained mica but much of the optical properties is concealed by iron oxide staining and many mica flakes are not preferentially oriented. Patches of coarse quartz and minor feldspar are elongated and fairly strictly oriented but the field of view of the microscope seldom includes more than one such patch and the cumulative effect is lost.

The quartz mosaics of which the lensoid patches mainly consist are coarse to fine in grain size and are close to equilibrium in grain shapes. Many of the patches include open cavities with rectilinear, sometimes rhombic, shapes. The patches may at one stage have contained coarse carbonate crystals which have now been dissolved out. Some of the open cavities are lined with amorphous limonite, indicating that the dissolution of the contents of the cavities antedated the mobilisation and oxidation of iron.

The limonitic occurs as red, translucent pseudomorphs after fine grained pyrite, as fracture fillings and as a red-brown impregnation in the sericitic mica flakes. Some limonite grains are formless.

A little jarosite is present in some of the open cavities that are lined with limonite.

c) Alteration

1) No dolomite is present but, if a carbonate was once present in the lenses of quartz, it may have been dolomite.

2) Silica has been mobile enough to become concentrated in lensoid patches. A little feldspar has also been mobile in this way. The mobilisation of both species is probably isochemical within the system of the rock unit, if not within the confines of the specimen itself.
3) The mass of interstitial sericitic mica is probably largely the product of alteration. However, it is not clear whether it was produced by the decomposition in place of a fine grained feldspathic matrix or by the alteration of clay minerals by solutions carrying potassium. The pervading limonite stain conceals the fine detail of the texture of the sericite. There is no clear evidence of the introduction of potassium and the alteration of potash feldspar is on balance the more likely genesis of the sericite. The process is thus a hydrous rather than a potassic metasomatism.
4) No ore minerals were identified.
5) No kaolinitisation was observed.

d) Origin

The specimen is a sediment composed of fine quartz, feldspar and mica detritus in an extremely fine grained, potash-rich matrix. If the original matrix was composed of feldspar, as appears possible, such finely divided feldspathic material was almost certainly derived from a volcanic glass falling as ash. Since the evidence of the cobaltinitrite stain is ambiguous and the nature of the sericitic matrix is largely concealed, the sequence of evidence and interpretation is somewhat precarious and should be regarded as indicative rather than conclusive.

Specimen B111, 6630 RS 210, TS C41995

Rock name: Mudstone

Hand specimen:

The rock is a soft, pinkish brown, fine grained sediment similar in appearance to specimen B100 except bedding is absent and the chip from which the section was cut has not reacted with the sodium cobaltinitrite. A large number of small, concretionary brown spots are visible on the sawn surface.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Quartz | 30 |
| Feldspar | 10 |
| Clay | 15 |
| Mica | 20 |
| Limonite | 25 |

The finest grain sizes which make up the major part of the rock certainly include sericitic mica and quartz. The mica tends to have gradational optical properties and it is assumed from the consistency of the hand specimen that substantial clay is present and that some of the platy minerals are probably illites which grade on the one hand to sericite and on the other to clays of low birefringence. Because of the fine grain size and a pervasive limonitic stain the optical identification of minerals in the low birefringent fraction is very imprecise. The assumption that no feldspar is present in this fraction is based on the absence of a cobaltinitrite stain. The assumption may not be valid if conditions of application of the dye were not standardised or if the feldspar is plagioclase.

b) Texture

Bedding is not as prominent in this specimen as in B100. The only mineral to display a preferred orientation is mica, of which many flakes are probably of sedimentary origin. These probably indicate the bedding plane but apart from this the fabric is massive. The matrix forms the major part of the rock.

Quartz occurs as very fine to extremely fine grains in the matrix of the rock. A patchy recrystallisation has increased the grain size, often in spherical bodies, up to a medium grain size in places. Quartz also occurs in a discordant veinlet and, with a texture indicating a chalcedonic origin, as an outer zone surrounding relatively coarse limonite grains. Finally, scattered quartz grains occur as detrital constituents up to fine silt grade.

Fresh feldspar, both plagioclase and microcline, is identifiable only as detrital fragments. Fine plagioclase may be present in the matrix.

Limonite is abundant as fine grains, probably replacing pyrite, as coarser masses surrounded by chalcedonic silica and as a strong stain permeating the platy minerals of the matrix.

The brown spots visible in hand specimen are produced by local redistribution of limonite.

c) <u>Alteration</u>

1) There is no carbonate in the rock.
2) Recrystallisation of silica has increased the grain size of the extremely fine matrix quartz but is probably isochemical.
3) There is no evidence of potash metasomatism except that some mica in the matrix may have originated as clay. Much of the mica is detrital.
4) No ore minerals were identified in transmitted light. Some recrystallisation of sulphide may have taken place and the origin of limonite surrounded by chalcedony is not known.
5) No kaolinisation was recognised.

d) <u>Origin</u>

The specimen is another example of non-carbonate sedimentation in the Skillogallee Dolomite sequence. The abundance of pyrite and absence of bedding indicates a stagnant environment with a plentiful supply of fine terrigenous material. Apart from fine, detrital quartz, feldspar and mica the sediment may have been precipitated chemically under conditions of acidity and oxidation potential which prohibited the deposition of dolomite. On the other hand a volcanic source cannot be excluded despite the apparent scarcity of feldspar.

<u>Specimen B122, 6630 RS 221, TS C41996</u>

<u>Rock name</u>: Feldspathic dolomite or crystal tuff

<u>Hand specimen</u>:

The specimen is bedded but part of it consists of a rapid repetition of fine beds and part of massive dolomite with little bedded fabric. The rock is strongly fractured. The weathered surface is coated partly by iron oxide but includes a coating of dendritic manganese oxide. No cobaltinitrite stain is evident.

Thin section:

a) Mode

Because the bedded fabric is marked by changes in minerals composition, the modal estimates are very approximate. One bed consists almost entirely of coarse plagioclase and dolomite, another of quartz.

| Mineral | % |
|---|---|
| Dolomite | 70 |
| Calcite | 5 |
| Plagioclase | 10 |
| Quartz | 5 |
| Limonite | 5 |
| Clay | 5 |

b) Texture

The massive dolomite is mainly fine grained but contains coarser scattered inclusions of marginally corroded quartz and feldspar and of limonite, probably after pyrite. Several generations of fractures cut the massive dolomite and some contain coarse grained quartz and limonite.

The fine beds are composed of varying proportions of quartz, plagioclase, limonite, dolomite and calcite. One bed consists almost entirely of quartz with a little limonite pseudomorphous after euhedral pyrite. The quartz is highly recrystallised and may originally have been a colloidal precipitate. A bed of limonite pseudomorphs in a clay matrix is adjacent to the quartz bed.

A short interval of bedded dolomite with a substantial component of detrital quartz separates the quartz and limonite beds from the most significant bed of all. This consists of relatively coarse grained, angular fragments of plagioclase in a matrix of coarse and fine grained dolomite and interstitial limonitic material which probably impregnates a clay. A few grains of quartz are scattered among the plagioclase crystals. From the refractive index and maximum symmetrical extinction angles the plagioclase appears to be a rather pure albite.

The calcite occurs at one end of the thin section where the two carbonates are closely interlocked in a medium grained mosaic. The dolomite tends to be bedded rather than massive at this point.

Discordant fractures and veins carry limonite, calcite and quartz.

c) Alteration

1) The dolomite, massive and bedded, is without doubt a sedimentary mineral and owes nothing beyond very minor marginal corrosion of quartz to any alteration process. Even recrystallisation appears to have been minimal.
2) Some mobility of silica is evident but has not resulted in any substantial alteration. Minor recrystallisation and marginal corrosion of quartz grains and the movement of small amounts of silica into discordant fractures are the only results of this mobility.
3) There is no evidence of potash metasomatism.
4) No ore minerals were recognised.
5) Kaolinite appears to be a sedimentary mineral.

d) Origin

The dolomite and calcite, and possibly the silica of the quartz band, are chemical precipitates under varied environmental values of Eh and pH. Quartz and plagioclase fragments, however, are detrital and have been supplied to an environment in which the quiet precipitation of carbonates was taking place. It is hard to avoid the implication, particularly for the plagioclase, that a shower of fragments was contributed to stagnant water by an agency which did not involve increased current action. A volcanic or pyroclastic eruption of what amounts to a crystal tuff is an agency capable of selecting phenocrysts of one mineral and depositing them in a stagnant aqueous environment.

Specimen B124, 6630 RS 223, TS C41997
Rock name: Dolomitic stromatolite
Hand specimen:

The specimen consists of undulating bands of grey and light brown rock. Discordant fractures are frequent.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 85 |
| Quartz | 10 |
| Limonite | 5 |

b) Texture

The dolomite is mainly fine grained and makes up the grey bands of the specimen. The brown bands are made up of coarse grained quartz in angular to sub-rounded grains together with similarly coarse grained dolomite in grains which tend to be irregular in shape. Limonite occurs in discordant fractures, in rare fine grains in the dolomite and as irregular interstitial patches in the coarse grained bands.

c) Alteration

Minor recrystallisation of quartz, dolomite and iron compounds are the only forms of alteration observed.

d) Origin

The sediment accumulated as fine grained chemical precipitates of dolomite trapped in algal mats in periods of low current velocities and high evaporation and as coarser grained detritus of both quartz and dolomite carried by more active currents in periods of higher rainfall.

Specimen B125, 6630 RS 224, TS C41998

Rock name: Sandy dolomite

Hand specimen:

The specimen is a finely laminated grey sediment with a pale rusty brown weathered surface. The surface also carries a few black spots which are probably manganese oxide.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 80 |
| Quartz | 20 |
| Limonite | Trace |

| | |
|---|---|
| Calcite | Trace |
| Organic matter | Trace |

Branching fractures are filled with amorphous material which is at different places blue, yellow and green. This colour change is due, respectively, to epoxy resin, limonite and a combination of the two. The green material is not a copper compound.

b) Texture

The laminations are plane, not corrugated or undulating, and are essentially sedimentary surfaces. However, variations in the organic content of different bands within the fine grained dolomite suggest that organisms played a part in the sedimentation. Algal mats probably covered the surface of the sediment but were passive coatings, not active reef builders in terms of the amount of sediment trapped.

The coarser grained sediment forming thin beds between the thicker bands of fine dolomite is the product of deposition by flowing water and consits of quartz and dolomite. The quartz displays slight marginal corrosion.

Calcite only occurs in very minor interstitial patches.

c) Alteration

There is no evidence of any alteration other than very minor marginal corrosion and recrystallisation of quartz.

d) Origin

The sediment is the product of an environment varying in kinetic energy from currents sufficiently strong to carry sand grade particles to stagnant and strongly evaporating water with a high alkalinity from which magnesium carbonate was precipitated. The cryptalgal laminations may indicate that the algal growth was not as vigourous as that producing stromatolitic reef structures or alternatively that a different species of alga was involved.

Specimen B126, 6630 RS 225, TS C41999

Rock name: Dolomite

Hand specimen:

The rock is composed almost exclusively of a fine grained, pinkish dolomite. It is faintly bedded and a few bedding planes are outlined by a red powdery iron oxide. This is probably the pigment responsible for the pink colour of the dolomite. A few flakes of mica up to 4 mm long are distributed randomly without preferred orientation through the rock.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 99 |
| Phlogopite | 1 |
| Quartz | Trace |
| Feldspar | Trace |
| Limonite | Trace |

The mica is colourless and virtually uniaxial optically. It is identified as phlogopite. It is possible that magnesite may be present but it does not form separate nodules.

b) Texture

The bedded fabric seen in hand specimen is developed by small lenses and short bands of slightly coarser grain size in the dolomite and by trains of small cavities where some dolomite has been dissolved out. In patches of coarser grain size the cavities are larger than in the mass of fine grained dolomite. In a few larger cavities a small amount of limonite forms a coating on the cavity walls.

The bedding traces are faint and neither plane nor always continuous but no evidence of any stromatolitic structure is visible and the dolomite contains no detectable organic matter. The texture may be the result of very weak and fluctuating current action or possibly of minor slumping in a massive deposit of fine dolomite particles.

Quartz and feldspar occur as fine, widely scattered grains.

The mica flakes are up to 2 mm long in the thin section. They are randomly oriented to any bedding and cause no disturbance to the sedimentary textures. They are probably a replacement mineral of diagenetic or post-diagenetic origin.

c) Alteration

1) The dolomite is sedimentary in origin and has undergone only local and very minor recrystallisation.
2) Quartz grains are only marginally corroded.
3) It may be assumed that the coarse grained mica flakes are the result of potash mobilisation but probably not of external origin.
4) No ore minerals are present.
5) No kaolinisation has taken place.

d) Origin

The rock is the product of chemical precipitation of dolomite, possibly with magnesite. Very minor, fine grained quartz and feldspar are detrital clasts. Coarse grained phlogopite is almost certainly derived from the reaction of potassium, silica and alumina in aqueous solution with the magnesium of the carbonate. The constituents may all have been derived internally, possibly in part from the scattered detrital feldspar.

Specimen B129, 6630 RS 228, TS C42000

Rock name: Dolomite

Hand specimen:

The specimen is a dense, fine grained, pinkish brown dolomite with well-marked, regular bedding. It is highly fractured and some fractures carry whitish quartz and clay.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 95 |
| Quartz | 5 |
| Kaolinite | Trace |
| Limonite | Trace |
| Organic matter | Trace |

b) Texture

The dolomite is bedded in regular planes. The beds are marked partly by grain size changes, partly by lines of cavities and partly by bands of slightly darker colour due to a small amount of interstitial organic matter. These cryptalgal laminates are typical of dolomite deposited between stromatolitic reef structures.

Quartz occurs as corroded grains in beds between the fine grained dolomite layers, as rare, scattered, fine grains within the dolomite and in a few discordant structures such as sub-spherical patches and in fractures. The coarse grained quartz in patches within the dolomite may be evidence of silica replacement of dolomite but, since the quartz is itself corroded, the dolomite subsequently replaced some quartz.

White kaolinitic clay fills parts of the network of fractures that cut the specimen. Other fractures carry dolomite, quartz and limonite.

c) Alteration

1) Minor mobility of carbonate is indicated by coarse grain size in discordant structures and by the minor replacement of quartz.
2) Some of the quartz may be of replacement origin and quartz has been itself replaced.
3) Potash metasomatism has not been observed.
4) No ore minerals were observed.
5) Mobility and probable introduction of kaolinite from sources external to the specimen has been recorded but the quantity of kaolinite involved is minor.

d) Origin

The rock originated as a carbonate sediment, mostly from chemical precipitation, with minor intervals of clastic sedimentation. Subsequent chemical interaction was quantitatively insignificant but included kaolinite which may be related to the process of copper mineralisation.

Specimen B130, 6630 RS 229, TS C42001

Rock name: Sandy dolomite

Hand specimen:

The specimen is a pinkish grey, fine grained rock with a regular, though not strongly accentuated, bedding and dark patches of glassy quartz. The weathered surface is stained orange except for the dark spots. Discordant fractures are marked by white, yellow and brown filling and by bleaching of the wall rock.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 75 |
| Quartz | 15 |
| Phlogopite | 5 |
| Limonite | 5 |
| Feldspar | Trace |

b) Texture

The bedding is seen to be less regular under magnification than it appears in hand specimen. Bedding planes are not sharply defined, and are undulating and discontinuous owing to abundant discordant structures. Pods of recrystallised quartz, which may have originated as sedimentary clasts, have expanded into the dolomite each side of the original sandy layers, in some instances bridging the gap between two such layers. Some pods of quartz, coarse grained dolomite and phlogopite mica occur in layers of fine dolomite and appear to be purely the result of recrystallisation without any sedimentary nucleus.

Some fractures occur along bedding planes but most are discordant. They contain limonite, minor quartz and fine phlogopite.

Quartz occurs as recrystallised, coarse grained mosaics along bedding planes, in discordant pods, as very fine grained detrital clasts surrounded by fine grained dolomite and very rarely in discordant fractures. The mosaics exhibit textures close to physical equilibrium but replacement of quartz by dolomite is widespread.

Phlogopite occurs along some bedding planes but probably not as a detrital constituent, scattered through the fine grained dolomite where it possibly is original and, most abundantly in discordant structures such as fractures and pods of coarse quartz and dolomite. Flakes are rarely as much as 0.5 mm long.

The abundance of feldspar may have been underestimated. Only a few grains of both plagioclase and microcline have been positively identified but many grains with a rectangular outline and low birefringence may be untwinned feldspar.

Limonite is relatively abundant as fine grains along bedding planes, probably pseudomorphous after pyrite, as patches in the fine grained dolomite and as the filling of fractures, often in close association with phlogopite.

c) Alteration

1) Somewhat higher mobilisation of dolomite has taken place in this rock than in the other specimens collected on this traverse. Coarse grained dolomite occurs in substantial patches. Dolomite replacement of quartz is common.
2) Quartz is more abundant and shows evidence of higher mobility in this specimen than in the others collected on this traverse. The introduction of some silica from an external source is possible.
3) There is evidence of potash metasomatism in the moderately abundant phlogopite. Much, if not all, of this is probably introduced and the close association of phlogopite and limonite in discordant structures is significant.
4) No ore minerals were recognised in transmitted light but the nature of the opaque minerals and the copper content of the oxide in the veinlets would be of interest.
5) No kaolinite was identified but the introduction of mica may be evidence of a related process.

d) Origin

While the rock certainly originated as a sediment, the influence of post-depositional processes with a possible origin external to the specimen is becoming apparent as the sampling traverse approaches the ore zone in the Burra open cut.

Specimen B136, 6630 RS 235, TS C42002

Rock name: Dolomite stromatolite

Hand specimen:

The strongly arcuate banding round two adjacent arches indicates clearly that the specimen is part of a stromatolitic reef. Individual bands are sharply outlined by changes in colour from slate grey to light pink. Radial fractures are common.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 98 |
| Quartz | 1 |
| Feldspar | Trace |
| Limonite | 1 |
| Calcite | Trace |

b) Texture

The distinction between grey coloured and pink coloured bands is partly that the grain size of the dolomite is, respectively, fine and coarse, and partly that the fine grained dolomite includes more interstitial organic matter than the coarse grained dolomite.

Quartz occurs along a few beds and as a few discordant pods. It has been coarsely recrystallised and marginally corroded.

A very few fine feldspar grains are probably detrital in origin.

A few fine grains of limonite, probably pseudomorphous after pyrite, occur in the dolomite bands. A little amorphous limonite occurs in some discordant structures.

Discordant fractures sometimes carry coarsely recrystallised dolomite but more often are empty or filled with limonite.

c) Alteration

1) A little recrystallisation of sedimentary dolomite has taken place and very minor amounts of quartz have been replaced.

2) Quartz has been recrystallised and marginally corroded by dolomite.
3) No potash metasomatism was observed.
4) No ore minerals were identified.
5) No kaolinitisation was observed.

d) Origin

The sedimentary origin of this lithology is undoubted. Little modification of the original rock has occurred and there is no evidence of the introduction of any material from an external source.

Specimen B143, 6630 RS 242, TS C42003

Rock name: Feldspathic mudstone or tuff

Hand specimen:

The rock is fine grained, friable and impregnated with iron oxide. It appears to be irregularly bedded but the weathering is too deep for many features to be discerned. The chip from which the thin section was cut, after impregnation with epoxy resin, has taken a widely pervasive yellow stain after treatment with sodium cobaltinitrite.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Clay | 40 |
| Quartz | 15 |
| Feldspar | 20 |
| Mica | 10 |
| Limonite | 10 |
| Black opaque mineral | 5 |

Both shaley and silty facies are present and modal estimates are particularly imprecise. The black opaque mineral may be manganese oxide.

b) Texture

The silty and shaley facies are juxtaposed in an irregular manner and only one of the silty beds shows an approximation to a regular, finely laminated texture. Junctions between facies are outlined by limonite and over the section as a whole, a pattern of disturbance is displayed. Most of the disturbance can be attributed to soft sediment structures rather than post-lithification alteration. There is ample evidence of the corrosion of solid quartz but these reactions affected individual grains and patches of mosaic quartz without mobilising the rock as a whole.

The quartz occurs in fine grains which are probably detrital and in elongated patches of more coarsely recrystallised quartz mosaics. Some of the elongated patches were probably parts of continuous veins and it seems likely that the replacement of some quartz by clay minerals has been complete. Most corrosion of quartz has resulted in embayed margins and irregular grain shapes.

Much of the silt grade detritus is feldspathic. Both microcline and plagiocalse are present, with the former predominating. The yellow stain on the hand specimen is clearly derived from the action of sodium cobaltinitrite on potassium in feldspar and indicates that this may also be the case in specimens where no feldspar can be identified optically and in which the stain has been attributed to sericite or clay. The intensity of the yellow colour in this specimen varies from point to point and indicates that the concentration of microcline is variable. This is confirmed under magnification. In the silty facies in particular, some areas are composed almost entirely of feldspar, with microcline predominating, with very little interstitial clay and a few grains of quartz. In other areas both quartz clasts and interstitial material such as clay, sericite and limonite are much more abundant.

The mica is a poorly crystalline muscovite and occurs both as detrital flakes and as fine, sericitic matrix material. Much of it is obscured by limonitic stain.

Limonite occurs as fine, round grains which are probably pyrite pseudomorphs, as patches, stringers and continuous bands along fractures and sedimentary surfaces and as a pervasive stain which makes the whole rock pinkish brown.

The black, opaque material is mainly interstitial and occurs in irregular patches.

c) Alteration

1) No carbonate occurs in the rock.
2) Appreciable mobility of silica occurred but was restricted in scale and probably did not involve any introduction from an external source.
3) The potassium content of the rock is considerable and some of the mica, particularly the interstitial sericite, may be the product of mobilised potash. However, it appears unlikely that potash was introduced from outside the confines of the sample represented by the thin section.
4) No ore minerals were identified.
5) Clay minerals of low birefringence are abundant, particularly in the shale but also in the matrix of the silty facies. Substantial corrosion and replacement of quartz by the clay is evident and it is possible that this was accomplished in part by the introduction of some kaolinitic components from outside the chemical system represented by the sample. No evidence was observed of a major kaolinisation process.

d) Origin

The clastic component of the sediment consists of poorly sorted, fine detritus in which feldspars, and particularly microcline, are abundant. The matrix of the silty facies and the substance of the shale is composed of fine clay and sericite. The feldspars are fresh and only a little reworking of the sediment is evident. While no definitive evidence such as glass shards or crystal splinters can be exhibited, there is a strong weight of evidence to suggest a volcanic source for the sediment. Many features are compatible with an origin as an ash cloud containing crystal and vitric fragments followed by rapid dumping into water with little current activity. With almost direct origin as a pyroclastic sediment, the specimen may be termed an ash fall, crystal, vitric tuff.

Specimen B145, 6630 RS 244, TS C42004

Rock name: Dolomite with a stromatolite

Hand specimen:

The specimen is composed of fine grained, pink dolomite and includes two distinct types of sedimentation. At each end is a section with fine, plane, regular bedding. In the centre is a mass in which banding is coarser and arcuate and which is clearly a stromatolite.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 100 |
| Quartz | Trace |
| Limonite | Trace |
| Organic matter | Trace |

b) Texture

The dolomite is mainly fine grained but slightly coarser grained facies occur in roughly arcuate bands and in patches which are discordant to the banding.

Quartz does not occur in bands or patches but only in scattered, corroded grains included in the massive fine grained dolomite.

Limonite occurs as fine grains after pyrite and as irregular patches and fracture filling. Some of the frequent cavities are lined with amorphous limonite.

c) Alteration

Alteration is limited to minor recrystallisation of dolomite, corrosion of quartz and redistribution of iron.

d) Origin

The specimen orginated as a chemical sediment partly trapped in the algal mats of a stromatolitic reef. The lithology is very little altered from its original state.

Specimen B147, 6630 RS 246, TS C42005

Rock name: Siliceous dolomite

Hand specimen:

The rock is a pink, fine grained dolomite with a rather weak bedding in which substantial quartz occurs in stringers along the bedding and large patches superimposed on the bedding.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite or magnesite | 60 |
| Quartz | 40 |
| Kaolinite | Trace |
| Limonite | Trace |
| Calcite | Trace |
| Black opaque material | Trace |

b) Texture

The thin section includes only the stromatolitic part of the hand specimen and bedding traces are broad and somewhat irregular. The fine grained material is dark in plane light but this appears to be more the result of edge effects in material of high refractive index than of the presence of interstitial organic matter. The carbonate may be magnesite rather than dolomite. Coarse grained carbonate occurs with quartz in both conformable and discordant structures.

The quartz of this carbonate specimen is distinctive in that much of it is fine grained. In some siliceous patches a range of grain sizes is present with quartz fine enough to be derived from a recrystallised chert interstitial to, or forming separate bands with, much coarser quartz. Both fine and coarse quartz appear to form mosaics in textural equilibrium. Quartz occurs in discordant fractures.

Kaolinite is not abundant but is present in two modes of occurrence. It fills the outline of rectangular crystals within the mass of fine carbonate. It may be an alteration product of feldspar in this situation. It also occurs in coherent lenses and patches in the coarse grained quartz-carbonate bands. In some instances it appears to be a cavity filling, in others it may be an alteration product of solid minerals.

Limonite occurs as a few scattered fine grains, probably after pyrite, but more abundantly as the filling of discordant fractures.

The black opaque mineral is patchy in occurrence and largely interstitial.

Calcite is very rare and occurs as scattered crystals within the mass of carbonate.

c) Alteration

1) Coarse grained carbonate in discordant structures is presumably the product of recrystallisation. Coarse carbonate in patches which are part of a bedding plane are possibly detrital but even in this situation some recrystallisation is likely. The accompanying quartz is at least party recrystallised and coarse grained beds would provide easier access to solutions than the massive, fine grained carbonate. Both fine and coarse grained carbonate replace silica grains marginally.

2) Silica has undoubtedly recrystallised in conformable structures and may be assumed to have been mobilised to fill discordant structures. The ultimate origin of most of the quartz is almost certainly detrital, some possibly in colloidal form. In the discordant structures however, it seems likely that some silica may have been contributed from external sources.

3-4) There is no evidence of potash metasomation or of ore mineralisation.

5) Some kaolinisation may have taken place in situ as an alteration process acting on existing minerals but some kaolinite has been carried into open cavities and may be, at least partly, of external origin.

d) Origin

Following an undoubted sedimentary origin some re-arrangement of detrital constituents took place and it is possible that a moderate amount of both quartz and kaolinite may have been added to the rock from an external source.

The main point of interest is the evidence that silica may possibly be deposited as a colloidal precipitate in the same conditions of low current velocity in which the carbonate precipitated. It is not necessary to propose a high current energy bringing in coarse quartz detritus since the amount of recrystallisation which is seen to occur can produce a coarsely recrystallised mosaic from fine colloidal silica. The only factor which is then necessary to change in order to precipitate silica rather than carbonate is the pH of the evaporating aqueous solution.

Specimen B150, 6630 RS 249, TS C42006

Rock name: Dolomite

Hand specimen:

The rock is a pinkish dolomite with coarse and rather irregular banding. It is probably stromatolitic but the evidence is not conclusive.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 100 |
| Limonite | Trace |

b) Texture

The grain size of the dolomite is uniformly fine and the texture under magnification is massive. The banding seen in hand specimen is produced by interstitial dark brown amorphous material which appears to be limonitic rather than organic. A few cavities are rectangular in shape.

c) Alteration

The only evidence of alteration is the dissolution of an unknown mineral to produce cavities with the outlines of former crystals.

d) Origin

On petrographic evidence the rock is of sedimentary origin and has undergone almost no subsequent modification.

Specimen B155, 6630 RS 254, TS C42007

Rock name: Sandy dolomite

Hand specimen:

The rock is a pink and grey dolomite with deep pink stain on the weathered surfaces. The sediment is finely bedded with regular pink, white and grey bands. Traces of cobaltinitrite stain are visible on the chip.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 90 |
| Quartz | 10 |
| Feldspar | Trace |
| Limonite | Trace |
| Organic matter | Trace |
| Calcite | Trace |

b) Texture

The fine bedding is marked by grain size variation in the dolomite, by discontinuous bands of quartz grains and by variations in the density of faint, interstitial organic staining.

The dolomite is fine grained but slightly varied in grain size. In bands containing quartz grains it is a little coarser and in other bands it is extremely fine grained.

Quartz occurs as isolated grains in the dolomite, as discordant patches, as partial filling for rectangular solution cavities and, most abundantly as grains and patches along bedding planes. The patches are mosaics in textural equilibrium. The grain size of quartz grains is substantially coarser than that of the dolomite. Most grains are corroded and partially replaced by dolomite.

Feldspars are rare and are mainly microcline. The grains tend to be better shaped than the quartz and have undergone less corrosion.

Limonite replaces almost euhedral cubes of former pyrite and fills discordant fractures, penetrating the walls with a rusty brown stain in places.

Organic matter forms a grey background to the dolomite by filling interstial spaces with a black stain which varies in intensity from place to place.

Calcite is very rare as scattered grains and partial linings to open cavities.

c) Alteration

1) The minor increase in grain size of dolomite in beds rich in quartz may be the result of a rather weak recrystallisation but may be an original detrital feature. Quartz has been marginally replaced by dolomite.
2) The evidence suggests minor mobility in the quartz content of the rock. Existing detrital quartz has been recrystallised and silica has been redistributed into a few discordant patches.
3) The few crystals of microcline present are too well-shaped to be detrital and are probably the product of very slight potash metasomatism. It is possible, however, that no potassium was added to the system.
4) No ore minerals were identified.
5) No kaolinisation was recognised.

d) Origin

The sediment is not stromatolitic but deposition was influenced by algal organisms. It may be described as a cryptalgal laminated dolomite. Subsequent events modified the distribution of silica, iron and potash but if any material of external origin was added to the system, it was of very minor significance.

Specimen B161, 6630 RS 260, TS C42008

Rock name: Dolomite

Hand specimen:

The rock is a pinkish dolomite but the weathered surface tends to be rusty brown with dark spots and dendritic patches. These are probably manganese oxide. The sediment is bedded but the fabric is poorly defined. The sawn chip displays fractures, some of which contain black amorphous material.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 95 |
| Feldspar | 4 |
| Quartz | Trace |
| Kaolinite | 1 |
| Limonite | Trace |
| Black opaque material | Trace |
| Calcite | Trace |

The feldspar displays simple Carlsbad twinning but extinguishes sharply in a way which is not typical of orthoclase. Rare grains display polysynthetic albite twinning and there is no evidence of cobaltinitrite staining on the chip from which the section is cut. The mineral is optically negative. The one crystal in which symmetrical extinction can be measured indicates a composition between oligoclase and andesine but the angles measured may not be the maximum extinction angles. It is concluded that the feldspar is probably a plagioclase of calcic rather than sodic composition.

b) Textures

The dolomite varies considerably in grain size but not in a regularly bedded manner. Very fine grained carbonate occurs as elongated masses which approximate to beds but are interrupted by areas of coarser grain size. Discordant structures carry coarse grained carbonate. Some of the fine grained material is so dark, without any organic colouration, that it may be magnesite rather than dolomite. Most of the coarse grained carbonate is contained in discordant structures but some fine bands of slightly coarser grain size than the large bands of fine carbonate may mark relict bedding traces.

In one vein which also contains kaolinite many rhombic outlines with a zoned internal structure contain patches of both clay and carbonate. These may be pseudomorphic relics of carbonate crystals which grew in hydrothermal solutions in conditions which fluctuated between those favouring precipitation and those promoting solution of the carbonate. The final balance was towards dissolution.

The plagioclase occurs almost exclusively as subhedral crystals in one system of branching fractures. The veins also contain minor quantities of a red-stained material which is believed to be kaolinite rather than calcite. A few plagioclase crystals occur within the main mass of fine carbonate and may originally have occupied rare cavities with a rectangular outline.

Quartz is present only as a few scattered, highly corroded grains in the fine dolomite.

Kaolinite has been introduced in several discordant veins and in one place forms a mass about 2 mm long. This is the same area in which the relict zoned outlines of carbonate crystals are seen. The kaolinite is interstitial to the pseudomorphs and solutions depositing the kaolin may have been responsible for the final dissolution of the carbonate.

Limonite forms pseudomorphs after pyrite and fills discordant fractures with an irregular zone of staining in the wall rock.

The black opaque material occurs in discordant fractures and appears to be genetically related to but to post date the kaolinite and possibly the calcite in the same fracture systems. It may be the same material that forms the dendrites on the surface of the specimen and is probably a manganese oxide.

Calcite occurs in one fine veinlet with kaolinite, limonite and the presumed manganese oxide.

c) <u>Alteration</u>

1) Mobilisation of carbonate has proceeded further in this specimen than in the dolomites described from the upper levels in the east and north of the pit. Recrystallised and coarse grained dolomite forms discordant patches and veins of appreciable size and more than one episode of recrystallisation has taken place. There is no evidence that any of the carbonate involved in these reactions originated outside the system but the evidence is strong

that the reacting solutions themselves were external in origin.

2) The virtual absence of quartz may reflect an almost exclusive carbonate sedimentation but may be the result, wholly or in part, of replacement of quartz by carbonate at the diagenetic stage or in later mobilisation.

3) Potassium minerals appear to be missing from the paragenesis but the evidence is overwhelming that plagiocalse has been introduced to the system, probably in hydrothermal solution. The origin of this is obscure but a rock of magmatic derivation described in SADME Petrology Report 83/28 (specimen B285) contained plagioclase phenocrysts of similar composition to the single crystal measured in this specimen, sodic andesine to calcic oligoclase.

4) No ore minerals were recognised.

5) Kaolinisation is more advanced in this specimen than in specimen B147 and is associated with solutions introduced in discordant fractures. It is not as advanced as in specimens from deeper in the pit and closer to the copper mineralisation. The relative positions of the samples suggest that a zone of kaolinitic alteration is associated with the mineralisation and the textural features suggest that the alteration is produced through discordant structures from a source external to the system represented by the thin section. Kaolinisation is not simply a diagenetic process.

d) Origin

The origin of the rock is sedimentary, as a chemical carbonate precipitate, possibly stromatolitic, but subsequent processes have modified it. The mobility of the carbonate is greater than that observed in specimens subjected only to diagenetic changes and the evidence of both plagioclase and kaolinite as introduced species along discordant structures suggests the influence of hydrothermal solutions with a source possibly related to the porphyritic igneous rock collected from the ore pile.

The black, possibly manganiferous, material, limonite and calcite are probably derived at a late stage and a low temperature, possibly as the products of weathering.

Specimen B240, 6630 RS 336, TS C42009

Rock name: Coarse, micaceous sandstone

Hand specimen:

The specimen is a light rusty brown colour and very friable. It has an irregular bedding marked by bands of coarse quartz grains. The intervening bands, and the matrix of the quartz are composed of a fine grained, crumbly, platy mineral stained with iron oxide. Careful scrutiny of the chip reveals that a few scattered grains have been stained yellow by sodium cobaltinitrite.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Quartz | 40 |
| Mica | 50 |
| Limonite | 10 |
| Feldspar | Trace |
| Kaolinite | Trace |

b) Texture

The main fabric is composed of alternating bands of quartz in grains and patches of mosaic and bands of a mica which is colourless apart from limonite staining. Quartz grains are up to 1 mm across and the patches of quartz mosaic are up to 4 mm across. The mica occurs in closely packed and strictly oriented masses of flakes about 0.2 mm long. The orientation is corrugated and flow structures round quartz grains suggest that the whole mass was at one time relatively mobile. The time was later than the major period of recrystallisation of the quartz and many quartz grains and patches exhibit marginal corrosion and replacement by mica. At least part of the silicification post-dates the formation of mica, however. In a few patches of quartz the grains include small mica flakes. Some of the quartz grains are isolated and it is not possible to see the extent of recrystallisation and corrosion by the surrounding micaceous phase. Both are probably considerable. Where quartz has grown into an interlocking mosaic it is seen to have reached textural equilibrium. Subsequent corrosion by solutions from which the mica was precipitated is seen to take place along the margins of exposed grains and to penetrate the mosaic patches along grain boundaries, along fractures and by enlarging the marginal embayments.

In some places the phase which is seen to have penetrated the quartz patches to the deepest extent is kaolinite. Kaolinite is not abundant but is significant in that, on this evidence, it may be a precursor to the mica. On this basis the mica is then seen to be at least in part the product of potash metasomatism. Evidence that some part of the potassium may have originated within the chemical system represented by the rock seen in thin section is formed in one patch in the section. Here the paragenesis is quartz, kaolinite and rare feldspar. Surrounding the patch a mass of mica has been frozen in a stage of encroachment into the quartz-kaolinite paragenesis in which the mica appears along grain boundaries of quartz and through interstitial patches of kaolinite. The feldspar is largely microcline but among the rare grains are a few that may possibly be plagioclase. Apart from this one area the feldspar is limited to a very few highly corroded relics of indeterminate composition among the mass of mica.

Limonite occurs as pseudomorphs after pyrite and as patches of rusty brown stain. There is also a light brown limonitic stain which pervades the micaceous facies with varied intensity.

c) Alteration

1) There is no carbonate in the rock.
2) Some of the silica was probably contributed to the sediment as detrital quartz or chalcedony but the size of patches of mosaic quartz suggests that much of the silica involved in recrystallisation processes was introduced from outside the specimen. There was either a series of recrystallisation episodes or a continuous process which overlapped with the formation of muscovite mica.

3) Although some of the potassium combined in muscovite originated in potash feldspar, the greater part of it almost certainly originated from an external source. It appears from textural evidence that the mica was emplaced by the potash metasomation of kaolinite.

4) No ore minerals were recognised.

5) On the evidence of the one patch in which mica has not completely replaced kaolinite, the clay formed a paragenesis with quartz and feldspar which was not quite an equilibrium assemblage. Kaolinite forms a matrix to the quartz and feldspar framework but had embayed the framework minerals to a relatively minor extent. The kaolinite may have been a component of the original sediment and the embayment may have occurred during diagenesis. However, the textural evidence is inconclusive on this point and the kaolinite may have been introduced from outside the rock, either wholly or in part.

d) Origin

The present form of the lithology owes more to alteration processes than to the original sedimentation. Both silica and potassium appear to have been introduced from a source external to the specimen and kaolinite may also be at least partly of metasomatic origin. Substantial remobilisation of quartz has occurred and muscovite mica has replaced a large proportion of the original sediment.

Specimen B241, 6630 RS 337, TS C42010

Rock name: Ferruginous shale

Hand specimen:

The rock is pale grey, soft, finely bedded and very fine grained but the specimen is mainly a brick red colour due to impregnation with iron oxide. The colour is uneven and on the cut surface can be seen to have penetrated adjacent beds differentially and to have been sealed off by a vein system at one point. The introduction of oxidised iron is clearly a late stage phenomenon and, since the specimen was collected from the edge of the pit close to the present land surface, may be a product of weathering.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Clay | 60 |
| Quartz | 15 |
| Feldspar | 10 |
| Mica | 5 |
| Limonite | 10 |

b) Texture

The clay is of low birefringence and is probably kaolinite. Both clay and mica are strongly oriented to produce a finely bedded fabric and are probably of sedimentary origin. The mica flakes are up to 0.2 mm long and may have been enlarged by recrystallisation subsequent to deposition. The clay may also have undergone recrystallisation but has not developed a coarse grain size. Some patches of clay are discordant to the bedding.

Quartz occurs as fine detrital grains with an irregular shape which is probably a product of reaction with the clay matrix. Quartz also fills a few discordant veinlets which cut across the section.

Both plagioclase and microcline are present but the feldspars are rarely fresh enough for conclusive identification. The rock chip from which the thin section was cut shows virtually no stain from the sodium cobaltinitrite treatment and either the feldspar is dominantly plagioclase or visual estimation has exaggerated its abundance.

The limonite stain is variable in density and includes patches marked by a centre of light colour surrounded by a zone or zones in which the oxide pigment has been concentrated.

c) Alteration

The only conclusive evidence of changes in the constituents of the rock subsequent to sedimentation is related to the movement of quartz into veinlets and the penetration of the rock by oxidised iron.

Small changes to the clay minerals and the mica are possible but the fine grain size and the iron staining make the evidence uncertain.

d) Origin

The rock originated as a fine grained, non-carbonate sediment in the Skillogallee Dolomite. It has apparently escaped major recrystallisation and the only alteration in evidence is probably related to the weathering action of groundwater solutions.

Specimen B244, 6630 RS 340, TS C42011

Rock name: Dolomite

Hand specimen:

The specimen is bounded by plane surfaces, one set of them parallel, but no evidence of bedding can be identified. The surfaces of the specimen may be joint planes or there may be a cryptic bedding in what appears to be massive, fine grained dolomite. Parallel fractures are visible on the cut surface. Well shaped dendrites of black, probably manganous, material decorate the joint surfaces.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 95 |
| Quartz | 3 |
| Limonite | 2 |
| Clay | Trace |
| Calcite | Trace |

b) Texture

Under magnification a very faint bedding is detectable through a weak preferred orientation of quartz patches. The major structures in the massive, fine grained dolomite are fractures.

The quartz occurs as irregular and highly corroded grains and patches of mosaic of moderate grain size. Coarser grained quartz occurs discontinuously in a network of fractures and in places has grown outwards by replacing the surrounding dolomite to form lenticular pods.

Frequent fine grains of what is now a limonitic iron oxide were probably originally sulphide, probably pyrite.

Many cavities of regular outlines are distributed throughout the dolomite without any apparent consistent orientation. The shapes are prismatic, rectangular and diamond shaped and usually are partially filled with fine clay minerals. The shapes are probably those of an evaporite mineral deposited with the dolomite and subsequently removed in its entirety due to a high solubility. Gypsum is probably the most likely evaporite mineral but in view of the high magnesium content of the sedimentary environment, the highly soluble magnesium sulphate, epsomite is possible as a transient precipitate.

Calcite occurs in one fine veinlet.

c) Alteration

The replacement on a small scale of dolomite by silica and the subsequent very minor replacement of quartz by dolomite again are the only significant replacement processes. Dissolution of evaporite minerals and the introduction of small amounts of clay into the solution cavities are extremely minor in importance and may have occurred soon after lithification of the dolomite.

d) Origin

The sediment originated as a massive precipitation of dolomite from solutions which became supersaturated due to evaporation. Only minor changes took place subsequently to sedimentation.

Specimen B257, 6630 RS 353, TS C42012

Rock name: Laminated grey dolomite

Hand specimen:

The rock is finely banded in shades of grey. A broken face of the specimen is spotted with small dendritic patches of black material, probably manganiferous, and only a coating of red iron oxide on a weathered surface is of the colour which has characterised most of the dolomite described here so far. The laminations are plane, without any evidence of stromatolitic structures. The rock is a cryptalgal laminated dolomite.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 99 |
| Quartz | 1 |
| Feldspar | Trace |
| Opaque material | Trace |
| Organic matter | Trace |
| Calcite | Trace |

b) Texture

The finely bedded texture is produced mainly by grain size variation in the dolomite. There is a tendency for the finer grained dolomite to be darker than the slightly coarser beds. This is partly due to edge effects on light scattering but the organic content of the finer beds is somewhat higher than that of the coarser beds. This is doubtless due to the proportionately higher area of intergranular surfaces and reinforces the darker colour of the finer grained beds.

A few fine cracks cut the dolomite fabric.

Quartz occurs as detrital grains and is coarser and more abundant in the coarser grained bands of dolomite. Grain shapes have been modified by minor corrosion.

The only feldspar grains recognised are a few fine microcline clasts.

The opaque material listed includes both the very fine grained pseudomorphs after pyrite which tend to be concentrated in the darker bands and a patchy opaque material which is interstitial and occurs in fine fractures. The former is probably an iron oxide but the latter may include manganiferous material.

c) Alteration

The alteration of the rock is minimal and consists of a little corrosion of quartz, the replacement of pyrite by limonite and the possible introduction of a little manganese.

d) Origin

The rock is a cryptalgal laminated dolomite of sedimentary origin.

Specimen B274, 6630 RS 370, TS C42013

Rock name: Feldspathic siltstone or tuff

Hand specimen:

The rock is very fine grained but is too gritty to justify the name of shale. A fine bedding can be distinguished with some difficulty in the specimen. Quartz veinlets cut the rock and a red brown stain pervades the whole fabric. The chip from which the section was cut has taken a deep, continuous yellow stain after treatment with sodium cobaltinitrite.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Potash feldspar | 40 |
| Plagioclase | 5 |
| Mica | 20 |
| Clay | 5 |
| Quartz | 10 |
| Translucent brown mineral | 15 |
| Limonite | 5 |

Very little feldspar can be recognised visually in the matrix of the rock. The high percentage of potash feldspar listed is based purely on the depth and continuity of yellow colour on the stained surface of the chip.

b) Texture

The most prominent mineral under magnification is a sericitic mica and it is the preferred orientation of this mineral that gives the rock its weakly bedded texture.

The matrix of the rock consists of minerals of low birefringence which are mainly too fine grained to be identifiable. Occasional crystals of microcline and rarer plagioclase are recognised but the assumption that most of this material is potassium feldspar is based on the response of the rock to treatment with sodium cobaltinitrite.

Some of the platy minerals are of low birefringence and are probably clays rather than micas.

Quartz occurs as isolated crystals of detrital origin and small patches of intergrown mosaic in the matrix of the sediment. Quartz also occurs in two types of discordant structures. A vein of varied width cuts the specimen and contains quartz of very varied grain size. In the wide parts of the vein the quartz grains are up to 2 m across but in patches at the margins of the thinner parts of the vein the grains are only a few microns across. Quartz also occurs in scattered patches with irregular masses of limonite.

Brown, translucent material with a high refractive index is an important constituent of the rock. It is often isotropic but some of it shows high birefringence. Because of the strong colour of the mineral the optical properties displayed are insufficient to identify it. More than one mineral may be involved or the variation may be the result of a varied degree of crystallinity in the same mineral. The material occurs as small, scattered patches, which may be replacement products of pyrite, and as a crystalline or partly crystalline margin to coarse grained, irregular masses of amorphous limonite. The close association with iron minerals suggests that the unidentified material may be an alteration product of pyrite, such as jarosite, or possibly a somewhat oxidised siderite.

It is assumed that the irregular patches of limonite mentioned above are replacing an iron sulphide, probably pyrite, which has been concentrated into coarser grained masses than the dispersed grains which were probably the original form of the mineral.

c) <u>Alteration</u>

1) Unless the unidentified brown mineral is in fact siderite, carbonate is absent from the rock.
2) Mobility of silica is evident in the mosaic quartz patches in the matrix, the discordant quartz vein and the patches in which quartz is associated with limonite and possible jarosite.

3) On the chemical evidence of the cobaltinitrite stain and on the optical identification of both sericite and microcline the potassium content of the rock is high. The depth and continuity of yellow colour in the stained chip indicates that potash feldspar is by far the most important component of the matrix. Some of the mica may be an alteration product of the microcline but the dominantly consistent preferred orientation indicates that most of it is an original sedimentary constituent of the rock. There is no textural indication that the microcline did not originate in the same way. The potash content of the rock appears on this evidence to be original and not the product of potash metasomatism.

4) Although no copper minerals were identified, there is evidence that the iron sulphide was mobile. In most of the specimens examined the only alteration of iron minerals has been the oxidation of what was almost certainly primary pyrite of sedimentary or diagenetic origin. The evidence in this specimen indicates a more active process in which iron was mobilised, with a silica gangue, to produce local concentrations of limonite and possibly jarosite. The process occurred on a small scale but may be related to that resulting in the ore grade concentration of copper elsewhere in the open cut.

5) Kaolinisation does not appear to have played a part in the genesis of the rock.

d) <u>Origin</u>

There is no petrographic evidence that the rock is more than a fine grained, feldspathic sediment in which rather minor redistribution of some constituents has occurred. The evidence of the intense sodium cobaltinitrite stain indicates that the content of potash feldspar is anomalously high. With no evidence of potash metasomatism it is almost inescapable that the most likely origin for a sediment of this composition is as a distal, ash-fall, crystal, vitric tuff.

Specimen B275, 6630 RS 371, TS C42014

Rock name: Dolomite with some alteration

Hand specimen:

The rock is a pale buff to cream dolomite in which patches of fine grain size are surrounded by coarser carbonate. Small, irregular black patches are scattered over the broken face. On the cut face the fine grained areas are seen to be fractured and veined by coarser dolomite. The chip from which the section was cut is spotted with yellow patches marking the position of dispersed potash feldspar grains.

Thin section:

a) Mode

| Mineral | % Fine | % Coarse |
|---|---|---|
| Dolomite | 95 | 70 |
| Quartz | 2 | 10 |
| Feldspar | 2 | 10 |
| Mica | 1 | 5 |
| Limonite | Trace | 5 |
| Calcite | Nil | Trace |
| Kaolinite | Nil | Trace |

b) Texture

The fine grained patches are massive but penetrated by fine fractures along which a little quartz and microcline have been introduced. Fine flakes of mica have penetrated the massive fabric of the fine dolomite itself. The mica is almost colourless but exhibits a faint light to darker pleochroism. It is probably a phlogopite.

The coarser grained dolomite does not exceed 0.3 mm and forms irregular and linear masses surrounding and penetrating the more coherent fine grained masses. It is closely intergrown with quartz grains up to 0.8 mm across, quartz mosaic patches up to 2 mm across and thin laths or plates of feldspar up to about 0.7 mm long. Where the feldspar has a recognisable twin pattern it is a microcline but is distinct from the microcline identified as clasts in sediments described earlier in this report. Detrital microcline tends to have a polysynthetic, cross-hatched twinning of varied but appreciable regularity. The microcline of specimen B275 is twinned in a patchy, very irregular and varied manner. It is of the type identified by X-ray diffraction in specimen B51 as a strongly triclinic, low temperature microcline (RB 83/28 p10).

Both quartz and microcline exhibit marginal corrosion and replacement by dolomite, the quartz to a greater extent than the microcline. In the earlier report this was taken as evidence of a hydrothermal dolomitisation at a late stage in the history of the rock. Examination of dolomitic sediments without evidence of external hydrothermal influence has shown that a late remobilisation of dolomite is a common phenomenon which may be entirely isochemical, quantitatively insignificant and unrelated to any mineralisation.

Pseudomorphs after pyrite are present but not abundant in the fine grained dolomite. Limonite has been concentrated into some fractures and into irregular patches in areas of coarse dolomite and quartz.

Some of the carbonate in the coarser patches has taken a faint pink stain from the dye alizarin red. The colour probably denotes a higher than average calcium content in scattered dolomite grains rather than the presence of true calcite.

Kaolinite has accompanied quartz and feldspar in some of the areas of coarsely recrystallised dolomite.

c) Alteration

1) Although dolomite has probably been neither added to nor subtracted from the original sediment, the extent of recrystallisation is greater than in the sedimentary dolomites beyond the range of mineralising solutions.
2) The areas in which quartz occurs are structurally controlled. The fine grained dolomite contains little or no quartz which could be ascribed to sedimentary sources. It seems likely that silica has been added to the dolomite. However, the extent of silicification is limited.
3) The strongest evidence for the addition of material to the dolomite is that relating to potassium. The textural evidence appears conclusive that both potash feldspar and mica, in the form of microcline and phlogopite respectively, have been added to the dolomite from a

source external to the immediate area represented by the specimen. The fine grained dolomite has been penetrated by watery solutions which precipitated a magnesium-rich mica while the coarser grained dolomite was invaded by a low temperature potash feldspar.

4) No copper minerals were recognised and only minor redistribution of pyrite, now altered to limonite, occurred.

5) Minor kaolinite appears to have accompanied the silica and potash.

d) Origin

The rock originated as a sedimentary dolomite. The sedimentary phase is now represented by the fine grained, massive dolomite. The massive material has been fractured, invaded and largely replaced by coarser dolomite. The process is not severe enough to be a tectonic brecciation but conversely is post-lithification in age and cannot be interpreted as a soft sediment, intraformational brecciation.

The fairly substantial recrystallisation was accompanied by the introduction of silica, alumina, potassium and water which precipitated quartz, phlogopite, microcline and a little kaolinite.

Specimen B292, 6630 RS 388, TS C42015

Rock name: Dolomite

Hand specimen:

The rock is a fine grained, grey dolomite which is massive apart from a weak, irregular banding marked by crenulated, non-planar and sub-parallel lines of brown grains. On the chip from which the section was cut, staining with sodium cobaltinitrite has revealed that a few of the irregular bedding traces are also outlined by the yellow colour which identifies potassium feldspar. A few fractures filled with quartz cut the sample.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 95 |
| Quartz | 5 |

| | |
|---|---|
| Feldspar | Trace |
| Kaolinite | Trace |
| Limonite | Trace |
| Calcite | Trace |

b) Texture

The dolomite itself is massive in texture. The weak bedding is revealed only by lines of fine grained limonite after pyrite and, less commonly by linear patches of scattered and highly corroded feldspar grains. Mobility in the dolomite must have been considerable, although this is not indicated by any increase in grain size. Both quartz and feldspar are strongly corroded and in places almost totally replaced. Replacement of quartz by dolomite persisted until after the formation of quartz veins as some of the quartz grains are separated by dolomite which has penetrated the contacts between them. Coarse dolomite occupies the whole of a vein at one point.

The quartz of the quartz grains is often in long crystals which are sometimes bent. It may have developed from chalcedonic silica.

The feldspar is not always identifiable optically. It is at least mainly microcline and displays a twin pattern that, if not always clearly cross-hatched, at least is polysynthetic. It is of the type formed as detrital grains in the Burra rocks rather than as metasomatic replacement products.

Kaolinite occurs in small patches throughout the rock but is particularly concentrated in the pyrite-rich bands. It commonly fills the spaces left open after the dissolution of an earlier mineral, probably quartz but possibly an evaporite mineral.

Limonite replaces early pyrite and accentuates the pyrite-rich bands by spreading out as a rusty brown stain.

Calcite occasionally replaces dolomite grains in the margins of fractures.

c) Alteration

1) As noted above, the dolomite became a replacement phase at least twice in the history of the rock. It replaced sedimentary silicate detritus, probably during

diagenesis, and it corroded quartz at a very late stage, after the emplacement of quartz veins. The process may not have involved any addition of carbonate from an external source.

2) Silica was recrystallised into small patches at an early stage and became mobilised into veins at a late stage in the history of the sediment. The latter process may have involved the introduction of silica.

3) The feldspars were probably detrital and no potash metasomatism was involved.

4) No ore minerals were recognised.

5) A little kaolinite was probably introduced but the nature of the process is not known.

d) <u>Origin</u>

The sediment consists largely of a chemical precipitate of dolomite deposited rather rapidly in highly alkaline conditions. It is probably the high alkalinity which is responsible for the dissolution of silicate detritus deposited sporadically during the carbonate sedimentation and its replacement by dolomite. The late stage mobilisation of dolomite and minor replacement of vein quartz may have been due to increased heat flow, possibly associated with the near-by copper mineralisation.

The small bands of scattered detrital microcline may be the remnants of more abundant silicate deposition, most of which has now been replaced, but may be the product of sporadic minor eruptions at a nearby volcanic centre.

<u>Specimen B293, 6630 RS 389, TS C42016</u>
<u>Rock name</u>: Feldspathic dolomite
<u>Hand specimen</u>:

The rock is a pinkish grey dolomite with yellow brown weathering and a well developed, though somewhat irregular, bedding. The non-dolomitic beds are weathered out at the surface of the specimen and there are a large number of rectangular cavities in the dolomite. Irregular and poorly defined beds are outlined in yellow brown with many open cavities on the surface of the sawn chip. There is no yellow stain on the surface treated with sodium cobaltinitrite. The specimen is strongly fractured.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 75 |
| Plagioclase | 20 |
| Limonite | 5 |

The plagioclase appears to be an andesine on the evidence of symmetrical extinction angles.

b) Texture

The bedding is seen in thin section to be marked by faint linear traces within the dolomite itself as well as by the bands of non-carbonate grains, which in this specimen are composed of plagioclase and pyrite pseudomorphs. The traces in the dolomite are partly of slightly coarser grain size and partly of varied organic content. Although the dolomite is mainly very fine grained, the bedding is irregular and discontinuous due either to soft sediment disturbance or to cross bedding in the fine, chemical precipitate. Rare coarse, euhedral, zoned carbonate grains occur with coarse plagioclase in a few discordant patches.

The plagioclase occurs in four ways. Fine grains are distributed along bands which are conformable with the bedding. Coarser grains occur in bands and patches which are discordant to the regular bedding but may be aligned on cross bedding planes. Other relatively coarse grains occur in bands and patches which coincide with fracture planes. It is not clear whether the fracture preceded the feldspar or vice versa. Finally, the coarsest grains of plagioclase are isolated in areas of fine grained dolomite. These are weathered out to produce the rectangular cavities, up to 3 mm long, which are seen in the hand specimen.

Limonite occurs as euhedral pseudomorphs after pyrite and as a weak brown stain along both conformable and discordant planes.

c) Alteration

1) Some mobility of dolomite is evident in the coarse, euhedral, zoned grains. Some marginal corrosion of plagioclase is evident. If quartz was ever deposited, its total absence would imply vigourous action by the dolomite in replacing it. There is no evidence that quartz was ever present but the majority of the dolomites at Burra do contain it, in however small a quantity.
2) It is purely conjectural that quartz may have been present orginally but has now been completely replaced by dolomite.
3) Potash metasomatism does not appear to have occurred.
4) No ore minerals were recongnised.
5) No kaolinite was identified.

d) Origin

The dolomite originated as a fine chemical sediment. It was deposited in shallow water and the bedding was disturbed by water movement or slumping in the sediment itself.

Much of the plagioclase appears to have been a detrital sediment but some occurs in discordant structures and may have been recrystallised. The very coarse grained plagioclase was possibly produced by growth round a nucleus at a stage in which the sediment was too soft to retain an imprint of being forced aside. The specimen is like B122 in that plagioclase occurs as a detrital mineral but like B161 in that the feldspar is associated with discordant structures and may have been carried in hydrothermal solution. A relationship with both pyroclastic sedimentation and fluids of magmatic origin is possible.

Specimen B294, 6630 RS 390, TS C42017

Rock name: Laminated dolomite

Hand specimen:

The rock is finely laminated by regularly planar beds distinguished by various shades of grey. A few beds are red in colour and a few grey beds are too thick to be strictly laminations. The chip from which the section was cut has responded to sodium cobaltinitrite staining with patches and schlieren of strong yellow colour.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 95 |
| Potash feldspar | 4 |
| Limonite | 1 |
| Quartz | Trace |
| Calcite | Trace |
| Organic matter | Trace |

The percentage given for potash feldspar is based more on the intensity of the cobaltinitrite stain than on visual evidence.

b) Texture

The bedded fabric is produced mainly by grain size variation in the dolomite but differences between beds are emphasised by a varied intensity in colouration by organic matter and by a limonite stain, derived ultimately from the original pyrite content of the sediment. Bedding planes are regular and a stromatolitic origin is improbable. The sediment is cryptalgal.

Grain size variation is rhythmic and very marked. There is a progressive decrease in average grain size upwards. It appears to be entirely of primary sedimentary origin, owing nothing to recrystallisation processes. Over most of the size range there is a consistent inverse relationhsip between the grain size of the dolomite and the thickness of the bed. The relationship only breaks down in the coarsest grain size in which the thickness of the bed is determined by the diameter of individual grains up to 2 mm across. This type of bed consists of single crystals, often zoned and often with euhedral crystal faces projecting from one side of the bed.

An explanation for this texture which is compatible with the proposed depositional mechanism of chemical precipitation from an evaporating body of water is that the form of the precipitate depends on the rate of precipitation. A solid precipitated rapidly from solution is usually of a flocculant texture in which individual particles are of fine grain size and irregular form. A solid precipitated slowly from solution usually forms wellcrystallised grains of coarse grain size and may exhibit perfect crystal faces on the side which grows freely in contact with the solution rather than with other solids. It is the latter feature which provides evidence of the facing of the bed.

The major control of the rate of precipitation is the relationship between the concentration of the solid in solution and the concentration at which the solution is saturated and above which precipitation of the solid out of the solution occurs. Minor controls are the temperature, pH and Eh of the solution, because these factors influence the concentration at which precipitation occurs, that is the saturation point.

It may thus be conjectured that the thick beds of fine grained dolomite were precipitated during hot, dry periods when, because of the high rate of evaporation and absence of an inflow of fresh water, the concentration of dolomite in solution was continuously held well above the saturation point so that rapid precipitation of a thick, formless deposit took place. The much thinner beds of coarser grain size are records of interludes during which reduced evaporation or the inflow of fresh water, or both since they are likely to be connected, brought the concentration of the dolomite solution much closer to the saturation point than the previous high degree of supersaturation. Precipitation was much slower and involved much less material. Crystal forces were given enough time to act on the incoming components to produce well organised lattices in coarser grain sizes.

The bed with the coarsest grain size of all is made up of single dolomite crystals up to 2 mm across. The volume of carbonate contained in the bed is comparable with that in many of the beds of finest grain size. This contradicts the relationship between fine grain size and thick beds which holds for most of the specimen. Many of the grains are bounded by euhedral crystal faces and some are repeatedly zoned. A possible explanation for this is that the very coarse grained beds represent a long period of time, longer than that represented by the thick beds of fine dolomite or the much thinner beds of a grain size between that of the finest and coarsest beds. The zoned structure of many of the very coarse crystals indicates that the concentration of dolomite in solution fluctuated above and below the saturation point and was probably never far from it. The coarsest bed of all lies in an interval of very rapid precipitation with sharp contacts to very fine grained dolomite on each side. A sudden influx of fresh water could create a sharp change from supersaturation to very close to saturation but the change back to supersaturation appears to be equally sudden. It is marked by the direct contact of euhedral crystal faces of the coarse grains with the mass of fine grained dolomite which precipitated on and around them. It is assumed that the euhedral crystal forms indicate an upward facing.

It seems that an alternative explanation to the suggested long period of time and sudden irruption of fresh water may be preferable to account for the coarse dolomite crystals. The zones in zoned crystals are separated by thin bands of brownish material which may be either organic matter or limonite. The bed of coarse dolomite is marked by a somewhat higher concentration of pseudomorphs after pyrite than the average in the specimen. Both these factors indicate that either organic matter or iron sulphide, or both, were precipitated in greater abundance than normal while the very coarse dolomite crystals were growing. Organic matter may have increased the viscosity of the water on the sea floor so that components arrived slowly enough to be incorporated in good crystal lattices. At the same time the decrease in both pH and Eh encouraged the precipitation of pyrite and inhibited that of the mass of carbonate. Instead of the concentration of carbonate in solution controlling the rate of precipitation, the saturation point was raised by the presence of organic matter so that the existing carbonate concentration fluctuated just above and just below the point at which it could precipitate. This explanation covers some of the features not satisfactorily accounted for by the 'influx of water' suggestion and indicates why the coarsest dolomite provides an anomaly in the relationship between grain size and bed thickness.

The potash feldspar is only seen as scattered and corroded fragments and on visual estimation would have been listed as about 1%. The extent of yellow colour on the chip treated with sodium cobaltinitrite suggests a higher feldspar content and the listed figure recognises this. The feldspar appears to be poorly crystalline but is probably a microcline with poorly defined twinning. It appears to be concentrated in the coarser-grained beds but the evidence does not permit a suggestion as to its origin.

Limonite occurs as a pseudomorphous replacement of pyrite grains, as irregular opaque material and as a rather diffuse stain in some fractures and isolated patches.

Quartz has been observed only as a few inclusions in very coarse dolomite. If it were more plentiful it would provide more evidence of a decrease in pH to more acid conditions. The very low abundance of the mineral minimises its significance in this respect.

Calcite occurs as scattered grains and small patches in which it replaces dolomite. It is particularly common in the vicinity of small solution cavities in the dolomite.

The possible significance of organic matter has been suggested. Apart from the possible occurrence between zones of dolomite crystals, organic matter is only observed in thin section as a weak to moderate dark colouration in dolomite beds. It is scarcely visible at high magnification but is probably an amorphous, interstitial kerogen. Some of the material between zones in dolomite consists of extremely fine, round particles of bright red colour. They are possibly droplets of a bituminous fluid.

c) Alteration

There is no convincing evidence of alteration in the thin section.

d) Origin

As already noted at some length, the rock is the product of the chemical precipitation of dolomite from an evaporating solution under varied conditions of saturation. Controlling variables appear to have been rate of evaporation, influx of fresh water, hydrogen ion concentration and oxidation potential. The variables operated through control of the rate of precipitation of dolomite. Origin of the potash feldspar is uncertain.

Specimen B295, 6630 RS 391, TS C42018

Rock name: Laminated dolomite

Hand specimen:

The rock is a finely laminated dolomite in which the regular beds are distinguished by colour differences in shades of pink and brown. The weathered surfaces are spotted with black dendritic patches but are coated with red brown limonite. Some of the beds are marked by a concentration of pore spaces. The chip has not been stained by treatment with sodium cobaltinitrite.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 75 |
| Calcite | 10 |
| Quartz | 1 |
| Opaque material | 14 |
| Organic matter | Trace |

b) Texture

The fine bedding is again largely the result of grain size changes but the rhythmic repetitions are much shorter than in specimen B294 and the variation in grain size is much smaller. There is no progressive change in average grain size throughout the section.

Bedding is also marked by variation in the density of interstitial organic matter and, more strongly, by intermittent patches and schlieren of black opaque material, the nature of which is uncertain. It may be manganiferous, ferruginous or organic but is completely opaque and hence not identifiable.

Pink stained carbonate is widespread but the intensity of the stain by the alizarin red dye varies considerable. Much of the stained carbonate is probably a dolomite with a higher than normal calcium content.

Only a few scattered grains of quartz are present. They are irregular in shape and marginally replaced. They are of uncertain origin and are not of much significance.

c) Alteration

There is no evidence of alteration except the very minor corrosion of quartz.

d) Origin

The same considerations apply to this sample as to B294. Cyclic precipitation of dolomite from solution was probably influenced by changes in the concentration of carbonate in solution produced by variations, in this case rapid and short-lived, in evaporation and the influx of fresh water.

Specimen B296, 6630 RS 392, TS C42019

Rock name: Dolomite

Hand specimen:

In hand specimen the rock appears to be fine grained and almost massive. On the weathered surface slight traces of a fine bedding are enhanced by the iron oxide coating. On the cut surface the only structures visible are saw marks and discordant fractures.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 100 |
| Opaque material | Trace |

b) Texture

In thin section a slight trace of bedding is evident in the otherwise massive, fine grained dolomite. Intermittent bands and lenses of slightly coarser grain size are faint indications of an oriented fabric but the direction varies from place to place.

Occasional bands one grain thick of very fine grained limonite outline local masses of dolomite which may be slumped accumulates of the precipitated carbonate. The trains of opaque grains are crenulated and resemble stylolites on a small scale and with weak intensity. They probably indicate minor consolidation through slumping in a very wet, flocculant precipitate.

Scattered discordant patches of more coarsely recrystallised dolomite are also probably the result of consolidation and water expulsion in soft sediment. Some of the coarse grains are zoned.

Opaque to brown translucent material which is assumed to be limonite but which may include organic matter occurs in discordant patches and in fractures. Dark material occurs with varied abundance to colour the carbonate in different shades of grey in thin section.

c) Alteration

No evidence of alteration apart from minor recrystallisation of the dolomite was observed.

d) Origin

The dolomite probably originated as a formless chemical precipitate deposited very rapidly in an enclosed body of water being evaporated to or close to dryness. Deposition was too rapid for the precipitate to be distributed stably and some disturbance occurred as it readjusted by minor slumping. Loss of pore water also produced minor discordant structures.

Specimen B297, 6630 RS 393, TS C42020

Rock name: Laminated dolomite

Hand specimen:

The specimen consists mainly of a well-bedded dolomite with a small stromatolite at one end. Cut through the centre it displays two algal reef structures with fine laminations between them. The slab cut for section making is composed mainly of the regularly laminated rock with one algal reef structure at one end.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 98 |
| Limonite | 2 |
| Calcite | Trace |

b) Texture

The section displays the well-bedded dolomite except at one end where areas of fine, massive dolomite are part of the stromatolite. Most of this structure is under the label.

The regularity of the bedding is seen in thin section to be less than examination in hand specimen would suggest. The depositional environment is more energetic than that of the last three specimens examined and a coarser grain size in the dolomite is probably the result of sorting by water flow rather than of slow growth from solution. Another result of current action in shallow water is minor cross bedding in the inter-reef sediment and severe disturbance to the bedding in the vicinity of the stromatolitic structure. The fine grained dolomite of the reef has been fractured and coarsely recrystallised dolomite has penetrated along fractures and between fragments. It is possible that the stromatolitic material is not in place but too little of it is present to be certain.

Limonite is present as opaque grains, irregular interstitial patches and filling for discordant veins. Where it is interstitial to coarse grained dolomite, limonite forms coarse grained patches.

c) Alteration

Alteration is limited to minor replacement of fine grained dolomite by more coarsely recrystallised dolomite in discordant structures.

d) Origin

Like specimens B33, B124, B136, B145 and possibly B150, the specimen originated in part as an algal reef structure. Dolomitic sediment trapped by the algae was fine grained but the floor of the basin between reefs was swept by currents energetic enough to remove any fine grained material. Minor redistribution of dolomite probably occurred during diagenesis.

Specimen B298, 6630 RS 394, TS C42021

Rock name: Dolomitic black shale

Hand specimen:

The specimen is a dark grey, very fine grained, apparently massive rock with frequent fractures filled with a white mineral and light grey, irregular to lensoidal patches. It was collected several kilometres south of Burra.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 90 |
| Organic matter | 10 |

b) Texture

The lithology is not one encountered within the Burra open cut. Extremely fine grained dolomite is impregnated with finely divided, formless black material which is assumed to be organic matter. At Burra, even in the finest dolomite, the organic matter is interstitial to dolomite grains.

A weak tendency to elongation and preferred orientation in dolomite grains and a more pronounced concentration of organic matter into elongated linear to arcuate patches imparts a fabric oriented along presumed bedding directions to the rock.

Fractures and discordant patches contain coarser grained dolomite which is free of organic matter.

c) Alteration

Only the minor redistribution of dolomite has altered the original sediment.

d) Origin

The sediment originated through the massive, and probably rapid, chemical precipitation of very fine grained dolomite. The discordant patches of recrystallised dolomite are probably soft sediment structures formed during dewatering of the carbonate mud. Some redistribution of dolomite continued after lithification. The difference between this lithology and those at Burra raises the question as to whether all the Burra dolomites have been recrystallised to an extent sufficient to exclude organic matter from the dolomite as well as to produce a reaction between dolomite and quartz at the margins of quartz grains. A further question is why no pyrite or silica was deposited, despite the modification of the depositional environment by abundant organic matter.

Specimen B299, 6630 RS 395, TS C42022
Rock name: Stromatolitic dolomite
Hand specimen:

The specimen is nodular in shape and displays the arcuate banding which is typical of stromatolitic structures. The main mass of the rock is composed of fine to medium grained dolomite but the visible banding is marked by the presence of quartz, limonite staining, open cavities and a blue-green material.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 99 |
| Quartz | 1 |
| Calcite | Trace |
| Copper-hearing carbonate | Trace |
| Clay | Trace |
| Limonite | Trace |

b) Texture

The dolomite varies in grain size between fine and medium but the distribution of grain size is not regular. Relics of the original fine stromatolitic dolomite are present in bands which are frequently interrupted by discordant structures of coarser grain size. The coarser bands between the fine dolomite have been subject to much recrystallisation of dolomite and of the small quartz content and contain many solution cavities.

It is in the areas of coarse recrystallisation and particularly in and around the open cavities that calcite and another carbonate have been deposited. The second carbonate occurs in fibrous botryoidal and spherulitic forms and is blue-green in hand specimen but pink-stained in the section which has been treated with alizarin red dye. The composition of the mineral is probably complex and may include both copper and calcium as cations and carbonate and hydroxide as anionic groups.

The clay component accompanies the non-dolomitic carbonates in small quantities. Some clay is of low birefringence and is probably kaolinitic but the major part of it is of high birefringence and is probably of illite type. Some sericitic mica may possibly be included but the masses of clay minerals are too fine grained to be conclusively identified and are stained with minor quantities of limonite.

c) Alteration

1) The degree of mobilisation and recrystallisation affecting the dolomite is probably greater than can be ascribed to processes of diagenesis along. The presence of hydrothermal solutions is evident in the deposition of copper minerals and it is likely that much of the recrystallisation of dolomite can be attributed to this agency.
2) The proportion of quartz is insignificant and the recrystallisation into mosaic patches and marginal corrosion is probably of diagenetic origin.
3) Very minor potash metasomatism would be indicated if the clay were shown to include an illite-sericite component.
4) The probable presence of copper in the blue green carbonate needs analytical confirmation and would indicate the mobilisation, or probable remobilisation of copper in carbonate solutions.
5) Very minor kaolinitic clay is associated with the presumed copper mineralisation.

d) Origin

The rock originated as a dolomitic sediment largely composed of fine precipitated dolomite trapped in algal mats in a stromatolitic reef. Subsequently it underwent a greater degree of recrystallisation than is compatible with purely diagenetic processes and was penetrated along coarse grained bands by solutions which dissolved out some components and deposited copper and calcium-bearing carbonates with a little clay. The specimen was collected from south of the Burra pit but is apparently within the ore zone.

Specimen B300, 6630 RS 396, TS C42023

Rock name: Coarse, dolomite sand in calcite matrix.

Hand specimen:

The specimen is coarsely crystalline without any recognisable bedding. The weathered surface is embossed with coarse grains and patches round which the matrix has weathered away. The slab cut for the thin section has retained a very strong yellow stain from the sodium cobaltinitrite treatment in scattered, irregular patches.

Thin section:

a) Mode

| Mineral | % |
|---|---|
| Dolomite | 50 |
| Calcite | 48 |
| Quartz | 1 |
| Potash feldspar | 1 |
| Mica | Trace |

b) Texture

The detrital fraction consists almost entirely of dolomite clasts made up of single crystals up to 3 mm across. A few of the dolomite crystals contain inclusions of mica, probably phlogopite. A very few grains of quartz may be of detrital origin.

Some of the clasts are in mutual contact but for the most part the sediment is matrix-supported. At many points dolomite grains are almost in contact but under magnification are seen to be separated by a thin sheet of matrix which has penetrated along grain boundaries.

At several points the dolomite has been penetrated by quartz as an interstitial matrix and in a few places the quartz is accompanied by a microcline or other potash feldspar with poorly defined twinning. Some, if not all, of the phlogopite inclusions in the dolomite were introduced with the quartz and microcline. The patches of silicate matrix are scattered and not abundant.

The main interstitial phase is calcite which forms a matrix not only to the dolomite but also to dolomite surrounded by quartz. The quartz-calcite contacts are sometimes marked by reaction rims and elsewhere the calcite has embayed and corroded the quartz and microcline.

c) Alteration

Calcite has replaced both dolomite and quartz to a minor extent. The introduction of potash feldspar and phlogopite constitutes a minor episode of potash metasomatism.

d) Origin

The dolomite clasts were derived from a very highly recrystallised dolomite but there is no evidence of its nature. The minor potash metasomatism may be an indication of the proximity of mineralisation but the specimen lacks interval evidence of this. The final invasion by calcite may have occurred in the normal course of sedimentation and diagenesis, of hydrothermal alteration or of calcrete formation at or near the surface.

## DISCUSSION

The suite of specimens was assembled from locations in and south of the Burra open cut copper mine which are relatively remote from the ore zone itself in comparison with those reported on in R.B. 83/28. In order to identify the processes of mobilisation and the constituents mobilised during the copper mineralisation it is important to distinguish any such processes which may have affected the unmineralised sediments. This is particularly necessary for the dolomites. It has been found that a variety of processes promote authigenic mobilisation and recrystallisation in dolomitic sediments throughout their early history and that only in extreme cases can recrystallisation be ascribed to the agency of hydrothermal solutions. In particular, petrographic evidence suggests that selective precipitation of either silica or dolomite, diagenetic recrystallisation of both and the replacement of one by the other in either direction may be promoted by variations in pH and Eh small enough to be controlled by the concentration of organic matter and the rate of evaporation relative to the influx of fresh water to the depositional basin.

Factors believed on petrographic evidence to influence the nature of sedimentation in the Skillogallee Dolomite at Burra are summarised below.

a) The depositional environment

Many of the sediments are well bedded with textures varying from finely laminated to coarsely irregular and arcuate in the stromatolitic reef facies. The depositional medium is clearly aqueous. While a few sediments in which coarsely granular textures are detrital may have been deposited in a moderately energetic environment, most of the sedimentation is fine grained and includes chemical precipitates which could only have been deposited in stagnant water. At the same time, such textures as intraformational conglomerates and cross bedding in the fine grained rocks indicate that the water was shallow and at times dried up completely.

The area at the time of deposition was remote from major ocean coasts and was either one of inland drainage or one in which access to the sea was very restricted and was for much of the time sealed off completely. At those times the only water movement was caused by the influx of drainage run-off or wind driven currents. A contemporary analogue of the depositional environment is more likely to be provided by the Coorong or an intermittent lake in the north of South Australia than by Shark Bay in Western Australia which is open to the ocean.

b) Non-carbonate sedimentation

This type of sedimentation includes both silica and silicates and occurs as fine silts and shales of terrigenous detritus and as bands of non-carbonate minerals within the dolomitic sediments. In the latter category some deposits are believed to be detrital but others may be chemical precipitates. Petrographic evidence suggests that the ultimate grain size of such material may not be reliable evidence of its original grain size because of the extensive recrystallisation prevalent in the sediments. In assessing the petrographic evidence the guiding principle has been that grains which are isolated or in contact at only a few points are probably detrital but that grains in contact along simple boundaries with junctions close to 120°, forming a mosaic patch which is discordant to the bedding, are recrystallised. There are many instances, however, in which the evidence is not entirely conclusive for one origin or the other.

Terrigenous sedimentation is not uncommon in the Skillogallee Dolomite and at Burra a broad band of siltstones and shales is exposed from north to south through the centre of the open cut. Within the dolomitic sequence bands of detrital quartz are frequent, particularly in stromatolitic reefs, and occasional beds of microcline or plagiocalse have been observed. The sedimentation of terrigenous detritus without carbonate can usually be explained convincingly by an influx of fresh water vigourous enough to carry fine clastic material while at the same time diluting the concentration of dissolved carbonate below the point of saturation and thus inhibiting carbonate precipitation. Where relatively coarse detritus is involved and there is no evidence of strong current action, the possibility of a contribution of wind-blown sand from a strongly dessicated terrain is a not unreasonable suggestion. However, several factors have prompted the suggestion that some of the terrigenous sediments at Burra are partly or entirely of pyroclastic origin.

c) Evidence for a pyroclastic contribution

Factors which may not individually indicate a volcanic origin but which in total provide strong, if not definitive, evidence of a pyroclastic contribution to the sedimentation are summarised below.

1. Beds in which the clasts are exclusively feldspathic.
2. Sediments in which the matrix is shown chemically to consist almost exclusively of potash feldspar.
3. Clasts of fresh microcline of a sharply twinned type.
4. Clasts of sharply splintered quartz.

In elaboration of the first point, sedimentary mechanisms are not normally selective enough to concentrate fresh, monomineralic feldspar detritus but the formation of a volcanic glass with feldspathic phenocrysts is not uncommon.

Secondly, a fall of ash composed of comminuted potash feldspar phenocrysts or glass with a high potash feldspar content is a more credible source for a sedimentary matrix composed of this mineral than any purely sedimentary origin.

Thirdly, the microcline which is optically identifiable in these sediments is twinned in a pattern intermediate between the fine cross-hatching of plutonic microcline and the patchy and imprecise twinning of the low temperature hydrothermal microcline of replacement origin.

Lastly, splintered quartz is not restricted to pyroclastic debris but is supportive evidence that little or no abrasion was inflicted on the detritus between its initial disruption and its incorporation into the sediment.

Additional evidence of a volcanic contribution to the sedimentation at Burra is external to the present investigation. The specimens described in the earlier report on Burra sediments (RB 83/28) included some displaying flow structures, in rocks believed to be both lavas and tuffs, and euhedral phenocrysts of microcline and plagioclase. The sediments with a probable pyroclastic contribution described in this report may be lateral equivalents of the more proximal ash flows and lavas or may be at a slightly different stratrigraphic level.

d) Carbonate sedimentation and diagenesis

Apart from the clastic components of stromatolitic reefs and the last specimen described (B300), the carbonate sediments examined are mostly the products of chemical precipitation of a generally fine grained deposit. One feature of this type of sedimentation which is clearly demonstrated by the samples examined is the highly reactive nature of the medium from which the sediment was precipitated and which was retained during at least the early stages of diagenesis within the deposit as a pore fluid.

A saturated aqueous solution of magnesium carbonate at the standard temperature of 20°C contains over 100 mg per litre of solute. The hot brine at the bottom of the Dead Sea which is used to exploit solar energy in Israel reaches a temperature of 90°C. It may be assumed that a solution capable of precipitating magnesite such as that from which the Skillogallee Dolomite was deposited would contain well in excess of 10% Mg $CO_3$, weight for volume. If, as is possible at Burra, terrestrial heat flow was increased by quasi-contemporary volcanism, an even more concentrated solution may have been developed. Since magnesia is a strong base and carbonic acid only weakly acidic, the pH of the solution from which the dolomitic carbonate was precipitated and which became the pore fluid of the precipitate must have been well on the alkaline side of neutral. The solubility of most silicates is higher at an alkaline pH than in an acidic solution except one of hydrofluoric acid.

Conversely, if the pH of the solution falls to the acid side of neutral, the solubility of carbonates increases and that of the silicates decreases. Rain water is slightly acid due to a low concentration of dissolved carbon dioxide from the atmosphere and even though it dissolves magnesium and other salts such as those of calcium and iron in its passage through the ground into the drainage, the influx of fresh water into carbonate-saturated solution from which the dolomite was precipitated almost certainly changed the pH towards more acid conditions, although probably not to the acid side of neutral.

A more effective acidifying agent in the depositional environment was organic matter, and more particularly its degradation products. It was probably a build up of these that promoted the deposition of colloidal silica and inhibited that of carbonate in some beds in a few of the sediments. Even more effectively, the diagenesis of organic matter strongly influenced the pH of pore solutions and probably accounts for the deposition of mosaic quartz in discordant structures produced during the dewatering of the carbonate precipitates. The presence of zoned dolomite and the reversals in replacement processes of one phase by another indicate that the pH of pore solutions fluctuated during diagenesis, probably controlled by the rate of degradation of organic components. Still further reactions occurred between ground water and the lithified sediments along fractures produced later in the history of the sediment. Some mineral constituents were completely dissolved out, leaving cavities. It is probable that the quantitative changes in pH, and in Eh which accompanied them, were relatively small but that they occurred over ranges critical to the stability of the major framework components of the dolomites.

Suggestions that the grain size of precipitated dolomite was controlled by the rate of precipitation have been discussed at length in the descriptive section and will not be further elaborated here.

e) <u>Metasomatic changes</u>

Examination of sediments which for the most part are remote from the ore zone has facilitated a clarification of the changes which can be ascribed to metasomatic processes caused by hydrothermal solutions associated with the copper mineralisation. In particular, evidence of the reactions between dolomite and silicates in carbonate-saturated solutions with pH control by organic matter indicates that only very complete and very coarse grained recrystallisation of dolomite can be attributed with confidence to the influence of ore solutions and that this influence was over-estimated in the earlier report (RB 83/28). Similarly, it is now clear that marginal corrosion of quartz grains by dolomite is not evidence of a late stage dolomitisation but of minor diagenetic reactions.

As far as silicification is concerned only the mobilisation of silica into discordant veins can be associated with ore formation but no reappraisal is necessary in this report since this was evident in the earlier investigation.

Evidence of potassium metasomatism is clear and consists of replacement by both low temperature microcline and muscovite or phlogopite. Kaolinitisation appears on some evidence to have been a precursor to potassium metasomatism. An association between these processes and the copper mineralisation itself was not encountered in the specimens described here but neither potassium metasomatism nor kaolinitisation was as abundant as in the specimens described earlier from the ore zone itself. This is perhaps confirmation of at least a spatial correlation with the mineralisation.

The only specimens in which copper bearing minerals were observed were from the northern end of the open cut and from a locality to the south of Burra. Both samples were of a low temperature redistribution of copper described in the earlier report as a late stage process. In the first instance the copper is contained in chrysocolla associated in this specimen with kaolinite and chalcedony. In the southern sample the copper is contained in a blue green carbonate which stained red with the alizarin dye and is associated with calcite.

An uncommon occurrence is the presence of plagioclase in the margins of a discordant fracture. The nature of this mobilisation process is not identifiable on the limited evidence available.

M Farrand.

MF:DP

DR. M.G. FARRAND