DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept. Bk. No. 83/28

COMMENTS ON THE PETROGRAPHY OF FORTY TWO THIN SECTIONS OF SAMPLES FROM THE BURRA COPPER MINE, S.A.

GEOLOGICAL SURVEY

By

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REGIONAL GEOLOGY

D.M.E. No. 454/82

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DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

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ABSTRACT

Forty two specimens from the open cut at Burra were examined in order to comment on a report from a consulting organisation. Despite a high degree of alteration it was possible to distinguish, with varying levels of confidence, siltstones, shales, dolomites, pyroclastics, lavas and cherts, as the original country rocks.

Five successive and often superimposed episodes of recrystallisation, alteration and mobilisation were distinguished. These consist of silicification, replacement by low temperature microcline, dolomitisation, kaolinitisation, and redistribution of copper carbonates and chalcedonic silica.

Primary copper mineralisation, probably as chalcopyrite, was associated with low temperature microcline whilst secondary copper mineralisation, involving the conversion of sulphide copper to malachite, was effected by solutions during dolomitisation. Minor redistribution of copper as carbonates and chrysocolla occurred in a final phase of mobilisation.

SADME PET. REP. 2/83

1:250 000 Sheet - Burra

1: 50 000 Sheet - 6630-I

Thin sections C 34940 - C 35317

INTRODUCTION

Forty two thin sections and hand specimens were received from John Drexel of the Mineral Resources Section for comment on the main features and on the interpretation placed on the samples by a consulting organisation (Amdel Rept. GS 1/1/271, Petrology and Geochemistry of Burra Copper Mine PR 2). The investigation is not intended to duplicate detailed descriptions already completed. All the map references cited are shown on Plan No. 83-143.

PETROGRAPHY

B5, TS C 34940

Locality: Pillar in old stope, bottom of cut, northern end. Map Ref. 317425.

Rock name: Fine grained, possibly volcanic rock, partially replaced by coarser grained quartz and microcline

Main features:

The rock is friable, pink and white in colour with fine grey veinlets and frequent cavities. The whole surface, apart from the veinlets, stains yellow with sodium cobaltinitrite. In thin section the pink material is identifiable as a closely-interlocked mass of microcline of medium to coarse grain size and extremely irregular, and often poorly-defined, shape. A few grains of microcline are of good shape and occur as individual

crystals rather than as interlocked masses. The microcline is densely turbid due to extremely fine grained exsolved iron oxide which gives the mineral its pink colour in hand specimen. Coarse grained quartz, some of chalcedonic origin, forms coarse veins and patches while a network of fine veinlets crosses the fine grained part of the sample.

The fine grained minerals are not identifiable optically and form a mass of low birefringence with, in places, an oriented texture which is probably bedding. Absorption of the sodium cobaltinitrite solution and the white, friable nature of the hand specimen suggests that kaolinite forms a substantial part of the rock. Permeation of the whole specimen by microcline of extremely fine grain size appears less likely to be the cause of the staining, as the microcline is visibly coarse grained.

Comment:

Evidence internal to the specimen itself is not conclusive enough to define its origin. However, with the hindsight of evidence observed in other specimens from the Burra open cut, it may be suggested that, on balance, the specimen B 5 is likely to be of volcanic origin. The fine grained matrix with a network of fine quartz veinlets and a few well-shaped felspars is similar to other specimens for which a volcanic origin is more convincing. An intrusive emplacement appears less likely from the fine, bedded texture.

The cavities visible in the hand specimen are probably produced by solution. There is no evidence that they are of vesicular origin.

The major part of the microcline, that forming interlocked masses, is almost certainly of replacement origin. A scan of the mineral by X-ray diffraction showed that it is of almost perfect

triclinic structure. This is typical of low-temperature hydrothermal microcline. In optical examination the patchy, coarse-grained and poorly-defined twinning is quite distinct from the sharp, cross-hatched twinning of granitic microcline. It is non-perthitic.

The individual, well-shaped crystals of microcline are compositionally identical to the replacement microcline but are believed to have originated as phenocrysts, possibly of sanidine but conceivably of plagioclase rather than potash felspar.

Absence of bedded mica distinguishes the specimen from most of the siltstones and shales of the Burra open cut.

B42, TS C 34946

Locality: In wall of old stope, near bottom of cut, northern end.

Map Ref. 318427

Rock name: Kaolinitised rock.

Main features:

The rock is soft and friable and consists of rounded white patches in a rusty brown matrix.

In thin section the white patches consist of an ultra-fine grained material of low birefringence and the brown matrix is seen to be a mixture of smaller patches of the same material surrounded by opaque iron oxide. Scattered grains and patches of quartz and colloidal structures of translucent red iron oxide are the other constituents.

Comment:

Optical mineralogy is almost useless as a diagnostic tool in this type of material. The two phases identified by X-ray diffraction are kaolinite and quartz. (The iron oxides are almost certainly amorphous and therefore not registered by X-RD).

The significant feature, as was reported by the consultant, is the cauliflower-shaped patches of kaolinite with a bimodal size distribution. The assumption that these patches are pseudomorphous is not justified and the only support for a suggestion of volcanic origin is that some volcanic rocks have a bimodal size distribution between phenocrysts and groundmass. However, the same may be said of framework and matrix grains in many sediments. The appearance of the larger kaolinite patches, resembling a cauliflower, is due to the coalescence of many of the smaller patches, which are therefore the fundamental 'unit'. A possible explanation for this regularity is that kaolinisation proceeds from a centre and rejects material which is not compatible with the kaolinite structure by forcing it outwards. In some places the process continues until adjacent centres of kaolinisation coalesce to form the larger masses but in most of the rock the build-up of material which is not susceptible to kaolinisation impinges on that rejected from an adjacent centre and halts the process, forming a relatively regular array of kaolinised patches due to a regular rate of diffusion.

This explanation is purely conjectural and should not be regarded as definitive. The only name for the material which is justified by the thin section is "kaolinitised rock". Field evidence may justify the name "kaolinitised dolomite". The process is too severe for weathering to be a likely cause. The alteration is probably hydrothermal.

B46, TS C 34948

Locality: Country rock, bottom of cut, south end near base of slump.

Map Ref. 316414

Rock name: Siltstone.

Main features:

The rock is a bedded sediment which takes a variable but ubiquitous yellow stain with sodium cobaltinitrite.

In thin section the bedding is seen to be marked by variation in the clay content of the sediment. In some bands the clay is a kaolinitic type with low birefringence, in other bands the clay is of moderate to high birefringence. It is probably an illite and a few flakes of unaltered muscovite are identifiable in the platy fraction.

The other constituents of the sediment are mainly too fine grained to identify but occasional grains of quartz, plagioclase and microcline are visible. The cobaltinitrite stain may be due to fine grained microcline or to clays.

Opaque minerals which are now iron oxide but were almost certainly pyrite originally occur as coarse grains in irregular to lenticular patches with a quartz gangue.

The pale brown colour of the sediment is due to rounded granules of translucent and amorphous limonite which is widely disseminated in fine to very fine grains, sometimes with an opaque oxide nucleus.

Comment:

The specimen is a normal siltstone. Clay-rich bands are occasionally lenticular and branched but this is probably due to a relatively shallow water origin rather than to a volcanic source.

B47, TS C 34949

Locality: Old stope, bottom of cut, S end.

Map Ref. 315415

Rock name: Mineralised, recrystallised ? siltstone.

Main features:

A medium grained sandstone has been impregnated with malachite. The rock is porous with many large cavities.

In thin section the sandstone is seen to consist mainly of quartz grains with a minor amount of a cross hatched, polysynthetically twinned mineral which is microcline. A minor, but widely distributed, constituent is a colourless to faintly brown mica. This occurs as fine dispersed flakes in the major part of the rock but as clusters of thick crystals in the part which is mineralised by malachite. Some of the latter mica is tinted green.

Malachite occurs in regular veinlets and as large irregular patches.

A few rosettes of acicular calcite are present.

There is a wide range of grain size in the microcline and, particularly, in the quartz. Some quartz is extremely fine grained but in randomly distributed patches the grain size is much greater and the quartz forms a mosaic of closely interlocking grains in contact along simple grain boundaries which often meet in perfect 120° triple junctions. Signs of such recrystallisation are visible in grains over a wide area of the rock.

Comment:

Comment was requested on the origin of the coarse grain size of the specimen since primary sandstones had not been mapped in the area. The fabric of the rock is certainly not that of an unaltered sediment. Quartz grains forming a fully annealed mosaic are necessarily the product of equilibrium recrystallisation. There is no evidence that the plain boundaries are the result of authigenic overgrowth on a detrital nucleus and it appears that the whole rock has been subject to a complete, though patchy, recrystallisation. There is no obvious spatial correlation between coarse quartz and malachite and the recrystallisation appears to antedate the mineralisation. Indeed, the malachite is seen in places to fill fractures in coarse quartz.

The mineralisation appears to have introduced mica and microcline possibly causing an increase in grain size of any existing mica and microcline. In this particular specimen there appears to be no quartz in the gangue of the mineralisation.

It is doubtful whether any evidence of the original nature of the rock has escaped modification by recrystallisation. There is no evidence of a sedimentary fabric. Examined at high magnification there is evidence of some recrystallisation even in the finest quartz. Probably a reasonable assumption would be that the rock was originally a siltstone. If all the microcline and mica are exogenic, the rock may have been a chert.

B50, TS C 34950

Locality: Bottom of cut near old workings. South of centre. Map Ref. 317419

Rock name: ? lithic-crystal ash-fall tuff.

Main features:

The rock is flinty and very patchy in hand specimen. Much of it has stained with sodium cobaltinitrite but in a pattern which appears to be fracture-controlled. Pink patches do not carry a strong yellow staining.

In this section by far the major part of the rock consists of fine grained material of low birefringence. It is cut by a dense and complex system of minor fractures filled with coarse grained quartz. Patches, stringers and individual crystals of microcline are common and some crystals are euhedral to subhedral in shape. Most are anhedral.

A significant feature is a sharply defined fragment of a fine grained, bedded sediment which is surrounded by the massive, fine grained material of the host rock. More poorly-defined patches of foreign material, both coarser and finer-grained than the host rock are present. Some appear to have andesitic texture.

Comment:

Many of the features of the specimen are equally diagnostic of a dehydrated and crystallised gel and a devitrified glass. Both process involve the crystallisation of an amorphous material. A somewhat tentative identification as a tuff rather than a chert is made on the balance of evidence rather than on any clearly definitive feature. The most significant factors influencing the diagnosis are the xenoliths which are partially digested and the euhedral microcline crystals which probably

pseudomorph phenocrysts. It is clear, however, that the microcline has been introduced as a low temperature replacement which may have concealed much evidence of critical importance.

B51, TS C 34951

Locality: Same as B50.

Rock name: Mineralised, hydrothermally altered ? tuff.

Main features:

Part of the specimen is identical to specimen B50 but the major part consists of a closely interlocking mosaic of medium to coarse grained microcline with complex and often poorly defined grain boundaries.

A small patch of malachite occurs at both edges of the section. In one case it is associated with calcite and possibly siderite.

Comment:

This is the specimen in which low temperature microcline was identified by X-RD. The presence of malachite is again correlated with abundant hydrothermal microcline.

B52, TS C 34952

Locality: Bottom of cut near centre.

Map Ref. 317422

Rock name: Mineralised, dolomitised, quartz-microcline rock.

Main features:

The rock is light grey and patchily stained with cobaltinitrite. In thin section it is notably more coase grained than the specimens examined so far and shows evidence of a complex sequence of events.

Veinlets of green carbonate and a carbonate which stains pink with alizarin red cut all other minerals. A colourless, non-staining carbonate forms a closely-interlocking mosaic of mutually interfering grains covering most of the section and euhedral to subhedral grains, some of which are extremely coarse in grain size, enclosed by a mosaic of quartz and potash felspar. The relationship of the quartz and felspar is uncertain as they are rarely seen in contact in the few patches where they have not been replaced by carbonate.

Comment:

The history of the rock probably extends beyond the limit of available evidence. The earliest identifiable constituents, the coarsely crystalline quartz and microcline, are probably themselves the result of recrystallisation, possibly of the fine-grained sediments examined above.

Coarse grained dolomite has replaced about 75% of the earlier assemblage but is older than the malachite-calcite mineralisation. This is demonstrable in the case of green and pink-stained carbonate which fills fractures and grain boundaries in dolomite.

The age relationship of the opaque minerals and dolomite is less clear. Much of the malachite is developed from opaque minerals, presumably chalcopyrite. In places malachite occurs as a rim round an opaque grain where it is in contact with dolomite. This would suggest that the sulphide ore may antedate the dolomite but that the carbonate ore may be derived, in part at least, by reaction with the dolomite. Mobility of malachite solutions then persists after the crystallisation of the dolomite.

B53, TS C 34953

Locality: Bottom of cut near centre.

Map Ref. 317423

Rock name: Altered ? lava.

Main features:

The rock is coloured in shades of pink, red, brown and blue-grey which merge into each other. It is stained with sodium cobaltinitrite in patches with a contorted banding.

In thin section the rock is very similar to B50 in that most of it is fine grained, there are many fine, quartz-filled veinlets, euhedral to anhedral potash felspars and sharply to poorly-defined xenoliths. The rock differs from B50 in that the xenoliths are much more abundant, coarse felspar replacement is less abundant, fine replacement is more abundant and there are strong indications of flow. Flow bands are quite regular in places and consist of coarsely to finely granular bands and bands in which crystallisation of amorphous silica is evident in feathery and rosette-shaped structures.

Comment:

The flow banding is regular enough in places to suggest a lava rather than an ash-flow tuff or agglommerate. It is crowded with xenoliths and may have been subject to some auto-brecciation while flowing. Potash felspar replacement has affected the phenocrysts and the fine-grained groundmass but has not introduced much new coarse grained felspar.

B54, TS C 34954

Locality: Bottom of cut near centre, close to B52.

Map Ref. 317422

Rock name: Mineralised, dolomitised, quartz-microcline rock.

Main features:

The rock is patchy with pink and grey areas. Yellow sodium cobaltinitrite stain is also very patchy and lighter than in previously described rocks.

In thin section the specimen is similar to B52 in that a relatively coarse grained quartz-felspar mosaic has been largely replaced by dolomite. In this case, however, the dolomite in fine grained and takes a weak pink colour from alizarin red stain. It may be a calcium-rich dolomite. Veins carrying both malachite and azurite are the latest constituent of the rock, cutting through dolomitised areas. Much of the potash felspar is untwinned.

Copper carbonates are associated with opaque grains, presumably of chalcopyrite, but there appears to be no systematic association between copper carbonates and dolomite. The best developed malachite and azurite are interstitial to a mosaic of quartz and minor potash felspar which are intergrown along complex grain boundaries. Trails of oriented fine flakes of colourless mica are frequently included in the quartz.

Comment:

The same sequence of events is demonstrable in this specimen as in Sample B53. Differences are : a) finer grained dolomite (Possibly with a higher calcium content); b) less potash felspar; c) a consequent association of copper mineralisation with quartz (containing muscovite) instead of with microcline; d) the presence of substantial azurite.

Malachite is the carbonate found in contact with opaque copper sulphide, presumably as a direct alteration product. When re-distributed in veinlets and in patches interstitial to quartz, azurite is as abundant as malachite.

B57, TS C 34956

Locality: In area of old workings, north end of cut.
Map Ref. 316428

Rock name: Recrystallised ? chert.

Main features:

The rock is siliceous with a patchy, pinkish beige colour and a variable grain size. There is no cobaltinitrite stain.

In thin section the rock is seen to be composed almost exclusively of quartz. The texture is of a closely intergrown mosaic of grains with a very large variation in grain size. Grain sizes tend to be concentrated in patches but these are not entirely exclusive. Fine grains occur within coarse patches and vice versa.

In the finest grain sizes the size and shape of individual grains tends to be variable. In the coarsest grain sizes the same applies and intergranular sutures are often complex. In many patches of intermediate grain size the quartz mosaic is almost perfectly annealed with simple grain boundaries meeting in 120° triple junctions. Strain polarisation is generally absent but a few coarse grains exhibit it in a mild form.

Comment:

The same pattern of patchy quartz recrystallisation as was seen in specimen B47 is visible in B57. The whole rock has been recrystallised but to varying extents at different points. No direct evidence of the original rock remains but the extremely

pure silica of which the rock is composed indicates that a chert would be a reasonable suggestion. A clastic quartz sediment of very fine grain size is unlikely to be totally devoid of clay minerals.

The origin of the patchy nature of the recrystallisation may be related to a fracture pattern which is now totally obscured.

B59, TS C 34957

Locality: Wall of old stope, bottom of cut near northwest edge.

Map Ref. 315425

Rock name: Kaolinitised rock.

Main features:

The specimen is a crumbly green material but must have included a relatively coherent slab from which the thin section was prepared, after impregnation with resin. The section consists mainly of a fine-grained felt of a material with a flaky texture at high magnification and a low birefringence. No identification by optical properties is possible but the material is probably kaolinite. Irregular and altered grains of microcline are still occasionally identifiable. Quartz is more common as patches and discontinuous veins. Ragged and altered flakes of muscovite are also present.

The ore minerals present fall into two categories. The first consists now of veins, patches and isolated grains of limonite which are often intergrown with malachite. This type of occurrence appears to be pre-kaolinisation as kaolin is seen in places to penetrate fractures and grain boundaries in limonite/malachite masses. The second type of mineralisation consists of dispersed patches, and branching and irregular veins

filled with fibrous malachite, often with a central filling of a second generation of malachite. The veins are the latest feature of the rock, cutting through patches of kaolinisation.

Comment:

Suggestions as to the ultimate origin of the rock must be purely speculative as a long history of recrystallisation and alteration has completely obscured the evidence. Using the specimens examined up to now as a basis for speculation it is suggested that the original parent-rock, possibly a normal sediment, was cut by quartz veinlets and permeated by hydrothermal solutions carrying microcline, a little mica and a copper sulphide mineralisation. Kaolinisation of the felspar took place in a more comprehensive way than in B42, somewhat later than or at the same time as some malachite formed from the copper sulphide. Finally a redistribution of malachite into a system of veinlets occurred in at least two stages.

It is unlikely that a chert could be so completely kaolinised but any cracks in the material, perlitic or not, are due to changes of volume during alteration and are not inherited from a volcanic origin.

B60, TS C 34958

Locality: Wall of old stope, north west edge of bottom of cut. Adjacent to B59.

Rock name: Possible tuff with quartz and microcline replacement.

Main features:

A mottled red and white rock is almost completely stained by sodium cobaltinitrite. The matrix is too fine grained to determine whether this is due to microcline or kaolinite.

Microcline is identifiable as abundant, irregular, poorly-defined and poorly twinned grains and patches of medium to coarse grain size. Coarse grained quartz is present as veins and patches with and without microcline. Fine quartz, some of it of chalcedonic habit, occurs as patches and in the fine veinlets which appear to distinguish volcanic rocks in the Burra open cut. A little apatite is present.

Opaque minerals are present but do not appear to be copper-bearing. Sharply bounded cavities, often with a rhombic outline, mark the former presence of crystals, possibly of dolomite, now dissolved out.

Comment:

The evidence on which this sample is tentatively identified as a pyroclastic is not as strong as that for B5. Only the fine veinlets and chalcedonic silica, with a few possibly phenocrysts and some fine crystals of apatite, constitute petrographic evidence in favour of a volcanic origin. The strongest evidence is the locality of the specimen.

B72, TS C 34959

Locality: Third bench up north end of cut, western side.
Map Ref. 314433

Rock name: Mineralised, dolomitised, quartz-microcline rock.

Main features:

A grey rock of fine grain is spotted by yellow-stained grains of a coarser grain size, both scattered and distributed in bands. In thin section the major part of the rock consists of fine grained dolomite replacing potash felspar and quartz. The remainder of the rock consists of relict microcline and quartz. The microcline is scattered generally throughout the rock in

'windows' in the dolomite but also tends to be concentrated in bands which are picked out by the cobaltinitrite. It is not clear what determines the position of the bands.

The quartz occurs as remnants of veins, in places contorted with highly strained crystals. At one point quartz and dolomite crystals are intergrown in a short length of vein but in most patches of quartz the dolomite is only marginal.

Thin branching veinlets of malachite cut all other phases.

Comment:

The specimen is similar to B54 in that the dolomite is fine grained and the latest phase is malachite in fine veins. It differs in having a higher content of microcline of pre-dolomite age.

B73, TS C 34960

Locality: In area of slump, south end of cut 20 m east of B46.

Map Ref. 318415

Rock name: Siltstone with microcline replacement.

Main features:

The rock is a pink and grey, thinly banded sediment which has taken a light yellow stain except at one side where a pink, more massive facies is not stained. In thin section the rock is seen to be a bedded siltstone similar to specimen B46 but in which replacement by microcline is more advanced. The microcline occurs as identifiable, medium grained crystals in bands between the clay-rich bands rather than a fine grained impregnation which

is not identifiable optically. The more massive side of the specimen is composed of an irregular intergrowth of microcline and a little quartz with very little mica. The reason why it is not stained with cobaltinitrite is not evident.

The clays are of moderate birefringence and are probably montmorillonitic although a few flakes of fresh muscovite suggest that illites could also be present. There is an almost perfect preferred orientation in the clays.

Comment:

The rock was almost certainly a normal siltstone, similar to B46. Microcline has almost completely replaced the non-mica fraction of the rock and the little remaining quartz has been thoroughly recrystallised. The coarser grain size of the microcline is strong evidence for late-stage introduction. If it were primary it would not have been concentrated with the fine clay.

B74, TS C 34961

Locality: Extreme southern end of cut, one bench up, southwest edge of slump.
Map Ref. 317411

Rock name: Siltstone with incipient recrystallisation.

Main features:

The rock is a buff coloured, weakly bedded sediment with a grain size of sand grade. In thin section the grain size is evidently largely due to recrystallisation and the original grade is that of a siltstone. Complete absence of cobaltinitrite staining shows that the rocks has escaped the introduction of low

temperature microcline and exhibits only the early stages of the recrystallisation of quartz which, when complete, results in the development of a rock like specimens B47 and B57.

The matrix of the rock is kaolinitic and contains quartz, felspar and mica. Mica-rich bands, somewhat less distinct than in other siltstones described, also contain clays of both illite and kaolinite type. Some kaolinite is unusually coarse-grained. The matrix is coarser grained overall than the siltstones described above and, in view of the undoubted recrystallisation of coarse quartz, the question of overall grain growth cannot be ignored. There is a distinct difference, however, in the shape as well as the size of matrix grains. Matrix quartz tends to occur as grains of simple shape, often quite sharply angular, which are surrounded by kaolin and almost certainly of clastic origin. The coarse quartz occurs in single grains and polycrystalline patches with complex margins and intergranular sutures which vary from simple to complex. Marginal complexity is partly due to an interstitial mode of growth but is mainly due to major corrosion and minor embayment by kaolin of the matrix. It appears that the rock has been subjected to a minor degree to the late kaolinisation process which is seen in its terminal stage in specimen B59.

Both plagioclase and microcline occur as fine detrital constituents, often retaining the shape of cleavage fragments. Although the rock is clearly a re-worked sediment, some of the clasts may be volcanic in origin.

The kaolinitic matrix has itself been partially replaced by late carbonate. The main type of redistributed carbonate is malachite but there are a few grains of a brown carbonate which is probably siderite and a slight development of a fibrous carbonate which takes a pink stain and is thus calcite.

Comment:

The rock is a slightly felspathic siltstone in which the quartz has been partly recrystallised. It has avoided the dolomitisation, potash metasomatism and primary copper mineralisation but has been mildly affected by late kaolinisation and later redistribution of carbonate mineralisation.

B83, TS C 34963

Locality: Bottom of cut, eastern side.

Map Ref. 319418

Rock name: Dolomitised ? siltstone

Main features:

A beige coloured rock absorbs the sodium cobaltinitrite stain in patches. A faint preferred orientation is evident. In thin section the rock closely resembles B52. The difference is in the persistence of bands of mica which, though poorly defined, permit the identification of the probable original rock type as a siltstone. Patchy staining is due to 'windows' in the dolomite which expose microcline of the coarse grained, low temperature type. Silicification of the original siltstone was even more pronounced and patches of coarse grained quartz mosaic are frequently exposed. None of the original siltstone remains.

The dolomitisation is of the fine-grained type where grains are in contact but euhedral rhombs and less well-shaped crystals occur in coarser grain sizes when developed in patches of quartz.

Comment:

The original siltstone has undergone silicification, felspathisation and dolomitisation.

B84, TS C 34964

Locality: Southern end of cut, two benches up from bottom. South west tip of slump.
Map Ref. 316409

Rock name: Kaolinised silicified rock with malachite.

Main features:

The rock is friable and deeply weathered due to its kaolin content. In thin section the main constituents are coarse grains and aggregates of quartz and a matrix of kaolinite which has corroded the quartz marginally and along fractures and grain boundaries. A few patches of microcline persist but in a strongly altered form.

Patches of fibrous malachite and amorphous limonite have replaced both kaolinite and remnant quartz. The kaolinite absorbs pink stain from the alizarin red but a few pink patches are composed of fibrous calcite.

Comment:

The rock has been subjected to silicification, felspathisation, kaolinitisation and redistribution of copper and iron.

B86, TS C 34965

Locality: South east side of cut, three benches up from bottom. Middle of slump.

Map Ref. 318414

Rock name: Kaolinitised, silicified, felspathised ? siltstone.

Main features:

The rock is fine grained, buff coloured, friable and bedded. In thin section the rock is a mass of fine grained clay minerals of both kaolinitic and montmorillonitic types. A preferred orientation is exhibited by the montmorillonite flakes, which may be original to the rock. The kaolinite flakes are random in orientation.

Occasional fine grains of quartz persist in the main part of the rock but most of the quartz occurs as coarser grains in lenticular patches. Even this is not abundant. A few grains of plagioclase and microcline are also identifiable in the coarser patches.

Grains of limonite, probably after pyrite, are scattered throughout the rock and are concentrated into stringers along the bedding.

Comment:

The kaolinitisation has obscured most other features but from the oriented clay and grains of limonite, the original rock was probably a pyritic siltstone.

B87, TS C 34966

Locality: Fifteen metres north of B86 on same bench.

Map Ref. 319416

Rock name: Dolomitised, silicified ? siltstone.

Main features:

There are enough similarities between this specimen and B86 for an assumption of a similar origin as a siltstone. The rock is buff coloured with a weak preferred orientation and grains of limonite probably pseudomorphing pyrite. Quartz occurs as scattered fine grains and as patches of coarse grains. Scattered grains of microcline are visible and a few mica flakes remain, giving the rock a weak bedding.

The major difference between this rock and B86, only 15 m away, is that the rock has been largely replaced by fine grained dolomite rather than kaolinite.

Comment:

Specimens B87 and B86 are roughly along strike from each other and in relatively close proximity. B87 is, on the other hand, closely similar to B83, some 30 m distant. It would be instructive to plot the limits of each type of alteration, from silicification to the redistribution of copper carbonates. The shape of the areas affected by each type would be a strong indication of whether it is strata-bound, fault-controlled or spread from a pipe-shaped conduit.

B94, TS C 34968

Locality: North east side of cut, four benches from the bottom.

Map Ref. 323428

Rock name: Kaolinised ? tuff.

Main features:

Pervasive kaolinisation has largely obscured the original fabric of the rock but those traces that remain are not of regular bedding. Sericite flakes in one corner of the thin section are oriented in a completely random manner and cover an area which appears to be a detached fragment rather than a stratiform bed. Fresh grains of microcline and plagioclase in the matrix of the rock suggest rapid deposition and lithification following fragmentation. Thus there is evidence to indicate, though not to prove, a volcanic provenance for the original rock, and more probably a direct deposition of pyroclastic materials of various grades rather than a reworking of volcaniclastic debris into a sediment.

Kaolinisation has affected the whole rock but not to the extent of complete replacement. Even without magnification the effect is seen to be patchy. In some parts the only effect is an increase in the volume of a kaolinitic matrix leaving detrital quartz and even felspars unaltered. In other parts almost the whole rock has been converted to feathery kaolin. The different volume changes have produced disruptive forces within the rock which have broken up and displaced quartz veins. The corrosive power of the kaolin-bearing solutions is illustrated by the embayment of the broken fragments of quartz. A more severe kaolinitisation would have completely replaced even the coarse quartz.

Comment:

The rock may be near the margin of the area affected by kaolinisation. There is no evidence of felspathisation, dolomitisation or economic mineralisation but the kaolinite may have obscured earlier alteration. The felspar recognisable optically is detrital and does not amount to anything like 85%. Yellow colouration may be due to absorption of cobaltinitrite by kaolinite.

B97, TS C 34969

Locality: Bottom of pit, southeast side. North west corner of slump.

Map Ref. 317416

Rock name: Siltstone

Main features:

The specimen has a clear sedimentary texture derived mainly from clay minerals, illite or montmorillonite, with a strict preferred orientation. The sediment has been subject to a moderate degree of recrystallisation of quartz in lenticular patches and discontinuous bands. There is a substantial proportion of kaolinite present but detrital quartz and felspar grains are neither corroded nor altered and the kaolinite is probably original to the sediment. The fresh felspars are possibly evidence of a volcanic contribution to the siltstone but the evidence of sorting and bedded deposition indicates that the rock is a normal water-laid sediment.

There is a substantial proportion of amorphous limonite, partly as detrital grains, probably after pyrite, and redistributed into veinlets. Some of the brown translucent mineral is possibly jarosite.

A mineral not encountered in many specimens described earlier is apatite. This appears to occur as detrital grains but is also involved in recrystallisation processes. Apatite becomes quite coarse grained in patches of recrystallised quartz, particularly in the vicinity of a vein of quartz with an unusual banded texture.

Comment:

The highly stained hand specimen appears to contain a major proportion of potash felspar (80% in the consultant's report). As in several specimens examined previously, there is not enough identifiable felspar in the thin section to account for the extent of cobaltinitrite staining. Either potash felspar is present in grains too fine to identify or the stain is being absorbed by kaolinite.

The presence of apatite in the rock and its participation in recrystallisation process raises the possibility that copper-bearing phosphates are present.

B105, TS C 34971

Locality: North east side of cut, five benches from bottom. Map Ref. 324426

Rock name: Siltstone

Main features:

The rock has a finely bedded texture outlined by clays of both low and moderate birefringence and by translucent material which is probably limonite but may include organic matter. Quartz and felspar tend to be angular and mainly equidimensional but some elongated, even splintery, quartz grains are present and tend to be strictly oriented. Splintered quartz and fresh felspars are often taken to indicate a volcanic source, minimal

abrasion during transport and rapid burial and lithification. The sediment is water laid and well sorted but it is possible that a close volcanic source provided much of the detritus. However, there is no evidence of volcanicity such as cuspate glass shards. Both plagioclase and microcline are present.

Small spheroidal and lenticular patches of recrystallised quartz, with a pleochroic green mica in places, are the only evidence of recrystallisation. No sulphide was seen.

Comment:

The specimen exemplifies the country rock of the Burra mineralisation with almost no subsequent alteration.

B107, TS C 34972

Locality: Northeast side of cut, 35 m north west of B105 on same bench.
Map Ref. 324429

Rock name: Kaolinised, felspathised, silicified ? siltstone.

Main features:

The main constituents are the mass of fine grained kaolinite which makes the hand specimen crumbly, a large proportion of relict microcline and a lower proportion of plagioclase and quartz. The felspar and quartz grains are indistinct in outline and highly fractured, with kaolinite replacement along fractures. The poor definition of grain boundaries is due to embayment and pitting by kaolin-bearing solutions. Co-sedimentation of kaolin and felspar would produce sharply defined grain boundaries. Some degree of grain-size sorting would be evident and adjacent but detached grains would not be in optical continuity as fragments of a felspar wedged apart by alteration are seen to be.

Other constituents are dispersed, very fine grains of sericite mica, a few grains of a pleochroic green epidote and abundant grains of limonite, possibly rejected during kaolinisation.

Comment:

The high percentage of felspar mentioned in the consultants report includes kaolinite. No dolomite was seen.

B116, TS C 34973

Locality: North end of cut, five benches from bottom near old workings.

Map Ref. 317436

Rock name: Mineralised siltstone.

Main features:

The rather friable siltstone has a high kaolinite content but of primary depositional origin rather than from secondary kaolinitisation. A well marked bedding is due to concentrations of sericitic mica and clay, probably illite, in strictly oriented bands. Angular to irregular grains of quartz and microcline are surrounded by a matrix of kaolinite and are almost certainly of detrital origin.

Recrystallisation of quartz into coarse and medium-grained mosaics has taken place in lenticular patches and irregular bands which in this specimen are also filled with opaque iron oxides with a limonitic alteration product. Much of the oxide is pseudomorphous after euhedral pyrite and there is some evidence of copper. Malachite occurs in patches and thin veins and occasionally as fringes round opaque nuclei.

Part of the mineralisation is clearly of the latest type but the occasional alteration of sulphide copper to malachite may be of earlier date, although there is no evidence of dolomite in the specimen.

Comment:

Two items of ore genesis not previously encountered in these specimens are that pyrite is concentrated with quartz in early silicification and that dolomite may not inevitably be associated with the conversion of sulphide copper to malachite. The affinity of much of the malachite is not entirely clear.

B127, TS C 34973

Locality: Northern end of pit, two benches from top.
Map Ref. 324443

Rock name: Dolomitised ? siltstone.

Main features:

The major part of the rock consists of a fine grained carbonate which takes a light pink colouration with alizarin red stain. Windows in the carbonate reveal medium grained quartz and their alignment gives a bedding trace.

The carbonate is finer grained than has yet been encountered and is a deeper pink but the textural relationship between it and the quartz of the 'windows' is identical to that of other samples described.

Comment:

Despite the finer grain and possible higher calcium content of the carbonate, the textures displayed in relation to the earlier quartz suggest that the dolomite is secondary rather than primary.

B128, TS C 34977

Locality: Ten metres west north-west of B127.

Map Ref. 323443

Rock name: Dolomitised siltstone.

Main features:

Fine grained dolomite is again the major constituent but in this case has not taken up any pink colouration from the alizarin red stain. Differences in grain size of the dolomite, the alignment of unaltered quartz grains and the preferred orientation of rather coarse grained muscovite flakes all give the rock a fine lamination.

The mica flakes are corroded marginally, disrupted and partly replaced by the dolomite and are probably original detrital constituents of the sediment. Quartz grains which remain unreplaced are coarser grained than might be expected in a finely laminated sediment and have almost certainly been recrystallised. The mica flakes are similarly coarse grained and the cause may be assumed to be the same. It has been noted in other specimens that the recrystallisation tends to be patchy and may not have affected adjacent rocks.

Comment:

Dolomitisation appears to have followed a patchy recrystallisation of what is assumed to have been a finely laminated siltstone. The grain size of the dolomite to some extent duplicates that of the original rock. Dolomitisation of coarse grains is incomplete.

B138, TS C 34978

Locality: Extreme northern end of cut, third bench down from top.

Map Ref. 321465

Rock name: Dolomitised ? siltstone

Main features:

The rock is almost identical to specimen B127. The fine grained carbonate which forms the major phase is stained pink and may be calcium-rich. Textures clearly indicate that it has invaded and replaced a quartz mosaic, probably recrystallised from an original siltstone. A very few grains of plagioclase were seen and a few untwinned and irregularly twinned felspars which are probably orthoclase and microcline respectively. In the absence of felspar a possible origin as a chert might be contemplated. Mica is not present.

Comment:

Textural features, such as marginal embayment of quartz and euhedral dolomite crystals included in quartz, are the same in this specimen as in all others described and a suggestion of late dolomite replacing an earlier quartz mosaic is inescapable.

B141, TS C 34979

Locality: Two metres west of B116, near old workings, sixth bench, north west side of cut.

Map Ref. 316436

Rock name: Agglomerate, slightly kaolinitised.

Main features:

The rock is a jumble of fragments of diverse lithologies, both sedimentary and volcanic. It is not a brecciated rock of uniform type. Recognisable felspar amounts to only a trace.

There has been a moderate amount of kaolinisation of the matrix of the rock but the clastic fragments are not notably affected. Some of the matrix clays, as well as those of the clasts are of higher birefringence than is typical of kaolinite and are probably montimorillonitic. No volcanic glass has survived.

A patchy malachite mineralisation is dispersed through the rock. The patches are composed of radiating fibres of malachite and sometimes have a nucleus of opaque material, possibly copper bearing sulphide originally. Most patches are rounded but some are irregular or even elongated. A few occurrences of malachite are in thin veinlets. Round the margins of the patches the fibrous carbonates are often stained pink and are presumably calcitic in composition. Some patches are emplaced interstitially to quartz grains and have a sieve texture while others apparently replace the whole rock.

Comment:

In this specimen the two phases of malachite mineralisation occur together in the absence of dolomite. This suggests that the process may not be as clean cut as examination of specimens earlier indicated. The alteration of copper-bearing sulphide and redistribution of fibrous malachite may occur as a single process. Solutions which are the agency for the process may not simultaneously dolomitise country rock.

The yellow colouration of patches of the hand specimen is almost certainly due to sericitic mica rather than microcline.

B157, TS C 34980

Locality: Near north east limit of pit, two benches from top. Map Ref. 327423

Rock name: Dolomitised, silicified sediment.

Main features:

The same fine-grained, pink stained carbonate that was seen in B138 forms the main component of this specimen. Rounded and anular patches of coarse quartz mosaic are enclosed in, and partly covered by, the carbonate, which is taken to be a calcium-rich dolomite. Kaolinised patches, often with rectilinear outlines, are probably pseudomorphous after felspar

Comment:

The sediment has been affected by silicification, felspathisation, dolomitisation and kaolinisation. The relationship between dolomite and kaolinite is not clear but both are secondary.

B184, TS C 34988

Locality: South end of cut, two benches up from bottom. Map Ref. 316409

Rock name: Contorted, altered rock.

Main features:

The specimen is friable due to a substantial kaolinite content. The hand specimen shows no staining with sodium cobaltinitrite but many grains have been lost. The most outstanding feature is a contorted foliation.

In thin section the foliation is seen to be crenulated in places as well as contorted. It is formed by a mass of ragged mica flakes altered to both illite and kaolinite and crystallised with a patchy limonitic material which is a deep red colour in

places, possibly due to a high copper content. The micaceous bands have been broken up as well as contorted.

Between the bands are patchy areas of microcline and quartz. The microcline is broken up in places into splinters and cleavage fragments. It is poorly twinned but even untwinned grains are probably microcline rather than orthoclase as they resemble the rest of the felspar in every other respect. the microcline is heavily turbid due to exsolved granules of iron oxide and is altered marginally and along cleavages to kaolinite. It is patchy in distribution and its overall abundance is hard to estimate. It is in the order of 20-30%.

Quartz is present in similar abundance and with a patchy distribution between the micaceous bands. The grains are highly fractured, embayed and rounded by corrosion. The corrosion has been effected by solutions depositing both kaolinite and semi-opaque oxide material. The latter is mainly a light yellow brown limonite but in places has a deep red colour, possibly due to a high copper content.

Comment:

The disturbance which has affected the rock is local and may not be tectonic in origin. Breaking up the quartz and felspar and contorting the micaceous bands has been accomplished due to the mobility produced by kaolinisation. The stresses involved may also have been produced by volume changes accompanying the alteration to clay of both mica and microcline. The original nature of the rock has been largely obscured by these changes and by the earlier recrystallisation of quartz and the introduction of low temperature microcline, mica and ore minerals, probably sulphides initially. The microcline does not amount to 60%. There does not appear to be enough evidence to justify the

proposal of a volcanic origin for the rock, which is more likely to have been a normal siltstone such as is the major country rock type in the area of the open cut.

B185, TS C 34986

Locality: Same bench as B184, 15 m south west.
Map Ref. 315408

Rock name: Silicified and sericitised rock.

Main features:

The main constituents of the rock are granular quartz and a felted mass of sericitic mica, clays and a pleochroic green chlorite. Fractured and poorly crystalline microcline is a minor constituent.

Quartz grains are both rounded and embayed by solutions depositing sericitic mica and the other platy minerals. The felted mass penetrates grain boundaries and corrodes the grains marginally. At first embayment gives the grains an irregular shape but finally the grains are rounded. Enough quartz remains to show that the rock was a mosaic of quartz grains before invasion by the solutions which deposited the felted minerals.

A relatively minor amount of microcline was introduced earlier, possibly not much earlier, than the sericitic mass which is the major type of potassium metasomatism in this rock.

The rock is considerably less disturbed than B184.

Comment:

The earliest recognisable feature of the rock is recrystallisation of quartz. The high quartz content raises the possibility that the rock may originally have been a chert. The next event was the introduction of a minor quantity of low temperature microcline, followed by a substantial amount of

sericitic mica and clay, possibly at different times. There is no evidence that the rock was ever dolomitic but complete replacement of earlier dolomite is possible. There are relatively fine grains of opaque minerals present but no evidence of copper mineralisation.

B199, TS C 34994

Locality: East side of pit near centre, one bench up from base.

Map Ref. 317419

Rock name: Dolomitised shale.

Main features:

The rock consists of an ultra-fine grained mass of clay minerals with low birefringence, fine flakes of mica with a strict preferred orientation, a few scattered grains of microcline, plagioclase and quartz and wide-spread, fine-grained, dispersed crystals of dolomite. The hand specimen has taken a light cobaltinitrite stain which is almost uniform over the section. This is not related to the relatively few scattered grains of identifiable microcline and must be due either to a widely spread microcline which is too fine to be identified or to absorption of the stain by the fine sericitic mica, probably the latter. The scattered crystals of dolomite vary in shape from anhedral to euhedral but there is little doubt that it is the youngest phase, apart from a few patches and a thin vein with coarse quartz and dolomite.

Relatively coarse grained and well-shaped crystals of iron oxide, probably after pyrite, have been introduced, in several instances with a 'gangue' of quartz, apparently after chalcedonic silica. There is no evidence of copper minerals.

Comment:

This example of shale adds a fifth lithology to the succession of country rocks which includes siltstone as the major rock type and minor chert, pyroclastics and lava. The abundance of potash felspar is uncertain and cannot be determined optically. The dolomitisation differs only in continuity from many other specimens examined.

B215, TS C 35001

Locality: In old workings at bottom of cut near centre. 15 m east of B5.

Map Ref. 317423

Rock name: Altered ? tuff or ?? lava/

Main features:

The specimen is quite heavily stained with cobaltinitrite in a fairly even distribution although the rock is severely brecciated. In this section much of the stain can be seen to originate in optically identifiable, though often poorly crystalline, low-temperature microcline. Much of the matrix of the rock is very fine grained, however, and appears to be kaolinitic rather than felspathic. Since this is material for which optical methods are not ideal in identification, the question of pervasive, fine grained microcline or kaolinitic absorption of cobaltinitrite stain is unresolved.

Another problem relating to the microcline is resolvable with some degree of confidence. The optical properties of the microcline are relatively constant throughout the thin section but two quite distinct modes of occurrence are represented. In one case the mineral occurs in large, irregualr patches of poorly-defined grains of generally fine grain size. These

patches are almost certainly of secondary, replacement origin which in other specimens has been correlated with copper mineralisation. In the contrasting situation the microcline occurs as coarse-grained, sharply defined and sometimes euhedral crystals. Similar forms were observed in specimen B50, about 45 m south of B215 in the bottom of the cut. In describing B50 it was suggested that crystals of this type might be phenocrysts of volcanic origin. The same possibility applies here and is compatible with the outcrop of volcanic rocks at B52 and B53. In the latter case a tentative identification of a lava was made. For specimen B215 there is no petrographic evidence such as flow banding to support such a suggestion but the possibility is none the less raised as a potential explanation of the brecciation. If this is in fact autobrecciation produced by flow during the cooling of a lava it would account for the required stresses in an area where tectonic stress appears to be minimal.

The similar composition of the proposed phenocrystal microcline to that of the secondary microcline may be attributed to potash metasomatism of phenocrysts at the same time as the matrix or groundmass.

Frequent apatite crystals testify to the rejection of calcium and the presence of phosphate in the alteration process.

Another feature worthy of mention is the scattered occurrence of a brown, weakly pleochroic, acicular mineral with high birefringence. It occurs as irregular and fragmentary patches and also as bundles of columnar to acicular prisms with a gangue of quartz. The refractive index of the mineral is too high to obtain a good extinction angle but it is probably

straight. However, cleavage and twin composition planes at an angle to the long axis suggest that the mineral may be monoclinic. It is possibly a rare phosphate.

No sulphides remain and there are few opaque grains.

Comment:

There appears to be consistent evidence for a NNW-SSE outcrop of volcanic rocks possibly including lavas, about 165 metres long, between samples B116 and B215.

B218B, TS C 35004

Locality: Bottom of cut near centre. 2.5 m west of B53
Map Ref. 317422

Rock name: Mineralised, dolomitised quartz-microcline rock.

Main features:

Dolomitisation covers much of the specimen but, from what evidence remains uncovered, the original rock consisted of an intergrowth of coarse quartz and microcline cut by even coarser grained, highly strained quartz in a network of veins. The vein quartz has been granulised and broadly fractured but retains a high degree of strain polarisation.

Dolomitisation post-dates felspathisation and is apparently younger than even the vein quartz.

This specimen demonstrates very well the two stages of malachite mineralisation and their relationship to the dolomite. The first generation of malachite surrounds and incorporates opaque material, presumably originating as chalcopyrite, and is either neatly intergrown with dolomite crystals or has inclusions of perfect dolomite rhombs. This malachite is contemporary to slightly older than the dolomitisation. It is not necessary for dolomite to be in

contact with opaque material for malachite to be formed. It appears that solutions carrying calcium, magnesium and carbonate ions will react with copper-bearing sulphides without precipitating dolomite in the immediate vicinity. The second stage of copper carbonate mineralisation only involves malachite in this specimen, in contrast to specimen B54 in which azurite occurs. The malachite is redistributed in thin veinlets which may be seen to cut dolomite grains. A small amount of calcite is also found in these veinlets.

Comment:

Although the coarsest of the quartz veins appears to be free of dolomite, hence possibly later than dolomitisation, in thin section it is seen to be invaded and marginally corroded by both dolomite and malachite.

B218E, TS C 35003

Locality: As for B218B.

Rock name: Mineralised and kaolinitised ? chert.

Main features:

The least altered parts of the rock consist of a fine to medium grained intergrowth of minerals with a low birefringence, most of which appear to be quartz. This is the justification for a tentative identification of the rock as a chert. Most of the textures are those of authigenic recrystallisation and it is certain that, if any volcanic glass were originally present, there would be no remnant of it left after the recrystallisation.

Other parts of the rock are more strongly altered by coarse recrystallisation of quartz and by replacement of the whole fabric by clay minerals, by a few flakes of muscovite and by a brownish green tourmaline which occurs as bundles of acicular crystals.

Malachite occurs as fragmentary patches and in a network of veinlets. A small amount of calcite is present in the veinlets, usually in a fibrous form which is also common in the malachite.

A fine grained mineral of fibrous to platy habit and moderate to high birefringence lines the walls of many of the late, malachite-bearing veinlets and fills veinlets and spheroidal to vermiform cavities independently of malachite. This has been identified by the consultant, on the basis of X-ray diffraction, as chrysocolla.

Comment:

The original rock was possible a chert but this identification is conjectural and based on an apparent high silica content. No original textures remain and the evidence would offer no support for a proposed volcanic origin. The proportion of microcline is very low.

B243, TS C 35009

Locality: Extreme southern end of cut, three benches down from top.
Map Ref. 315404

Rock name: Siltstone.

Main features:

The rock is a normal fine-grained siltstone consisting of quartz, clay, microcline, plagioclase and iron oxide. Platy minerals and limonite stringers give the rock a bedded fabric.

The fresh detrital felspar may suggest a volcanic origin for some of the detritus but the rock is a normal well-sorted water-laid sediment.

A system of lenticular patches of coarse grained quartz with a preferred orientation conformable to the bedding and with margins outlined by iron oxide impart a spotted texture to the rock. The lenses are sedimentary in origin although the contents have been recrystallised. Since the lenses are bedding-controlled they must be pre-diagenetic in age and must originally have been disc-shaped or spherical (since compacted) bodies which have been replaced by or were originally filled with silica, which may have been colloidal.

Comment:

There is no evidence as to whether the forms were pseudomorphous, algal or due to depositional features such as bubbles or ripple markings. There does not appear to be sufficient foundation for the proposal of a volcanic origin, with the quartz lenses as infilled vesicles.

No fresh pyrite was seen but much of the granular opaque oxide is probably pseudomorphous after pyrite.

B253, TS C 35011

Locality: North west side of cut, second bench from bottom.
Map Ref. 315432

Rock name: Mineralised quartz-microcline rock.

Main features:

Original features of the rock which are still discernible consist of coarse grained quartz and microcline. However, these features are probably themselves secondary and the ultimate origin of the rock may have been a fine grained sediment such as

a silt. The absence of staining in the abundant microcline is possibly due to the impregnation of the crumbly sample with an epoxy resin.

The physical disruption of the sample is probably due to kaolinisation but the fragments are hardened by chalcedonic silica and chrysocolla. Alteration of the microcline itself tends to produce sericitic mica but a wholesale kaolinisation has proceeded around the fragments. The brown, highly birefringent mineral noted in specimen B215 occurs in scattered fragments in B253 and a few red-stained patches may be composed of calcite, though this is not identifiable optically. Kaolinite is also faintly pink.

Irregular patches of malachite appear to be replacing microcline.

Comment:

The rock is highly felspathic, the absence of staining may be due to impregnation with epoxy resin. Fragmentation may be chemical but, in view of the proximity to the Kingston Shear Zone, could be tectonic. Mineralisation is of the late stage, redistributed type.

B259, TS C 35012

Locality: North west side of cut, two benches from top.
Map Ref. 313441

Rock name: Micaceous recrystallised siltstone.

Main features:

The rock is similar in many respects to B184 and B185. Micaceous bands are slightly contorted and frequently disrupted. The mica is sericitic muscovite but is stained with

limonite. There is substantial granular limonite present which, as in B184, is concentrated in the micaceous bands.

Between the bands of fine grained mica are coarse grained bands of quartz and microcline. There is a tendency for these phases to occur in separate bands but intergrowths of the two are not uncommon. Quartz grains are fractured and vary considerably in size but tend to be equidimensional. Many of the microcline grains are elongated almost to the point of being described as vermiform. A little mica occurs interstitially to the quartz and microcline.

Comment:

One patch of fine grained quartz may be close to the original rock but even that may be partially recrystallised. The coarse microcline must have been introduced under conditions of moderate stress. There is no evidence of dolomite or of a volcaniclastic origin.

B261, TS C 35013

Locality: Same bench as B259, 40 m to the north.
Map Ref. 314444

Rock name: Kaolinitised quartz-microcline rock.

Main features:

The rock is very similar to specimen B259 except that the sericitic mica has been altered to clay minerals, the most abundant of which is kaolinite, and that the oxidised iron phase includes a fibrous, highly birefringent mineral in spherulitic grains which is probably jarosite. The quartz and microcline are almost identical to those of B259.

Alteration of the sericitic mica has left a few highly birefringent flakes, which may be relict mica or illitic clay, and some moderately birefringent flakes which may be illite or montmorillorite, but kaolinite with low birefringence is the major phase. In one area of the section the kaolinitic alteration has affected the whole rock.

Comment:

The origin of the rock is probably sedimentary and a reasonable conjecture would be that it was a siltstone but no direct evidence remains.

B270, TS C 35018

Locality: NW side of cut, three benches from top, 25 m east of B259.

Rock name: Dolomitic sandstone.

Main features:

The rock is a medium grained sandstone consisting of angular to sub-angular quartz and microcline, a little ragged and altered muscovite and a large proportion of dolomite.

The dolomite consists of large and often well-shaped crystals and finer grains which form an irregular mosaic in the matrix of the rock. Much of the dolomite is probably detrital but the rock has not escaped some degree of recrystallisation and much of the matrix dolomite is possibly of secondary origin.

Comment:

This is the first example enmcountered of a detrital dolomite. Even this has been modified by minor dolomitisation. Lithic fragments of microcrystalline potash felspar were not observed and the evidence does not sustain a volcanic origin.

B271, TS C 35019

Locality: Same bench as B270, 20 m to south.

Map Ref. 314440

Rock name: Dolomitised quartz microcline rock.

Main features:

In this specimen fine grained, dolomitic alteration dominates over any detrital dolomite which may have been present. In addition, patches of extremely coarse grained dolomite are incontestably of secondary origin.

Remnants of quartz in 'windows' in the dolomite consist of a mosaic of medium grains intergrown along simple grain boundaries with 120° triple junctions. These are equally incontestably recrystallised and could not be primary detrital grains.

Evidence in the case of microcline is not as overwhelming but among the few grains visible some are of the elongated shape which is seen in sections described earlier. These could be, but are very unlikely to be, of detrital origin. A few grains are intergrown in clusters. It is a reasonable assumption that the microcline, too, is secondary.

Comment:

Even considered on its own limited evidence this specimen appears likely to have been composed of secondary quartz and microcline before dolomitisation. Taken with the large number of other silicified and felspathised specimens in the batch under investigation, the conclusion is virtually inescapable that the rock was already highly altered before dolomitisation took place. The original nature of the rock is obscure.

B285, TS C 35027

Locality: Ore stockpile.

Rock name: ? lava, ? porphyry, ? tuff.

Main features:

The rock has many features in common with the other specimens from the central zone which have been identified tentatively as of volcanic origin. It has a few well-shaped microcline crystals, which may be phenocrysts, as well as a little patchy and poorly-defined microcline which may be introduced. A fine-grained ground mass is cut by fine quartz veins. Other patches appear to be partly absorbed xenoliths.

The major difference between B285 and rocks described as volcanic earlier is the substantial (c 15%) content of plagioclase. This is only identifiable optically as phenocrysts and the percentage is underestimated if there is plagioclase in the ground mass. Maximum symmetrical extinction angles are in the order of 14°. On this basis the plagioclase composition is either a calcic albite or a sodic andesine. Since the optic sign appears to be negative, the plagioclase is identified here as a sodic andesine, close to oligoclase, rather than the albite identified by the consultant. It may be relevant that one of the relict xenoliths appears to have an andesitic texture, which was also observed in specimen B50.

Other felspars are either untwinned or have such a complex twin pattern as to be unidentifiable. Possibly high temperature felspars of mixed composition have unmixed into potash fespar and plagioclase in small domains.

Other phases present which are worthy of note are: apatite; the brown acicular mineral with high birefringence encountered elsewhere and an opaque mineral in irregular grains frequently surrounded by a red-stained zone.

Comment:

The textural and compositional similarity and similar xenolith content of specimen B285 and the other rocks of presumed volcanic origin in the lower part of the cut suggest a co-magmatic origin. The difference marked by the presence of plagioclase is perhaps the result of a less complete penetration by solutions carrying microcline. In this case the rocks of igneous origin may not only be co-magmatic but also contemporary. There is no textural evidence to permit identification of the mode of emplacement of specimen B285 and the word 'porphyry' is only included because it has been used elsewhere to describe the rock. Certainly there is no evidence of any significantly different mode of formation, for example an intrusive rather than extrusive origin. Only the field relationships provide the key to the problem and these may not be readily determined.

DISCUSSION

The specimens examined are not necessarily representative of the country rocks of the district since they were chosen particularly from the Burra open cutpit to represent highly altered and genetically controversial material. On this basis, and despite the fact that the local formation is known as the Skillogalee Dolomite, the dominant lithology of unaltered rock is a fine grained and, in places, finely laminated siltstone. The presence of fresh grains of detrital felspar and relatively

unabraided splinters of quartz suggest the possibility of a volcanic origin with rapid sorting and lithification of at least some of the detritus. The siltstone may thus be a purely local facies of a dominantly dolomitic formation.

Among the specimens examined only one was recognisable as a sedimentary dolomite and the extent of secondary dolomitic replacement was problematical in this sample. Other sedimentary lithologies of minor abundance among the samples examined were shale and possible chert.

Despite the high degree of alteration it has been possible to identify with reasonable confidence a series of volcanigenic rocks which occur consistently in a north-south belt down the length of the cut near the bottom and just west of centre. The exact nature of these rocks is not conclusively identifiable but tentative identifications of lava, tuff and agglomerate have been made. The samples include a specimen representing (but not in place) a rock described in earlier reports as an intrusive porphyry. There does not appear to be any substantial difference between this rock and the specimens here identified as volcanic in origin, apart from the presence of a plagioclase which may simply have survived the potash metasomatism affecting the other rocks. The concept that the igneous rocks, despite their current alkali-rich composition, may originally have been dacitic or even andesitic, is compatible with the presence of apatite and of the nature of some xenoliths. The known association, in 'copper porphyries', between acid to intermediate calc-alkali plutons and copper sulphide mineralisation may be of some significance in this context.

Within the Burra open cutpit it is possible to identify five successive episodes of mobilisation, recrystallisation and alteration and to relate the primary copper mineralisation to one of these episodes, the introduction of microcline, and the conversion of copper sulphide to malachite to another, dolomitisation. Final redistribution of copper carbonate as both malachite and azurite occured as the latest episode of mobilisation.

The first episode to affect the country rocks involved the recrystallisation of quartz. This was initiated in dispersed patches but in places involved conversion of the whole rock into a mosaic of grains in a state of equilibrium with simple grain boundaries meeting in 120° triple junctions. It is open to question whether the recrystallisation was isochemical or whether it involved the introduction of exogenic silica. The identification of some rocks as possible cherts is based on the presumption that nothing substantial was added or subtracted from the rock and that the quartz now recrystallised represents the original composition of the sediment. The presence of quartz veins, however, demonstrates that some silica was in fact mobile and may possibly not have been restricted to identifiable veins.

Another component which was possibly mobile at this stage is iron, probably as pyrite. Sedimentary, syngenetic pyrite was an original component of some siltstones and has visibly undergone recrystallization. The mineral is now a limonitic oxide but tends to be associated in a recrystallised form with the veins and patches of coarse grained quartz. In some cases coarse grained opaque iron oxide occurs in patches with quartz which shows evidence of a chalcedonic origin.

The most important episode of alteration (episode 2) from the economic point of view consists of widespread replacement of earlier material, whether already recrystallised or not, with an almost perfectly triclinic, non-perthitic and therefore low temperature, microcline. This episode involved solutions which carried copper-bearing sulphides, almost certainly chalcopyrite or another iron-copper sulphide phase since later malachite is associated with an opaque iron oxide. This constitutes the primary copper mineralisation. Muscovite mica is involved in this episode of recrystallisation, as either mimetic growth of sedimentary mica, conversion of clay minerals to mica and/or the direct precipitation of muscovite from solution.

Chronologically the next episode of alteration (episode 3) involves the dolomitisation of sediments and their recrystallised or felspathised derivatives. The extent of dolomitisation varies somewhat between samples but, apart from the coarsest vein quartz, the alteration affects the rock as a whole and is not selective between constituents. The dolomite tends to be calcium-rich in some areas. During this episode, copper was leached out of copper-bearing iron sulphides and was reprecipitated as malachite, sometimes at a distance from the former sulphide, sometimes as a haloe around grains of opaque oxide, and sometimes remote from the dolomite itself. The malachite is in the form of patches and irregular veins.

The last major alteration (episode 4) was an episode of kaolinisation which affected all previous material, including dolomitised rock. The process, which is hydrothermal rather than meteoric, started with expansion of the clay matrix by corrosion of clasts in the sediments but ended by total replacement of all rock constituents. In a few specimens the alteration is to montmorillonite as well as, or even in place of, kaolinite.

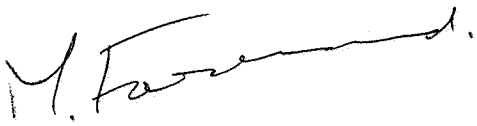
The final episode involving mobile solutions (episode 5) is quantitatively minor on the evidence of the specimens examined. The nature of the solutions is uncertain but the constituents precipitated from them are malachite, azurite, calcite, chrysocolla and chalcedony. Wholesale alteration is not involved in this episode but the copper carbonate and colloidal silica were redeposited in a network of fine veinlets and small patches. Both carbonate and silica tend to be fibrous.

Minor components of mobile phases are boron and phosphorus.

Thus, the primary and secondary copper mineralisation at Burra, on the evidence of the specimens examined, was emplaced in a sequence of siltstones with a volcanic association, which form part of the Skillogalee Dolomite Formation. The country rocks have been altered and mineralised by a series of hydrothermal solutions. The ore-body is not stratiform, is almost certainly epigenetic and may possibly be related to a diorite or granodiorite sub-volcanic pluton. Some of the solutions involved resemble late stage differentiates of a granitoid. The conjunction of a major earth lineament and a branched fault may have provided a channel up which volcanics, hydrothermal solutions and diapiric breccias have passed.

If the suggestion of a plutonic source rock at depth is correct, the ore grade may improve downwards. Carbonate alteration does not appear to have effected much concentration

and may even have produced a dispersion of copper. A gravity survey to target a drilling programme might be a useful exploration method.



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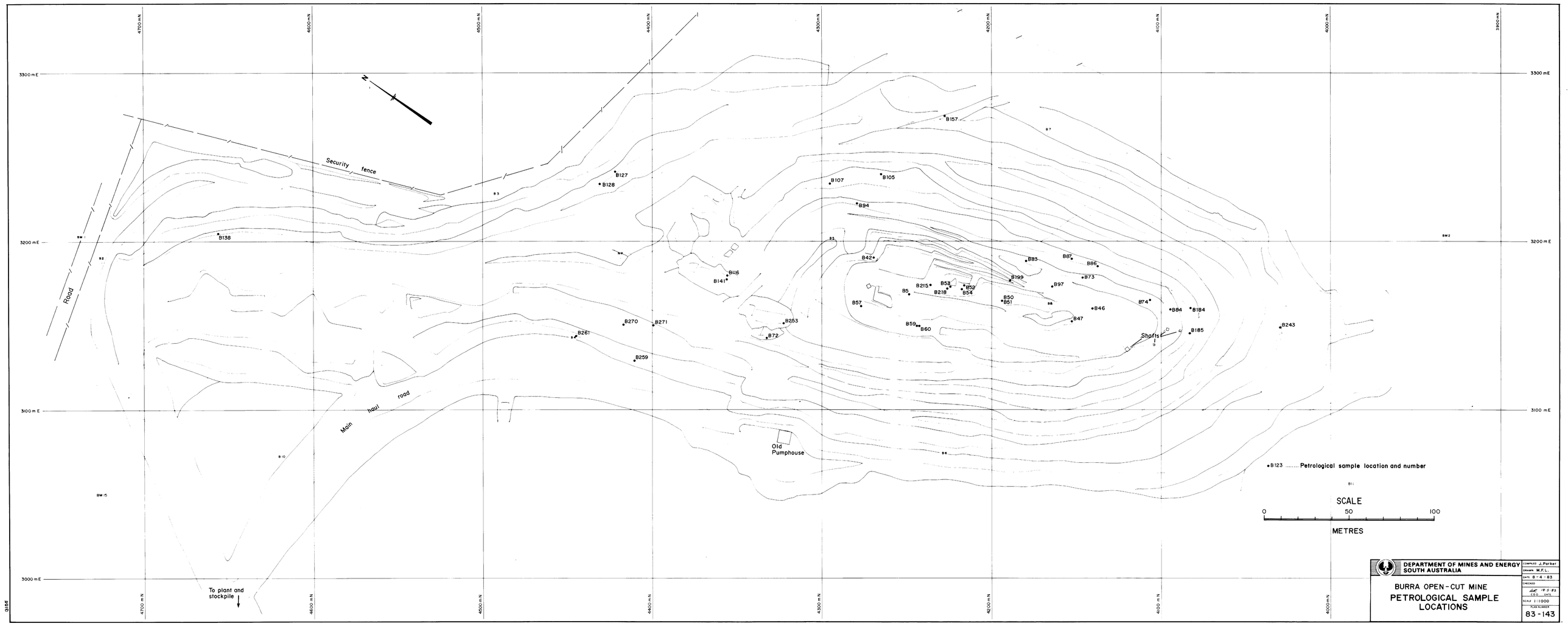
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Main haul road
To plant and stockpile
Old Pumphouse
Shafts
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B107
B105
B94
B127
B128
B138
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