THE UNIVERSITY OF ADELAIDE
DEPARTMENT OF ECONOMIC GEOLOGY

THE GEOLOGY OF AN AREA IMMEDIATELY SOUTH OF BURRA, WITH PARTICULAR REFERENCE TO MINERALISATION

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C O N T E N T S

SUMMARY

An area of some 25 sq. miles was investigated including Burra and the district due south of it.

The copper deposits of Burra, of such fundamental importance to the early colony, were discovered in 1843 and subsequently worked by the S.A. Mining Association, who obtained some 234,600 tons of ore of approximately 22% grade. The mine finally closed in 1877 due to cessation of mining, drop in the price of copper etc.

The area is essentially a part of the Mt. Lofty - Flinders Ranges and is of mature topography. The rock sequence consists of a series of marbles, limestone, dolomites, fluvio-glacials, quartzites and shales of Sturtian and Torrensian age folded into a series of gently north-pitching folds, the fold axes lying approximately 1 mile apart. Folding is most intense in the vicinity of the Burra Mine and the Princess Royal Mine, where a closed dome structure occurs. Strike faulting along the axes of anticlines is quite prominent, the Karinga Fault extending right through the area and having a stratigraphic displacement of up to 10,000 feet. The only igneous rock found was a felspar porphyry outcrop, lying about ¼ mile west of the Burra Mine.

Copper mineralisation consisting of mesothermal veins chalcopyrite, bornite and pyrite in a gangue of calcite, quartz with occasional barite is common throughout the area. These veins commonly occur in reverse strike faults. Supergene carbonate derived from the primary mineralisation is common, and is believed to have been formed by the precipitation of downward percolating acid copper solutions with carbonate wall - rock.

The two main mineralised zones of the area are the Princess Royal Mine where low grade veins occur in a brecciated and shattered zone at the axis of the dome structure, and the Burra Mine where low grade veins occurred in the brecciated zone between two strike faults. Precipitation of carbonate has been considerable at the Burra Mine, where the supergene ore occurred as a cigar-shaped "blanket". The primary ore was localised by the

intersection of the two strike faults with a series of dolomites and limestones.

From an examination of the area, the likelihood of finding a new orebody is remote, and the discovered orebodies appear either to be worked out or else uneconomic.

INTRODUCTION

An area of some 25 sq. miles was investigated, as shown by the included map. Some 14 days were spent in the field, this work being supplemented by air-photo interpretation, examination of thin and polished sections, and x-ray powder photo work.

Mapping was done directly on vertical air photos, from which a map was prepared by the slotted template method. All data were transferred from the photos to the map by tracing or resection. The map enclosed is largely a fact map, only some interpretation was necessary due to the similarity of rock types.

The area was investigated in 1939 by R. W. Segnit, also in 1942 by S. B. Dickinson. No real geological work was done before this, although some of the old mine plans indicate where ore occurred. The only previous mention of the geology of the area is in the Record of Mines of S.A. (1908), where it is mentioned that the "country rocks" (in the vicinity of the mine) are much broken and twisted, and consist of a cherty siliceous formation, crystalline white and grey limestone, blue slaty shales, and argillaceous sandstone.

HISTORY

The copper deposits at Burra, situated about 100 miles north of Adelaide were discovered by Strear, and Shepherd, who found specimens at the north end of F.H. Dutton's Princess Royal run in 1843. Soon afterwards, a bullock driver Thomas Pickett, found an outcrop of rich cuprite ore near Strear's find. The South

Australian Mining Association obtained an option on the northern 10,000 acres of the lease in 1845, and the Princess Royal Company obtained the southern 10,000 acres at £1 per acre. The latter however abandoned working in 1851 after hoisting only 588 tons of ore.

The S.A. Mining Association worked the Burra Mine for 29 years, producing some 234,600 tons of ore of grade approaching 22%. When the industry was at its height up to 600 teamsters would drive 6000-7000 bullocks to Port Adelaide, carrying ore for shipment to Swansea to be smelted. This was found expensive, as in 1849 the Patent Copper Company established a smelting works in Burra. At this stage 1400 men were employed by the mine.

The deepest shaft, Morphett's was a vertical one 600 feet deep, raising 2 million gallons of water per day to keep the mine drained.

In 1869, after a 2 year closedown open cut methods were used to mine poorer ore remnants, (Plate 12) gravity dressing having been installed to treat low grade ores.

The mine finally closed in 1877, after the oxidised ore had been almost completely mined out, and the deeper primary ore showed no possibilities. Other contributing factors to the cessation of mining were a significant drop in the price of copper, pumping expenses, depth of mining, railway freights and a decrease of grade in the open cut. Further information on production may be obtained from Dickinson's report.

The mines were of fundamental importance in the economic development of South Australia.

<u>PHYSIOGRAPHY</u>

The physiography of the area is essentially mature, consisting of well-rounded undulating hills of elevation 1500-2000 ft, trending more or less north - south, conforming to the geological trends of the area (see plate 6). Around Burra itself, there, appears to be very little relation between the geology and topography.

Trees are scarce, and the country is devoted to grazing of sheep, with occasional farming, except on the quartzite ridges which are useless.

The area is essentially a part of the Mt. Lofty-Flinders Ranges, no block faulting was found however. The average rainfall is 17.7 inches, falling off rapidly to the east, once the St. Vincent's Gulf-Murray River divide is crossed.

Rock outcrops are very sparse improving to the east with decline of rainfall. The water table lies 150 ft. below the surface at Morphett's shaft, in the other shafts this may be much less i.e. as close as 40 ft. to the surface.

Erosion has been moderate west of the Murravian Divide and very active east of this where the plains between ridges are covered with up to 50 ft. of coarse Recent alluvium brought down mainly from the hillsides. Earth movements have continued until Recent times, as indicated by the deep entrenchment of streams in alluvium (Plate 7).

The only evidence of an old peneplaned land surface may be seen in the vicinity of Stein's Trig Point, on the ridge due east of Burra, where the surface of the ridge as seen in silhouette on the skyline is amazingly flat.

Dickinson states that, "the Burra Mine area is actually within a more or less sheltered portion of the terrain which is more deeply dissected beyond the limits of the mine itself. Its sheltered position probably accounts for its preservation from erosion in post-Pliocene times. It may also account for the depth of oxidation and the large accumulation of secondary ore". No evidence can be seen for this statement: the mine area seems no more protected than any other as erosion has been fairly constant throughout the western portion of the area under examination.

STRATIGRAPHY

It is most difficult to divide the stratigraphic sequence in the Burra area into a number of well-tied parcels as there is much lensing, also rock types are so similar and grade into each other very slowly that boundaries are so indefinite as to be empirical, depending on the observer.

A general sequence however may be -

Recent - Alluvium

Precambrian -	(4) Shale - sandstone group)	Sturtian
	(3) Fluvioglacial group)	
	(2) Calc. shale group	
	(1) Limestone - dolomite group)	Torrensian
	(a) Upper limestone)	
	(b) Banded limestone)	
	(c) Marble)	

Igneous :- Felspar porphyry.

No unconformities exist in the district apart of course from the alluvium.

This sequence differs totally from that given by Segnit, as does my general interpretation, so much so that no attempt will be made to correlate Segnit's work with my own.

The sequence given above is essentially that given by Dickinson.

An attempt was made to correlate the area with areas further south. A direct correlation was made with the work of Robinson in the Marrabel district, using his own and air photos. It was attempted to correlate the work with the work of the Mines Department on the Kapunda Sheet, but structure in air photos was not continuous. However on the basis of the two fluvioglacial horizons that occur in the Burra and Marrabel districts which strike north-south and also occur in the vicinity of Kapunda to the south, it is considered that the area fits into the Torrensian and Sturtian sequence of the Adelaide system. The rock column in the Kapunda area is -:

<u>Sturtian</u>

8. Upper tillite - occasional erratics of quartzite, gneiss and granites in a green massive sandy matrix.
7. Flaggy arkose.
6. Coarse arkose.
5. Fine laminated blue shales.
4. Lower glacial - a few horizons of boulder tillite with erratics of granites, quartzite etc. Also grits, conglomerate and gritty quartzite with varved shale.
2. Well laminated shale with a few interbedded subglacial quartzites.
1. Well bedded pebbly quartzite.

<u>Torrensian</u>

Undifferentiated - mainly shales, phyllites and slate, calcareous in places, block carbonaceous shales, quartzite, dolomites and white marble.

This sequence fits in quite well with the stratigraphic sequence as found in the Burra area, hence the Burra rocks may be termed Torrensian and Sturtian without much doubt.

These rocks also on rock type seem to fit in quite well the concept of a marginal facies or foreland facies of a geosyncline, as given by Pettijohn. The rock types fit exactly except for the lack of erosion breaks and calcarenite. The varving with rafted grains and pebbles is quite typical as is the lensing. This obviously required much more work before a correct decision may be made on geotectonic environment may be made however.

Dealing with the Burra sequence in order:-

<u>5. Alluvium</u> This has been mentioned earlier and consists of clays and sands with occasional well-rounded pebbles and small boulders. Most of the valleys, particularly towards the east are covered in alluvium, with thicknesses up to 50 feet.

<u>4. Shale - sandstone group</u> This group has a thickness greater than 5,000 feet as may be seen from the section. Actually the

rock types are intermediate between shales and slates and sandstones and quartzites - many of the so-called shales on examination are found to have a definite cleavage inclined to the bedding, often making it difficult to measure the bedding direction. Nearly all the sandstones have been metamorphosed to quartzites, often gritty in places. The group mainly consists of shales and slates, commonly containing small limonite cubes pseudomorphing pyrite of obvious syngenetic origin. These shales and slates, often cleaving into fine laminae, are quite commonly chocolate or purple have occasional 100 ft, thick bands of quartzite interbedded with them. Occasional calcareous shale bands are also found. The group is confined to the extreme east of the area under investigation.

3. Fluvioglacial group These beds are perhaps the most heterogeneous of the whole sequence and consist of a definite tillite with semi-rounded quartz, quartzite, gneiss, chert and limestone pebbles with graduation to a shale or slate very similar to the shale-sandstone group.

The final product of the gradation is what is thought to have been a fluvioglacial clay, and is now a slate. This grades imperceptibly into the shale-sandstone group, illustrating the difficulty of subdividing the rocks of the area. Occasional bands of quartzite up to 300 feet thick are found, forming the ridges, being inclined to lens out. These are inevitably gritty, being well jointed, the joints being veined with quartz - gash veins are present also. Dickinson states the tillite is characterised by the presence of numerous massive lenticular coarse-grained sandstone beds which in many places show current bedding structures. It is believed to be of fluvioglacial origin. No sandstone was found, what has been described as sandstone is a typical semi - recrystallised massive quartzite, breaking across the grains. No current bedding was seen.

None of the rocks in this group are true tillites - by their degree of rounding they must be considered as fluvioglacial sediments, the larger pebbles being ice-rafted. In many places varving occurs with well-rounded pebbles present in the shale groundmass.

A lens of redbeds was found in the tillite on the east side near the Morgan Road, which on polished section examination was found to consist almost entirely of hematite with a few large angular quartz grains. Near this a lens of quartzite was found with a small lens of almost pure talc in it. This illustrates the very complex lensing common in the area - in places two section traverses run ½ mile apart can only be correlated on a very broad stratigraphic outline.

2. Calc shale group This horizon is also very heterogeneous, grading imperceptibly into the sequences above and below it. Rock types are calc shale, massive dolomite, carbonaceous shale, slate and calc. schist. Occasional lenses of quartzite are also found. Lensing is so common and complicated particularly in the southern portion of the area near the Princess Royal dome, that the group could not be subdivided further in the time available, so the sequence has been lumped together into one group (after Dickinson).

The most common rock type is a soft blade calcareous shale, very near a slate in its degree of metamorphism, in fact becoming more slate-like and laminated with decrease of $CaCO_3$. This commonly grades into a sooty black carbonaceous shale, in which chert bands are commonly found. The degree of cleavage seems to depend on the amount of $CaCO_3$ present.

Some mud and limestone pellets in limestone were found, which by their orientation and the joint traces of bedding seen, indicated current bedding.

1. Limestone - dolomite group This group may be easily subdivided, as boundaries are clear cut. The group is found mainly along the Burra Creek and in the vicinity of the Burra Mine.

(a) Upper limestone - consisting of grey limestone in places massive or dolomitic, but mainly with well-defined bedding planes about 2 inches apart. Stylolites were found in this rock in the Burra railway quarry, possibly having been caused by solution effects. Pyrite marks were also found (Plate 9). This limestone grades imperceptibly in some places, suddenly in others, into the calc shale group. It is most imcompetent as shown by the lack of fractures, and persistent puckering and crenulations found (See plate (8).

(b) Banded dolomite - the only true marker bed in the whole sequence, is a massive grey-black rock with very fine white bedding planes about ½ inch apart. (Plate 11). Dickinson gives the results of two analyses confirming the rock to be a true dolomite. Puckering and crenulations are very common, particularly in the vicinity of the Burra Mine where the geological structure becomes more complicated. Lenses of block chert about 1 inch thick are quite usual. In the mine area, bedding planes and fractures in the more competent chert bands have been completely kaolinised by acid rich ground water (from breakdown of sulphides) moving along these channels.

(c) Calc. shale zone - Dickinson mentions a zone of calcareous and cherty shales which are particularly well-developed in the vicinity of the Burra Mine. These rocks are yellowish-brown in colour, soft and friable in character with some thin beds of finely banded chert and dolomite. They outcrop prominently in the Burra Mine open cut and have proved cupfriferous for considerable distances both north and south of the orebody ! There is definitely a rock type corresponding to this description in the vicinity of the open cut, only on going more than 300 yards from the mine area it is not seen, except in isolated areas in the Upper limestone or Banded dolomite where copper mineralisation is found. It seems that unless lenses of calc. shale occur spasmodically and acts as favourable beds for copper mineralisation which seeks out these lenses (a highly unlikely and fortuitous idea) that this zone is in effect altered wall-rock, silicified partly, then kaolinised and made friable by circulating acid solutions from the break-down of sulphides. Field evidence seems strongly to suggest this, especially as no definite boundary may be found in the mine area (the nature of the boundary is well seen in the quarry off the main road on the southern outskirts of Burra.

(d) Marble - The stratigraphically lowest bed in the area is a recrystallised limestone, which has become a yellow to grey fine-grained marble. Intensity of recrystallisation varies with intensity of folding; in the vicinity of the Burra Mine the marble exhibits its coarsest grain, in areas further to the south it may scarcely be distinguished from the Upper limestone. A few rehealed brecciated zones have been found in this rock, particularly west of the mine - the cause of this brecciation may be due to shearing movements, or possibly may have occurred at the time of the intrusion of the porphyry. The brecciation of the marble in the mine area itself is impossible to determine, due to the amount of leaching that has occurred. The marble is silicified to a large extent west of the mine near the porphyry contact.

Numerous angular floaters of a granite gneiss suggestive of Archaen rocks were found on the hill due south of the mine, only exhaustive searching revealed no outcrop. A similar occurrence was found on the east side of the area near the Morgan Road. It seems a mystery how they got there - a farmer would have to be rather misguided to cart and scatter the float!

The only igneous rock found was a felspar porphyry. This occurs only in a very limited area west of Burra Mine, and can be mapped by surface float.

Microscopically the rock consists of a black indeterminate ground mass containing large ragged irregular felspar phenocrysts, microscopically it is of hypidiomorphic texture consisting of altered microcline phenocrysts in a groundmass of ragged irregular grains of altered pyroxene, biotite, quartz, magnetite and sphene. The rock has been highly altered, probably mainly by age.

Other altered rocks occur nearby, so altered that it is impossible to determine whether they are sedimentary or igneous. Silicification and contact metamorphism of the enclosing marble is very intense for a radius of 50 yards or so in the vicinity of the porphyry - this is accompanied by much brecciation, indicating that the brecciation is most likely due to the intrusion, as the marble is most incompetent and does not fracture under the most intense folding.

Metamorphism is not intense in the district, as may be gathered from the rock types described. The metamorphism is surprisingly uneven e.g. shale may be found in slate - as mentioned before this is probably due to change in chemical composition.

STRUCTURE

The rocks in the area have been thrown into a series of gently pitching folds, striking approximately north-south, their consecutive axial planes being approximately 1 mile apart. The pitch is never greater than 10°, except in the Princess Royal dome area, where the pitch may be as great as 70°. The pitch is to the north except in the Princess Royal area, where a well-developed dome structure occurs, approximately 1 mile long and ¼ mile wide, exposing the Upper limestone in surface outcrop, due to erosion of the calc shale group. The north and south noses of the dome tend to be silicified, as in the line of the axial plane, which is also brecciated and heavily veined with quartz.

Apart from these major folds, much minor folding may be seen where outcrops are good - folds ranging from 12 feet between axial planes in the more competent rocks to microscopic crenulations and puckers in the less competent limestones. Folding is probably much more complex than recorded, but due to scarcity of outcrop, structures are to a large extent hidden.

Folding is particularly intense in the vicinity of the Princess Royal dome and the Burra Mine (incidentally the two main mineralised zones of the district). At the Princess Royal dome puckering is evident especially in the chert bands and lenses. The Upper limestone has been metamorphosed to a fine-grained marble, and silicified, making strike and dip difficult to measure. In the Burra Mine area, folding is most complex, as may be seen from the face traces of beds on neighbouring hills: some overturning may have occurred, only as the country rock is again mainly marble, bedding is most difficult to determine.

Perhaps the dominant structural feature of the area is the Karinga Fault. This is a strike fault occurring at the crest of one of the major anticlines, running almost due north-south, approximately following the position of the Burra Creek. The fault has been traced from the southernmost portion of the area to approximately one mile south of Burra, where it curves across the strike to an almost east-west direction, cutting off beds, and finally disappears under a cover of alluvium, ¼ mile south of Burra Railway Station. It was not picked up again in the beds east. The stratigraphic displacement varies from 5,000 feet near Princess Royal H.S., where the limestone - dolomite group is found on either side of the fault, to 10,000 feet a mile south of Burra where the Calc. shale group lies against the marble. Displacement is west side down (relative). The dip of the fault is unknown, but from such considerations as the dip of beds, and the dip of the axial plane of the anticline, the fault probably dips a few degrees east of vertical, making it a reverse fault. Surprisingly, the fault is not associated with large crush zones - it may only be traced by cut-off of beds, occasional gossanous outcrops, and intense silicification up to 200 yards wide, particularly in the limestone and marble. In the northernmost portion, the fault is most difficult to follow, and may best be traced by cut off of beds on air-photos. The fault on disappearing under the alluvium, most likely curves again and resumes its north-south strike trend i.e.

Faulting is by no means common in the district, what there is being dominantly strike faulting, with occasional minor oblique faults. Examples of these strike faults are two in the mine area, Kingston's and Tinline's, which occur only in the zone of maximum movement. It seems that the faulting of the area was initially associated with the folding as nearly all are faults occurring on the crests of tightly folded anticlines. There seems to have been no recent movement on these faults (complete absence of unhealed breccias, slickensides etc.). Silicification is quite common along fault lines.

Jointing is common in the more competent rocks, notably in the quartzite, and usually occurs in three directions :-

(i) parallel to bedding
(ii) perpendicular to bedding
(iii) tension joints across axial planes.

These joints in the quartzites are invariably filled with quartz veins.

Cleavage is very prominent in the slates, and is usually at a slight angle to bedding. It is of course lacking in the quartzites limestones and shales.

MINERALISATION

Copper mineralisation, often with accompanying silicification is common throughout the area.

Silicification is found in the marble surrounding the porphyry near the mine area, on a hill just south of the Karinga Fault south of Burra, where subgreywacke grading into quartzite has been silicified, and disseminated pyrite has been introduced, and on two isolated hills west of this (see map). These two hills had shale as their original rock type, but have now been brecciated (they are thought to lie on a strike fault on the axis of an anticline intensely veined with quartz and silicified. The original shale banding and bedding may still be seen however.

Apart from the copper occurrences which will be mentioned later, iron rich gossans are extremely common, particularly along the Karinga Fault and other smaller faults. The limonite in these gossans is non-indigenous as indicated by the absence of any boxwork structure, and of a brick-red colour, indicating low-grade sulphide (pyrite) mineralisation, with hardly any copper.

Copper occurrences may be divided into:-

(i) Along Karinga Fault
(ii) West Burra Mine
(iii) Princess Royal Mine and the a rea surrounding
(iv) Burra Mine and environs

(i) Karinga Fault - Apart from the gossanous outcrops mentioned earlier, two or three small copper prospects lie on the Karinga Fault. These consist of malachite and azurite in either banded limestone or marble. Where mineralisation has occurred, the country rock has b een made yellow and friable, very reminiscent of the mine calc. shale mentioned earlier. The mineralising solutions are thought to have used the Karinga Fault as a channel-way. No specimens of the primary minerals producing the supergene malachite and azurite were seen.

(ii) West Burra Mine - According to records, this mine is situated on an east-west striking fissure of from 1-4 feet wide. The mine was found to occur in a band of impure limestone in the Fluvioglacial group. Chalcopyrite, bornite and pyrite occur in a gangue of calcite and siderite, often in very large crystals, with quartz. Much quartz, calcite, pyrite and chalcopyrite is disseminated through the country rock. Secondary are (malachite and azurite) mined in very small quantities. Some secondary covellite and chalcocite was found on the dumps, indicating some slight secondary sulphide enrichment.

(iii) Princess Royal Mine and area - The copper mineralisation of the Princess Royal Dome lies on or about the main north-south axial plane of the dome. Faulting has occurred along this axial plane with brecciation, marked silicification and milky quartz veins up to 2 ft. wide running along the strike. These quartz veins have gossans scattered along their length, the quartz having a honeycomb structure where pyrite has been leached out. Other gossans consist of massive limonite with chalcedony. The axial plane of the fold is itself marked by a line of gossan.

The Upper limestone, which forms the central core of the dome is recrystallised due to folding movements so that in places it resembles the lower marble. Jointing is quite common in the limestone, the joints lying in two planes at 45^{o} to the strike of the axial plane.

Disseminated mineralisation consisting of quartz, calcite, pyrite and chalcopyrite with silicification is fairly prevalent in the zone of brecciation.

Ore deposits occur in the quartz veins, accompanied by large quantities of barite and calcite. No primary ore was found on the dumps at the Utica Mine (the southernmost group of shafts); ore consisted of cuprite and malachite with chrysocolla, occurring as both gash-like masses and disseminated particles pseudomorphing pyrite and chalcopyrite (indicating oxidation in situ) in the quartz and barite.

At the Princess Royal Mine, malachite is found more frequently as incrustations, indicating that it is non-indigenous. Azurite is rare. Chalcopyrite, pyrite, native copper, cuprite and bornite were also found. These mines continue east over the hill forming the Murravian Divide to the Upper limestone -calc. shale group contact. Mineralisation is found in a more calcareous phase of the calc shale group and consists of incrustations of malachite with partial kaolinisation of the wall-rock, very reminiscent of some of the small prospects around the Burra Mine. The wall-rock is very similar to Dickinson's calc. shale "mine" formation, again suggesting that it may be an alteration product.

The location of the Princess Royal mineralisation is due to a strike fault possibly of negligible displacement acting along a belt of attenuation due to tight folding, fracturing the rock, allowing the introduction of copper mineralising solutions.

One mile to the north-east from the Princess Royal Mine, other small copper showings were found in the calc. shale group. The mines lie along a small strike fault worked by a line of gossan and brecciation, the ore being both disseminated in the country rock, and also in quartz veins which narrow down to fine stringers. The only primary ore minerals found were bornite and pyrite, with some slight secondary sulphide enrichment as indicated by the presence of chalcocite and covellite in small quantities. The main ore minerals however were the usual incrustations and botroidal forms of malachite with minor amounts of azurite. Several non-indigenous limonite gossans occur. Erosion in this area has been great, as shown by the alluvial outwash and depth of alluvium at the foot of the hill at which the prospects occur. Perhaps this explains why the oxidised zone is not larger, and that more primary ore was found near the surface than is usual in the Burra district.

(iv) Burra Mine - No descriptions of the Burra orebody have been preserved and as leaching of outcrops by acid waters has been intense, the geology and structure of the mine area is almost impossible to unravel. Added to this, workings are now completely inaccessible, so that any description of the geology of the mine area must really come from previous records, and examination of mine dumps.

The Burra orebody is located in a fault zone in the hanging wall of Kingston's Fault on the steep east limb of the regional anticlinal fold. The fault zone is bounded by two major breaks, Kingston's and Tinline's Faults, the former being more prominent. In between these, there are minor faults and brecciated zones such as Lander's Fault. Highly folded rocks, crumpling and cemented brecciated structures characterise the area. The orebodies lie in the banded dolomite bed, and to some extent in the marble, which is brecciated to a greater or lesser degree. Dickinson states that the major ore-bearing bed is the calc. shale - this has been discussed earlier.

It is estimated that the ore outcrop had a length of 800 feet and a maximum width of 250 feet. The wealthiest portion is the area of open cut seen today. The surface outcrop was characterised by gossan, some of which may still be seen on the surface. This gossan was analysed in 1850, and found to contain:-

iron oxides	89%
H_2O	10%

Traces of Cu and Z_uCO_3

In places there was a great deal of copper in the gossan - this is probably due not as much to the fact that the protore contained a high ratio of copper sulphides to pyrite, as is usually the case, but rather that the H_2SO_4 and $F_{e2}(SO4)_3$ solutions which transport the copper, were neutralised by the carbonate wall-rock, and hence unable to carry the copper far.

The orebody was essentially a cigar-shaped oxidised body extending to a depth of 300 feet approximately i.e. the water table (unless raised since) in no way influenced the cut-off of the oxidised ore. Primary sulphides began to appear at 180ft., though oxidised minerals are recorded at a depth of 510 feet in Kingston's Lode. Below 180 feet, the ore was confined to individual and fissures, and contained primary sulphides as well. The supergene are bottomed in low grade hypogene mineralisation, the actual position of veins not having been determined.

The only known diamond drilling in the area was done by the Government in 1899, with the purpose of striking Lander's or Kingston's Lodes from an inclined hole. The hole reached a depth of 1,400 feet and entered a brecciated lode formation at 780 feet. At 813 feet, chalcopyrite and quartz were observed, and continued with depth. The actual log of this hole could not be located.

Minerals found in the oxidised zone were:-

native Cu - usually arborescent

cuprite - in octahedra, fine grained, laminated, massive or earthy.

malachite and azurite - crystalline, fibrous, massive and earthy.

chrysocolla - rare

atacamite - has been reported, was not found: its presence is doubted, malachite was probably mistaken for it.

The malachite and azurite are often found in nodules, the central core consisting of azurite with an exterior of malachite. The malachite is also found as disseminated particles and incrustations in joints, fissures etc. Cuprite and native copper are always altered to malachite on exposure to air. An example of the textural relations of these three minerals may be seen in the photo (1), where cuprite and native copper are seen together, being replaced by malachite.

Some secondary sulphide enrichment occurred as seen by photo (2) where chalcocite may be seen replacing chalcopyrite along fractures. The enrichment was only incipient as far as can be ascertained by reports, and very few specimens of chalcocite were found on the dumps.

The primary mineralisation was of low grade, probably not more than .5% copper. It is of definite mesothermal character, both in texture and mineral content. Ore minerals found by the examination of polished sections of the limited number of specimens available were:-

chalcopyrite

bornite

pyrite

Chalcopyrite and bornite were by far the most common, although no doubt if more specimens were available, other minor minerals would have been found. These minerals were found in small disseminated grains in a gangue of calcite and quartz, usually of sacchoroidal texture, occasionally with small shears and bands of calcite and quartz. Quartz is often found in rhombohedral grains, indicating it has replaced earlier calcite. There were at least two generations of quartz, the simpliest sequence being:-

quartz
calcite with ore minerals
quartz

Intermineralisation movements occurred, as some of the earlier quartz is seen to be broken and filled by later quartz and calcite. Some slight past mineralisation movements occurred also as some ore specimens were found to be slickensided with the formation of much chlorite on the slickensides.

A limited amount of chlorite, probably formed by the metamorphism caused by shearing movements was found; this is unusual, as one would expect chlorite to be one of the first minerals to be replaced by the downward leaching acid copper solutions. This chlorite is not confined to slickensides, but disseminated in fine grains through parts of the mullock.

Apart from the calcite of small grainsize containing ore, calcite grading to siderite of a much larger grainsize up to 2 inches across is found on the dumps (Plate 13). It is not known whether this calcite is primary, derived from ore solutions or was formed by the recrystallisation of the marble during the folding and faulting movements. No specimens were found in situ; probably the specimens are primary vein material, as similar specimens are found at the West Burra Mine.

The primary sulphides broke down under oxidation to solutions carrying ($Fe_2(SO_4)3$, H_2SO_4 and $CuSO_4$. These solutions, as is usually the case, had a considerable effect on the wall-rock. In the mine area, on the walls of the open cut, all the country rock has been kaolinised, indicating that the limestone wall-rock was impure limestone. The wall-rock is now a yellow, friable, kaolin rock. It is interesting that copper (malachite) stains are found throughout the kaolin, bearing out the theory that kaolin may act as a precipitant of copper, by a type of base exchange.

LOCALISATION

The localisation of the protore was influenced by the intersection of the Kingston-Tinline's Fault zones with a series of dolomites and limestones, which no doubt, as is often the case, were favourable to the precipitation of ore. This seems to be the main localising feature throughout the district - the intersection of a fault zone, very often a reverse strike fault, with a limestone, dolomite or a calcareous shale bed. Apart from this, due to lack of data, no more may be said about ore localisation.

Dickinson states that the mineralisation is believed to have been derived from an igneous source, possibly from the same source which supplied the felspar porphyry dike outcropping about ¼ mile west of the mine. This is doubtful, as firstly the evidence is purely circumstantial, as no other igneous bodies are found near the other mineral deposits of the district, and secondly on microscopic examination the porphyry is seen to have been highly altered with age and possibly sheared almost beyond recognition, suggesting an age older than the period of mineralisation. We will not be certain of the genetic origin until the origin of the whole South Australian copper belt has been determined, a most difficult proposition.

Regarding the orebody itself, it must be pointed out that the supergene oxidised ore made the Burra Mine an economic possibility, and that the protore is of too low grade for economic mining.

Several points influence the formation of a supergene copper orebody:-

(a) The terrain must be such that for optimum enrichment erosion keeps pace with leaching. It is believed that these conditions occurred during the period of peneplanation (before late Pliocene), and that since, erosion has perhaps been more dominant. Dickinson uses the fact of the recent dominance of erosion over leaching to explain the fact that the ore outcropped at the surface and that there was no leached zone. This may be so, or the orebody may never have had a leached zone due to the strong precipitating power of the carbonate wallrock. The former conclusion is most likely, as assuming the ratio of pyrite to copper sulphides was high enough to transport the iron, and not leave it as an indigenous gossan, the iron would be carried as $Fe_2(SO_4)_3$ etc, and would tend to be precipitated, before the copper, as jarosite, goethite etc. As no masses of limonite were found, it must be assumed that erosion has removed this.

(b) Suitable protore must be present. This has been proved so.

(c) Climate must be temperate for optimum enrichment. This was so.

(d) These must be a suitable length of time for erosion, leaching and enrichment (most supergene bodies are pre-Pliocene). This was so, obviously.

(e) For secondary sulphide enrichment, the wallrock must be inactive i.e. must not be rich in K_2O (from sericite, felspar etc) or carbonates, otherwise the acid solutions ($Fe_2(SO_4)_3$ and H_2SO_4) bearing the copper will be neutralised, and precipitation as oxides or carbonates will occur.

Hence it may be seen that all the factors are present for successful supergene enrichment, and from the last point mentioned it is seen why oxidised ore is found even below the water table. Another cause of oxidised ore is extreme aridity, where the ore is oxidised in situ, however definite evidence of transportation may be seen, as shown by the botroidal, concretionary and encrusting textures of the carbonate ore. Therefore it may be concluded that the primary veins were decomposed by oxidation, and downward leaching of the copper (with or without iron in quantity) occurred. These solutions reacted with the carbonate wallrock, especially in fissures or brecciated zones with large surface area, forming a cigar-shaped oxidised orebody.

CONCLUSIONS

The Burra orebody as described by mining reports contains no ore reserves. No new orebody is to be expected, as the orebody is essentially supergene and conforms to a normal blanket cigar-shape which cuts off for good at its periphery. A few remnants may remain, but to find a large supply of ore a new vein must be found, with wallrock suitable for supergene carbonate or sulphide enrichment.

From examination of the area, none of the copper deposits found contain primary ore anywhere near economic grade. It may be assumed that another oxidised orebody is not present in the area, as some type of outcrop would indicate its presence - even if buried by alluvium, significant traces of copper should be found.

Hence the only chance of finding a new orebody seems to be in finding a primary deposit buried by alluvium, a very doubtful chance, considering the nature of the mineralisation in the area. Perhaps the only chance of finding an orebody (and not worth the expense) would be to conduct a self potential geophysical survey over the areas covered by alluvium, in conjunction with a geochemical survey, paying attention to the areas where the favourable beds would be expected to occur. An S.P. survey was done in about 1942, on the extension of Kingston's Fault to the Racecourse, a likely area, but no anomalies were found.

Plate 1.

Cuprite (white) being replaced by malachite (dark grey)
Light grey =
Magnification x30 approx.

Plate 2.

Incipient replacement of chalcopyrite (cp) light grey by chalcocite (cc) dark grey.
Magnification x30 approx.

Plate 3.

Chalcocite (white) in quartz gangue. The cc is secondary and has obviously replaced cp in situ. Magnification x30. Grey in cc mainly pits.

Plate 4.

Bornite (darker grey) and chalcopyrite together. On one specimen, nothing may be said on age relationship. Magnification X30 approx.

Plate 5.

Felspar porphyry, showing altered microcline (white) with altered pyroxenes (grey). Magnification X30 approx.

Plate 6

Taken from the silicified hill mentioned in the text looking east showing the undulating topography, and the quartzite bands causing N-S trending ridges.

Plate 7.

Burra Creek, near Princess Royal H.S. showing downcutting of recent alluvium.

Plate 8.

Upper limestone in the mine area, showing crenulations and bedding.

Plate 9

Ripple marks in Upper limestone at Burra Railway quarry.

Plate 10

Upper limestone in Burra Railway quarry. Photo is of a vertical face showing tension joints indicating a northerly pitching fold.

Plate 11

Banded dolomite, magnification $\frac{1}{4}$x

Plate 12

Burra Mine open cut.

Plate 13

Solid calcite gangue found on dumps at Burra Mine (see text p. 23) Magnification ½x.

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