ABSTRACT

The Burra Burra Mine is in complexly folded Torrensian dolomites and limestones forming the faulted axial region of a major anticline. The ore body mined was largely of secondary origin and confined between two faults, Kingston on the west and Tinlines on the east. The ore body occurred at the junction between cherty dolomites and a clastic limestone with a large mass of marble breccia along its western margin. Secondary ore consisted of carbonates and oxides in the breccia and the ore bedand detrital copper minerals deposited as part of a clastic breccia in sink holes and solution cavities in the dolomites and ore beds.

Primary sulphides occur disseminated in the marble breccia and in stratiform habit in the ore bed. Kingston's so-called "lode" may be mineralised marble breccia.

The marble breccia appears to be of diapiric or sedimentary origin and there is evidence to support a sedimentary origin for some of the copper sulphides. No igneous rocks have been discovered within 20 miles of the mine and any hydrothermal activities were probably at comparatively low temperature. The possibility of extensive stratiform and disseminated copper sulphide mineralisation in the marble breccia and ore bed requires testing by further drilling and geophysical surveys.

A RE-INTERPRETATION OF THE BURRA BURRA COPPER DEPOSITS..[1]

by

W. JOHNSON..[2]

INTRODUCTION

The re-interpretation of Burra Burra geology and ore formation discussed in this paper has resulted from a detailed and comprehensive investigation of the mine and its surrounding district begun in December 1961 and in progress at the time of writing. (February 1963). When, in 1961 the writer was given charge of the exploration and investigation of non-ferrous metals in South Australia, the investigation of the Ediacara silver, lead, and copper, mineral field had commenced already. After an examination of the records and reports, of other non-ferrous metal deposits it was decided that the Burra Burra mine was the most promising, and accordingly work was begun as soon as personnel became available. The decision to investigate Burra Burra was given impetus by a report by Thomson (1963) suggesting a sedimentary origin for the copper mineralisation. Though this suggestion proved to have been based partly on erroneous interpretation of the observed facts there is no doubt that sedimentary processes have played an important part in the emplacement of the Burra Burra copper deposit nor is there any doubt that high temperature hydrothermal processes were inactive.

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LOCATION AND HISTORY

The Burra Burra mine is in a depression in a small group of hills on the western side of the Burra Creek 100 miles north-north-east from Adelaide on the main road and railway line to Broken Hill. The eastern scarp of the northern Mt. Lofty Ranges is 10 miles east of Burra.

The ore body was discovered by a shepherd named Pickett in 1845 and rapidly exploited owing to the fact that it was rich from the grass roots down, a fact testified to by the reported profit of £19,751.10. 2. from 2959 tons of ore for the half year ending 30th April, 1846. (Dickinson 1942 .68)

Mining continued under the control of the South Australian Mining Association until September 1877 when the mine closed down after earning a profit estimated at £826,585.12. 4. From the end of 1864 the mine operated mainly at a loss.

In all 234,648 tons of ore was treated, sold and more than 700,000 tons of ore and mullock was raised from the underground workings and the open cuts.

The mine closed because the exhaustion of the rich carbonate ores coincided with a period of falling copper prices. Contributory causes were increases in rail freight, heavy pumping charges to keep the mine dry, the apparently sporadic nature of mineralisation in the sulphide zone and the lack of adequate exploration and development of the sulphide zone ahead of the mining of the carbonate ores. The wasteful and inefficient mining methods of the day also contributed to the closure.

In 1898 and 1899 two drill holes were sunk to depths of 1004 feet and 787 feet respectively. Both cut copper sulphide mineralisation for which no assays are quoted.

In 1901 a new company, the Burra Burra Copper Co. N.L., commenced exploring above water level in the southwest corner of the open cut and other places and some ore was extracted. This company stopped operations in 1907 and since that time only sporadic prospecting activity has been reported.

PREVIOUS GEOLOGICAL WORK

In 1899 H.Y.L. Brown (1908) reported on theresults of the deep bore drilled east of Peacock's Shaft. He considered it proved the downward continuation of Kingston's lode and recommended as a result the dewatering ofthe workings.

After Brown's report there is no record of any geological examination until Segnit did some mapping in the district as part of his investigation of Proterozoic/Cambrian stratigraphy in South Australia (Segnit 1939). His description of the mine repeats that of H.Y.L. Brown's (Brown 1908). His most important contribution was to classify the marble breccia at the mine as tillite.

Following Segnit a report on the economic geology of the mine was included by Dickinson in his Bulletin on some South Australian copper fields (Dickinson 1942). He stated that the rich secondary ore body was an enrichment of sporadic small primary lodes hydrothermally emplaced along fault zones. Dickinson considered exploration for primary deposits inadvisable but recommended geophysical survey of the alluvium covered area north of the mine.

Some preliminary geophysical testing was done in the mine area by the Bureau of Mineral Resources (Thyer 1952) and then another geological survey was made by Wegener (1952) under the direction of K.R. Miles. Wegener recommended geophysical survey of another alluvium covered area 1 mile north of the mine.

The Geophysical surveys recommended by Dickinson and Wegener were completed with negative results.

Miles also submitted a brief report recommending drilling of two holes. One on structural grounds to be drilled east of the Burra Creek and the other to be directed westwards under the open cut to obtain stratigraphic lithologic mineralogical information in the primary sulphide zone. This latter hole would have been approximately in the position of the deep hole being drilled at present.

Finally Thomson submitted his report (Thomson 1963) postulating a slump origin for the large breccia mass west of the mine open-cut and recommending mapping and drilling. The verbal opinions of other geologists who have examined the Burra Burra mine briefly are quoted in Thomson's report.

GEOMORPHOLOGY

The cluster of low hills in which the mine was found constitute the well dissected convergence of two prominent ranges trending northwards from many miles to the south. These ranges are the two limbs of syncline with a valley between. East of the eastern range the Burra creek breaches, and flows southward, alongthe faulted axis of a larger anticlinal structure.

North of the minethe narrow synclinal valley opens out into a broader valley (the Mt. Bryan valley) along the axis of an anticline. The range of hills bounding this valley on the east is a continuation of the Princess Royal range, forming the eastern wall of the Burra Creek valley south of the mine, and like it, the eastern limb of a major anticline.

All the major valleys have broad cross section profiles. Their bottomsare occupied by wide alluvial flats and extensive piedmont slopes mantling the lower parts of their walls. All of the present drainage channels in the major valleys are too small for the size valleys which they occupy. The streams are entrenched 10 to 20 feet in the alluvium covering the valley floors.

The drainage pattern yields plenty of evidence of stream capture which no doubt took place in a much more pluvial climate cycle, probably preceding the one before the existing cycle.

At RL 1720 near Tinline's Shaft, on the mine hill, water-rounded quartz pebbles occur in the remnants of an old stream channel. These are too well rounded to have been eroded locally and it is probable that they are relics of a much more powerful stream which existed when the general level of the major valley to the north was at about this level or 90 feet above the level of the alluvial deposits forming its bottom at present.

In the carbonate rocks forming the "mine" hills solution cavities and sunk holes have developed extensively. The ore body was found in a depression which there is no doubt in the writer's mind formed partly by collapse of solution cavities.

Formation of the solution cavities and sink holes began during the erosive cycle preceding the one in which the Mt. Bryan valley was excavated to its present level.

The geomorphologic history of the area played an important part in the formation of the Burra Burra ore body as will be explained in later sections of the paper.

REGIONAL GEOLOGY

STRATIGRAPHY

The Burra Burra Mine is situated in complexly folded Torrensian dolomites and limestones near the faulted axial region of a major anticline which is one of a series meridionally trending folds of large amplitude and wave-length, forming the northerly continuation of the Mt. Lofty anticlinorium. In the area extending 23 miles west and 8 miles east of the town of Burra, and within the confines of the Burra 1 mile geological map (Johnson 1963), these folds expose a thick succession of sediments representing a major part of the Adelaide system.

The sediments range in age from the River Wakefield Group dolomites (Wilson 1952) outcropping in the Broughton River valley 5 miles west of Spalding on the western border of the Burra 1 mile sheet, to the Lower Marinoan upper glacial tillite exposed in the keel of a syncline, 1 mile west of the Mongolata goldfield.

The total maximum thickness of Adelaide System sediments present may be in excess of 45,000 feet. Estimated thicknesses for individual groups of rocks are given in the abbreviated stratigraphic column below. These are subject to considerable error because of the difficulty of finding an outcropping section, with well defined tops and bottoms of formations, which is structurally undisturbed.

STRATIGRAPHIC DIVISION	MAJOR LITHOLOGIC DIVISIONS	LITHOLOGIC UNITS	DESCRIPTION	NO.	THICKNESS FEET
MARINOAN UPPER GLACIAL SEQUENCE	Tillite	-	Bedded fluvioglacial boulder till with green and purplish buff shaly to sandy matrix	7	+500
	Calcareous shale/slate	-	Grey green and blue laminated shale and siltstone, phyllitic and slaty in part, some interbedded quartzites - some dolomite at base	6	10,000
MARINOAN INTERGLACIAL SEQUENCE	Pyritic laminated shale, siltstone sandstone	Pyritic current bedded shale sandstone	Grey green coarsely laminated to thin-bedded non-fissile alternating shale siltstone and sandstone with graded bedding, prominently current bedded and with abundant pyrite and slump structures, coarse sandstone at top.	5	2900 to 4500
		Calcareous laminated shale	Blue and green grey laminated hard calcareous shale (Tapley Hill Slate type) non-fissile.	4	
		Black Shale	Black carbonaceous pyriticfinely laminated slightly friable shale and siltstone		

STRATIGRAPHIC DIVISION	MAJOR LITHOLOGIC DIVISIONS	LITHOLOGIC UNITS	DESCRIPTION	NO.*	THICKNESS FEET
STURTIAN LOWER GLACIAL SEQUENCE	Glacigene beds	Green shale	Green grey faintly to strongly laminated non-fissile hard calcareous shale and siltstone some interbedded sandstone and sparse erratics	4	4500 to 12000
		Tillite	Abundant erratics in green structureless shale matrix - some fluvioglacial quartzites and silty shales - persistent quartzites at top	3	
		Blue green shale	Blue green strongly to faintly laminated shale with interbedded quartzites towards top	2	
TORRENSIAN	Blue dolomite, sandstone, black shale	Shale sandstone	Black laminated shale carbonaceous and pyritic Coarse white to buff dolomitic current bedded sandstone	2	+ 13000
		Blue dolomite	Blue black dolomite and dolomitic shale interbedded	1D?	
		Shale sandstone Dolomite shale	Interbedded blue shale and grey fine to coarse sandstone with some blue dolomite	1D? to 1A	
		Sandstone white dolomite	Pink to buff fine to coarse grained sandstone underlain by cream and yellow coarsely crystalline limestone or dolomite pyritiferous shale		
		Green dolomite	Light green flaggy to thick bedded dolomite with ripple marks - blue grey shale cream marble. Blue grey dolomite with whiteish grey lenticular bands		
		Sandstone	Red beds, pink quartzite and sandstone with ilmenite or haematite laminations some dark grey green shale		
WILLOURAN ? RIVER WAKEFIELD GROUP		Green ~~blue~~ dolomite	Green dolomite with whiteish buff banding showing boudinage structure, ripple marks and mud cracks present - Blue black flaggy dolomites, dark blue green laminated phyllitic shale - pink flaggy laminated quartzite		+ 1000

* Numbers refer to Dickinson's stratigraphic column (Dickinson 1942)

The stratigraphic column is a composite one compiled from the whole Burra 1 mile geological sheet. The Torrensian succession in particular being much more complete than that exposed in the vicinity of the Burra Burra mine. Here the blue and grey limestone and dolomite and overlying carbonaceous shale outcropping on the eastern side of the open cut may be correlated with the Auburn dolomites and part of the Mintaro Shales of Wilson (1952) and this may be of uppermost Torrensian age. The position of the marble and crystalline limestone on the west side of the open cut is obscure. It may correlate with the Upper Auburn Dolomite of Wilson (1952). However faulting has occurred along the contact of the limestone with the overlying dolomite, making its stratigraphic position uncertain. Some features of its lithology invite comparison with limestones and dolomites occurring at the base of the Torrensian succession farther west. Should this be its correct stratigraphic position then either the faulting has excised several thousand feet of the Torrensian sediments orthe succession is much thinner at Burra than it is on the western border of the Burra 1 mile sheet. Altogether a maximum of 4500 feet of Torrensian sediments occur in the Burra area compared with a thickness in excess of 13000 feet on the western border of the Burra 1 mile sheet.

While this assumed thinning cannot be proved for the Torrensian, because its base is not exposed in the Burra area, and because of excision of an unknown thickness by faulting, it can be demonstrated in the Sturtian, particularly the lower Glacial Sequence. This sequence is 12,000 feet thick east of Burra and then westward to 4,500 feet in the section east of the Clare Spalding road. A suspected unconformity occurs at the top of the Sturtian Lower Glacial Sequence.

Other noticeable features of the regional stratigraphy are the presence of two similar carbonaceous and pyritic laminated black shale and siltstone formations immediately below the base and above the top of the lower Glacial Sequence, the diminution in carbonate content of the sediments and a general decrease in grain size eastwards from the Spalding/Clare district.

The only igneous rocks known are irregular dolerite bodies intrusive into Torrensian dolomites, intensely folded and strongly crushed, in the valley of the Broughton River 8 miles downstream (west) from Spalding and a lenticular body of trachyte, probably extrusive, in the same area.

STRUCTURE

The whole of the northern Mt. Lofty Range in the Spalding-Burra area is composed of meridionally trending folds of large amplitude and wave length. Three anticlines with complementary synclines are encompassed within the boundaries of the Burra 1 mile sheet and the Burra Burra mine is situated near the axial region of the most easterly anticline. Though the major folds are rather simple and open the axial region of the anticlines is characteristically occupied by zones of heavy faulting, accompanied by complex subsidiary folding, usually in Torrensian carbonate rocks. The Mt. Bryan/Burra anticline exemplifies this type of structure. North of the mine the axial region is occupied by a valley, almost certainly carved out of rocks rendered susceptible to erosion by crushing and fracturing along a fault zone. South of the mine the axial plane fault can be traced by reason of an outcropping fault breccia. It is shown on Dickinson's regional map (Dickinson 1942 Fig. 21) as swinging to the north west as it nears the mine and disappearing under alluvium. This is the Kooringa Fault (Dickinson 1942) and the later regional mapping (Fig. 1) indicates that branches from it pass through the mine as Kingston's and Tinline's Faults ("Lodes") and continue north up the Mt. Bryan valley. One of these probably becomes the main plane of displacement as the displacement along the Kooringa Fault diminishes. Other faults have been mapped by Wegener (1952) and the writer in the Burra area (Fig. 1) and most are no doubt genetically connected with the stress which caused the Kooringa Fault. There is some evidence that the axial plane faults were active during sedimentation.

The system of faults of which the Kooringa is the chief observable representative had an important indirect, and perhaps direct, influence on ore occurrence in the district.

At the Burra Burra mine the stresses which caused faulting also resulted in structural brecciation and heavy fracturing and jointing which served to localise ore deposition in a manner to be described in detail in later sections of this paper. No copper mineralisation has been observed as yet along the Kooringa fault breccia on the Burra 1 mile sheet.

The plunge of all the major folds and of most of the subsidiary folds is to the north. An important plunge reversal occurs at the mine where a number of minor folds plunge southwards forming small elongated anticlinal domes and synclinal basins. A larger scale anticlinal doming brings the Torrensian carbonate rocks carrying sparse copper mineralisation to the surface in the Princess Royal Mine structure 8 miles south-southeast of Burra. Regional geology in the vicinity of Burra as shown on the map Fig. 1.

MINE GEOLOGY

STRATIGRAPHY

The main Burra Burra copper deposit is almost confined to a block of brecciated and complexly folded and faulted carbonate sediments of Torrensian age between two structures known as Kingston's and Tinline's Faults.

The detailed stratigraphic succession in the carbonate rocks is as follows, from the stratigraphic top downwards -

FORMATION	DESCRIPTION	UNIT	THICKNESS FEET
Black Shale	Laminated black and grey pyritic and carbonaceous shale and siltstone	2	+ 2500
Sandstone		2	20-30
Blue and Grey Dolomite	Dark blue, light blue and grey laminated to thin bedded and flaggy dolomite interbedded with yellow weathering shaly limestone or dolomite		
Blue Laminated	Grey pink and dark blue thin bedded to flaggy cherty dolomite. Dark blue variety has characteristic whiteish fine laminations	1C	200-3000
"Ore Bed" (Clastic Limestone)	Yellow and cream weathering sandy, clastic and perhaps slightly argillaceous clastic limestone or calcarenite with brown weathering very fine grained thin beds of cherty dolomites and siltstone	1B	40-100
"Shale"	Yellow and brown soft earthy shale, dolomitic shale, shaly dolomite, pink and blue grey cherty dolomite. Possibly the shale is a facies variant of the "ore bed".	1B	40-60
Marble Breccia	Breccia consisting of fragments of limestone and dolomites, chloritic sandy dolomite and yellow marble in a granular groundmass of yellow and cream limestone or dolomite.		400-500 normal to strike of enclosing sediments
"Marble"	Yellow, buff, white, and cream to grey, finely to coarsely crystalline limestone or marble with interbedded minor quartzite and siltstone	1A	+1000 ?

BASE NOT SEEN

The "Marble", or unit 1A of Dickinson (1942), outcrops as shown on the accompanying plan Fig. 1. Within the main outcrop, in the hill west of the mine, the few structure form lines depicted give some idea of the complexity of the folding within it. Because of this folding it is not possible to give a reliable estimate of the thickness exposed. Its true thickness is even more in doubt because its base is everywhere concealed by soil or alluvium or cut off by the Kooringa Fault.

Some minor clastic rocks occur within it, the most important being an argillaceous quartzose siltstone with prominent rosettes of magnetite or pyrite. This rock outcrops in the position of the "felspar porphyry" shown by Dickinson on his large scale map (Dickinson 1942).

The "Marble" is overlain by a thin rock unit which away from the mine could be described as a shale but which in the mine area is better described as a yellow clastic limestone or calcarenite.

The "Shale" exposed on the west side of the road metal quarry at the western entrance to Burratownship. Here it consists of yellow and brown calcareous shale interbedded with purpleshale, containing limonite pseudomorphs after pyrite, and pink purplish, blueish, and grey finely crystalline hard dolomite. Unweathered representatives of the shaly part of the sequence have not been observed and it is quite likely that they would prove to be shaly dolomites.

In the mine area the shale passes into yellow highly weathered clastic limestone (the "Ore Bed") with brown cherty dolomite interbedded and containing in places copper carbonates in nodules arranged along beddingplanes. Completely overturned and nearly circular folds with axial planes horizontal (in vertical east west section), which resemble those caused by slumping of sediments shortly after deposition can be seen in the ore bed, within the open cut. This influenced Thomson to postulate a slump origin for the breccia (Thomson 1963).

The contact ofthe "Ore Bed" with the overlying dolomites can be observed at the north end of the open cut. Here it is faulted and a band of material resembling a highly weathered shale intervenes between the overlying dolomite. This shale-like material also resembles part of the "Shale" outcropping in the aforementioned quarry and it is quite probably that the shale is only part of Unit 10 highly weathered along a strike fault.

The "Breccia" is included in the stratigraphic column as though it were a true sedimentary formation.

Various workers have suggested differing explanations for the breccia. Segnit thought it was a tillite (Segnit 1939). Dickinson (1942) referred it to brecciation along faults while not excluding other origins such as its being a talus. Coats (Thomson 1963) suggested a diapiric genesis for it and finally Thomson (1963) put forward his slump breccia hypothesis. Unfortunately the evidence is not unequivocal, except that against a tillitic nature, listed by Dickinson (1942).

The main mass of breccia occurs on the western side of the open cut and itseastern margin appears to follow in a rude fashion the sedimentary boundaries to the east (see Figs. 2 & 3). Other smaller masses of breccia are shown on Dickinson's map (Dickinson 1942). Most have some copper mineralisation associated with them.

The majority of lumps and fragments in the breccia consist of marbles similar to the various beds of Unit 1A. Other prominent rock types are yellow and cream laminated dolomite, and greenish finely laminated chloritic dolomite. Non-carbonate rocks are represented by two very large blocks of arkose and quartzite. One of these, a few feet west of Allen's shaft, (Dickinson 1942 Fig. 22) consists of a pinkish buff quartzite with prominent black heavy mineral laminae similar to basal Torrensian Rhynie Sandstone (Wilson 1952). The size range of the rock fragments is from fine grains up to blocks 30 feet long by 15 feet wide.

Conspicuous constituents of the breccia are large, clear, twinned porphyroblastic crystals of calcite. These occur singly or as large aggregates, developed in the granular matrix of the breccia.

Almost all of the features of the breccia can be construed as supporting more than one mode of origin. The shape and distribution of the breccia masses are more consistent with formation by diapiric folding and plug injection, or by slumping, than by faulting. Comparison with theundoubted fault breccia developed along the Kooringa Fault also casts doubt on a fault genesis for the marble breccia. The Kooringa fault breccia is a jaspery, highly siliceous and ferruginous mass where the fault passes through carbonate, yet the jasper and ferruginous material in the marble breccia is abundant only adjacent to Kingston's Fault.

Any explanation for the marble breccia also will have to account for the marked broadening of the marble west of the mine as the breccia only occurs in this overthickened section. The thickening of course appears to be mainly structural.

Bent and distortedblocks of rock within the breccia may indicate that the rocks were semi consolidated when dislocation commenced.

At one placein the open cut a fine grained variety of the breccia appears to be bedded.

There is thus evidence to support dislocation and brecciation of the rock in a semi-consolidated state, yet the presence of the breccia in an area of strong tectonic activity influences is prima facie evidence for its tectonic origin. Possibly pre-consolidation slumping, diapiric folding, and later faulting all played their part in the formation of the breccia masses as present exposed.

Unit 1C of Dickinson's subdivision is best exposed on the eastern edge of the road metal quarry at the road side at the southern town entrance. Here it is a dark blue dolomite with fine white laminations. At the mine the rock has been altered to grey cherty dolomite and white and pink laminated to thin bedded dolomite with interbedded regular bands of slump breccia.

This dolomite passes eastwards gradationally into blue and mid-grey thin bedded dolomites with some laminations interbedded with a yellow weathering sandy shaly dolomite (Unit 1D). In places the dolomites of this unit are hard to distinguish from those of unit 1C.

The overlying carbonaceous, pyritic, and dolomite or calcareous shales are outside the area of the mine proper.

Two other rock formations require mention because of their influence on ore-formation. The most important is a brown, yellow-brown and white breccia formed by the mechanical transport of rock debris into cavities and sinkholes formed by solution chiefly of the dolomites of Unit 1C (Johnson 1962). This breccia carries detrital copper carbonates and consists of two main types:

(i) A well cemented, compact, light greenish or brownish mass with angular to pisolitic detrital fragments of azurite or malachite and ferruginous masses. From remnants left in the workings these breccia masses filled the cavities in which they occurred. Inclined thin bedding and laminations are present, usually at the subhorizontal contact with the white dolomite butsometimes along the steep side contacts of the breccia and dolomite.

(ii) A brownish loosely compacted fine to coarse grained granular material with well developed cross-bedding in places. Malachite and azurite is erratically distributed through the breccia and in particular layers of the bedded material. Remnants show that this type of breccia did not always fill the cavities in which itoccurs.

Thesolution cavities can be observed down to present water level in the open cut (approximately 120 to 160 feet below the surface), and by inference from early descriptions of the mine workings, extend deeper. As might be expected solution is partially controlled by structure. The heavy jointing in the dolomites of Unit 1C associated with vertical partings along bedding planes, and fracturing along Tinline's fault allowed easy access of meteoric water and consequent prominent development of solution cavities. The solution cavities are abundant in the dolomites of Unit 1C and rare in the "ore bed". None have been observed

as yet in the marble breccia but logically there is no reason why they should not occur. In fact the depressed area of mineralised breccia 1050 feet west-south-west of Morphett Shaft almost certainly has sinkholes beneath it.

The other formation is an alluvial silt containing rounded pebbles of quartz and detrital copper carbonate occurring in shallow channels in the dolomite near Tinline's Shaft. This is thought to be an alluvial stream deposit of a much earlier geomorphologic cycle.

STRUCTURE

Faulting

The open cut is aligned north-west and practically confined between two faults designated as Kingston's on the western side and Tinline's on the eastern side. The amount of displacement along these faults is not measurable as both are sub-parallel to the strike of the rocks. Dickinson (1942 Fig. 22) showsboth faults terminating 500 feet south of Morphett's shaft. However shearing and brecciation is present along the "shale" (Unit 1B) south to its junction with the Kooringa Fault and it is suggested here that the two faults diverge as one from the Kooringa Fault and become separated 500 feet north of the main road.

Kingston's Fault has a different character from Tinline's Fault in that along it talcose and chloritic alteration products of the marble breccia and the "ore bed" have developed.

Other minor faults have been mapped in the area surrounding the mine and the presence of slickensides may indicate a faulted contact ofthe "ore bed" and the blue laminated dolomite" in the north west corner of the open cut.

Folding

Check mapping on aerial photographs enlarged to a scale of 100 feet to 1 inch has confirmed Dickinson's structural detail in the vicinity of the open cut. To the eastern side, immediately adjacent to the cut and north of the access road there are a number of shallow north plunging anticlines and synclines, then at about the entrance to the mine Dickinson shows the nose of a north-plunging larger anticline, which on his section (Dickinson 1942 Fig. 22) brings Unit 1B (the "ore bed") up to within 500 feet of the surface 1800 feet east of the cut. From the point of view of the new interpretations itis this structure which needs confirmation as it is thought that there is a strong probability of stratiform mineralisation in the "ore bed".

Unfortunately in this area superficial deposits obscure the dolomites and limestones and the structure can be inferred only by extrapolation from the areas of outcrop to the south and north. No reliance can be placed on lithology in structural interpretation in Unit 1D because the various beds comprising it are repeated up through the succession.

There is a marked change in plunge at about the south end of the open cut from a northerly plunge on the north side to a southerly plunge on the south side.

In the absence of refutative evidence Dickinsons structural interpretation is accepted for the present and is shown on the cross section Fig. 4.

Jointing

Several sets of joints are present in the mine area. The attitudes of these sets are as follows

	Strike	Dip
(i)	070° to 090°	80° to 85° South
(ii)	variable	5° South to 5° North
(iii)	080° to 100°	50° South

in addition a parting is present along the bedding planes of the vertically dipping dolomites.

Set (i) appears to be the most persistent and extensive. Near Timline's shaft on the east side of the open cut one can be observed cutting the dolomites for 50 feet above the open cut floo: In the road metal quarry near the main Adelaide - Burra road, joints of this set are spaced 3 to 6 inches apart in one section of the west wall ofthe quarry and carry lenticular quartz veins

¼ inch to 1½ inches thick. In the "ore bed" south of the water in the open cut and under the old sink-hole base a prominent joint crack of set (i) carries brown ferruginous and copper bearing breccia up to 2" wide.

The intersections of joints of sets (i) and (ii) and of set (i) with the bedding plane partings are particularly favourable locations for solution cavities in the dolomites of Unit 10 near Tinline's Shaft.

ORE OCCURRENCE AND CONTROLS

SECONDARY ORE

The rich secondary copper carbonate and oxide ore making up the bulk of the Burra Burra production, was mined from ore bodies which formed in three types of host rocks; namely, the marble breccia, the "ore bed", and the grey dolomites. The mode of occurrence is as follows:

1. The Marble Breccia

Copper carbonates form small masses of irregular shape and disseminations in the matrix, and in the fragments, of the breccia, thin veinlets in joint and shear planes, and disseminations in chloritic lode material ? associated with Kingston's Fault.

2. The "Ore Bed"

Copper carbonates occur as nodules along bedding planes; veinlets in joints, minor faults and shears; disseminated throughout the bedded material and in Kingston's Lode; in larger irregular ferrugin ous veins; and as part of a clastic breccia infilling solution cavities.

3. The Grey Dolomites

The copper carbonates occur as detrital grains and fragments incorporated in a clastic breccia formed by mechanical transport of rock and ore debris into solution cavities and sink-holes. From the clastic breccia the copper carbonates have migrated into joint and shear planes adjoining the solution cavities.

The overall shape of the composite ore body thus formed was highly irregular, as witnessed by the contours of the main open cut. Its eastern boundary consisted of the walls of those sinkholes and solution cavities which contained payable copper ore, with Tinline's Fault forming a general easterly limit beyond which few ore bearing cavities were found. In a similar manner Kingston's Fault forms the westerly limit of the zone of ore bearing rocksand in places a more regular boundary to the ore body itself. The boundary in depth of the secondary ore body was even more irregular than the lateral boundaries. The old photograph showing the open cut in operation illustrates this very well (Fig. 5).

Payable ore was apparently mined continuously over a maximum length of 900 feet, a maximum width of 400 feet, and to a maximum depth of 300 feet, but not of course in ore mass of these dimensions, in thearea outlined approximately by the present main open cut. Within these limits the rich ore ramified in irregular pods, veins, and lenses, with lower grade and unmineralised rock in between.

Oxidised ore extended northwards beyond the main open cut and was mined in a subsidiary open cut and from a number of shafts. Mineralised breccia, from which some ore was mined, also occurs 1000 feet south-west of Morphett's shaft.

The total quantity of ore and mullock mined is given by Dickinson as 700,000 tons including 470,000 tons of low grade ore and overburden removed by open cut methods. In the production table in his report (Dickinson 1942, pp. 68-70) the quantity of ore produced is shown at 234,648 tons. Presumably this was dressed ore.

From the meagre accounts of the mining operations it is almost certain that all but a few hundred tons of the material mined was oxidised ore and mullock.

The proportions of the ore which came from veins and disseminations in the marble breccia, veins and disseminations in the "ore bed" and clastic breccia in sink holes and solution cavities in dolomite and "ore bed" can only be guessed at. A likely minimum for the clastic breccia would be $^1/_5$ and it could be higher than ½ of the total ore. The remainder came from concentrations in the ore bed and the marble breccia with the least amount from the marble breccia.

Grades of secondary ore as actually mined cannot be estimated as the production tonnages refer to picked or dressed ore.

Assays of specimens of mineralised ground "grabbed" from the remnants of ore lenses of various types are as follows:

NO.	ASSAY VALUES			MATERIAL
	Copper	Gold	Silver	
A75/62	4.5%	2 dwt.	N.D.	Clastic breccia. Type 1
A77/62	5.2%	1.5 dwt.	N.D.	" " " "
A82/62	0.7	N.D.	N.D.	Clastic breccia. Type 2.
A83/62	0.9	N/D.	N.D.	" " " "
A84/62	1.8	2.5 dwt.	N.D.	Clastic breccia? Type 1
A85/62	2.5	0.5 dwt.	N.D.	Ore bed (with Cu carbonate nodules along bedding planes)
A86/62	3.1	N.D.	N.D.	"Ore bed".
A87/62	0.4	N.D.	N.D.	"Ore bed".
A88/62	3.3	2.0 dwt.	N.D.	Kingstons lode 88 Green material.
A89/62	0.9	N.D.	N.D.	Kingstons lode 89 Purple material.

The rich and extensive oxidised ore body was worked to the 30 fathom level, or approximately 180 feet below the present ground level of the bench on the western side of the open cut. Below this level the ore body contracted to a series of small and disjointed ore lenses. These were worked to a depth of approximately 300 feet along a strike length steadily contracting downwards. Workings continued to a maximum depth of 600 feet but very little ore was extracted below 300 feet.

The 180 feet level was presumed to be the bottom of the zone of secondary enrichment, with primary sulphides appearing below it, and becoming an increasingly important constituent of the ore minerals with increasing depth, though oxidised minerals were reported from a depth of 510 feet. The discovery that a large part of the ore was a clastic breccia transported into solution cavities brings into question the possibility that the 180 feet level also marks approximately the downward limit of the extensive formation of solution cavities. In the absence of any reliable geological information from the workings below present water level this must remain an inference reasonably deduced from the geomorphologic history of the area.

The natural water table is at present at R.L. 1605, varying seasonally about R.L 1600, while the 180 feet level is equivalent to R.L 1540. In the only other part of the state (Myponga Dam) in which the author has studied solution cavities in limestone they extend in abundance to a depth of 80 to 130 feet below the existing water table (Johnson 1960).

PRIMARY ORE

Information on primary mineralisation at the Burra Burra is limited to what can be deduced from fragmentary old reports, from the exposures of secondary mineralisation, and from mineralised unoxidised rock on the dumps of the deeper slates.

According to the old reports two well defined lodes, Kingston's and Sander's, were cut by the deepest workings. At 510 feet they were reported as carrying rich "purple ore" (bornite?) There must be some doubt as to the reality of these lodes for the unoxidised copper sulphide carrying material on the dump of Waterhouse Shaft, as mentioned below, is simply the unoxidised equivalent of the "marble breccia" so well displayed in the faces at the back of Grave's Shaft. Remnants of Kingston's supposed lode have been left in the open cut on the west side and here it consists of a soft, white, purple, and green, talcose chloritic material containing up to 3% Copper and a trace of gold. In the old reports it is mentioned as 10 to 15 feet wide at 510 feet depth with Sander's lode 15 to 18 feet wide. Field observations confirm the presence of Kingston's Fault, and of sheared talcose and chloritic material along it, but in the thickest section lineationsare present which can be interpreted as bedding and are in fact parallel to undoubted bedding of folds in the "ore bed" to the north and east of the "lode". Petrological examination of the "lode" material is not conclusive. It shows that the rock could be "a metasomatic rock, perhaps a feldspathised sediment".

Lumps of dark green mottled unoxidised marble breccia on the dumps of the deeper shafts contain abundant bornite and specimens of the bornite bearing breccia assayed 2.4% to 8.9% copper. These specimens probably correspond to the brecciated lode, containing copper pyrites, cut in No. 1 deep diamond drill hole sunk in 1898 at a depth of 780 feet (H.Y.L. Brown, 1908). The descriptions of Kingston's lode by Captain Sanders quoted by Gregory (Gregory 1940) sound very much like the mineralised breccia and it is quite probable that Kingston's "lode" as cut in the deep workings was merely a mineralised part of the breccia. At the surface the "lode" is a discontinuous feature although aligned along a linear trend, probably a fault, defining the western edge of the open cut.

Tinline's "lode" appears to be only the ferruginised infillings of solution cavities aligned along Tinline's Fault. It is significant that the ore associated with it was not followed belowthe 120 feet level.

Of interest in the study of the primary mineralisation is the discovery of a piece of unoxidised limestone containing bedded pyrite and chalcopyrite on the dump of a shaft. This is believed to represent a fragment of unoxidised "ore bed" in the marble breccia as none of the workings in the primary sulphide zone extended far enough east to penetrate the "ore bed", as shown on the section, Fig. 4. In the bedded sulphide specimen the bornite is later than the chalcopyrite whereas in the breccia chalcopyrite is exsolving from the bornite. The stratiform arrangement of malachite and azurite nodules in the "ore bed" is believed to reflect the arrangement of the primary sulphide in the unoxidised equivalent rock. Somewhat equivocal evidence of primary mineralisation in the "ore bed" comes from the diamond drill hole No. 2, shown in its approximate position on the section, Fig. 4. This hole cut copper sulphide mineralisation at a depth of 706 feet in a position where the structural interpretation of Dickinson places the contact between Units 1C and 1B or between 1B and breccia (the "ore bed"). It continued in rock showing copper sulphides to its terminal depth of 787'. No mention is made of breccia or lode in the meagre description of thehole..

Thus there is evidence for two types of primary mineralisation, disseminated bornite mineralisation in the marble breccia adjacent to a prominent structure (Kingston's fault) and stratiform chalcopyrite mineralisation in the "ore bed". No primary copper mineralisation has been detected in the dolomites (Units 1C and 1D) as yet. Specimens grabbed from the dump of Waterhouse Shaft assayed as follows. All are primary sulphide specimens.

NO.	ASSAY VALUES				MATERIAL
	Copper	Silver	Lead	Gold	
A112/62	2.4%	2.5 dwt.	0.01%	N.D.	Marble Breccia
A113/62	8.9%	10.5 "	N.D.	N.D.	" "
P333/62	6.5%	7.0 dwt.	-	NIL	
P334/62	8.2%	7.0 dwt.	-	NIL	
A144/62	6.8%	10.0 dwt.	0.1	N.D.	Ore Bed

N.D. = Not detected.

STRUCTURAL CONTROL

The two faults, Kingston's and Tinline's obviously form structural boundaries to the secondarily enriched ore body but their influence on primary mineralisation is not known.

Possibly of greater significance is the location of the ore body at a zone of plunge change, or axial culmination in the folds. It is suggested that the primary ore body plunges away with the structure both north and south of the mine and that the original secondary ore body reflected this in mirror image fashion, gradually dying out north and south as the depth of the primary mineralisation increased.

MINERALOGY

Some work has been done on unoxidised specimens of sulphide bearing marble breccia from the dumps of the deeper shafts and on specimens of clastic breccia and "lode" material. None of this work has been systematic and most is purely descriptive.

In the unoxidised breccia chalcopyrite, pyrite and bornite have been recognised as the commonest sulphides. In some specimens chalcopyrite is intergrown with pyrite and exsolving from or replacing bornite. In others bornite replaces chalcopyrite and occurs as inclusions in pyrite.

Bornite in one specimen is altered to neo-digenite at grain boundaries and in another covellite forms as an alteration product of bornite.

The unoxidised bedded ore is a dolomite with traces of calcite and detrital quartz and feldspar muscovite and chlorite have formed in the rock and the sulphides pyrite, chalcopyrite and bornite are present. Bornite replaces both pyrite and chalcopyrite and is itself altered to corellite along grain boundaries.

Tracesof lead and silver can be found in the assays of the copper bearing rocks and galena was discovered by Mr. Malcolm Mason in the dolomites of Unit 1D 200 feet east of Tinline's Shaft.

ORE GENESIS

PRIMARY ORE

The problem of the genesis of the primary ore is bedevilled by absence of critical information. No comprehensive mineralogical studies have been possible at this stage of investigation, all primary mineral exposures are inaccessible and no competent geologist had access to, and reported on the workings when the mine was open.

However it is certain that hydrothermal mineralisation in the form of solutions from late phase activity of a granite magma hadno place in thedeposition of copper minerals at Burra Burra. The nearest igneous intrusives are basic masses 20 miles distant.

How then were the primary copper minerals emplaced? The mode of occurrence of part of the carbonate copper minerals, and by reference of the primary copper minerals of the "ore bed" is stratiform. It may well have been deposited from marine waters, contemporaneously with the clastic limestone grains or have been deposited in the granular interstices at a much later date by solutions at an elevated temperature, the evidence will not permit a definite answer to this question. A biogenic or a true sedimentary origin as clastic grains for the copper sulphide in the orebed also cannot be excluded.

It is suggested further that after brecciation of the carbonate sediments and subsequent faulting the rising geothermal gradient; consequent on burial during folding, could have initiated redistribution of the sulphide copper of the ore bed and deposition of it, in the form of bornite, in the breccia matrix and as lodes in Kingston's fault.

Yet one cannot be dogmatic about primary ore genesis as too few facts are available and it is possible that the evolutionary history of the primary mineral deposit is much more complex than suggested above. It is unlikely to be any simpler.