DEPARTMENT OF SUPPLY & DEVELOPMENT

REPORT ON THE

GEOPHYSICAL TEST SURVEY OF BURRA COPPER MINE, S.A.

by

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Ministry of National Development

Report on the Geophysical Test Survey

Burra Copper Mine

South Australia

LIST OF PLATES

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A. INTRODUCTION.

The Burra copper deposit is situated in the northern Mount Lofty Ranges about 100 miles north of Adelaide.

The deposit, which consisted essentially of high grade secondary copper ore, was discovered in 1843 and had a productive life of 29 years. Approximately 700,000 tons of ore were raised during this period yielding 234,648 tons of dressed ore with an average grade of 22% copper. Apparently the only prospecting work conducted on the area since cessation of mining operations in 1877 comprises two diamond drill holes to depths of 1,004 feet and 787 feet respectively. These intersected low grade copper sulphide mineralization at 813 feet and 706 feet respectively but the records of the bores are inconclusive and cannot have any positive bearing on future developmental or prospecting work.

A detailed geological examination of the area in which the Burra copper deposit occurs was made at the end of 1941 by Mr. S.B. Dickinson of the South Australian Mines Department. As a result of this investigation, Mr. Dickinson has shown that the Burra copper deposit is associated with a number of geological features of which a fault zone and a calcareous shale horizon (which apparently has been favourable to ore deposition) are the two principal ones.

In the report which Mr. Dickinson prepared following his investigation of the area,* he has pointed out that the existing workings contain no known ore reserves. Furthermore, such developmental work as was carried out in the deeper levels of the mine, and the results of the two drill holes mentioned above, seemed to indicate that values at depth were generally of unpayable grade. He concluded that any successful revival of mining in the area appears to be dependent upon the discovery of entirely new deposits beyond the limits of past explorations. Mr. Dickinson has visualized the possibility of such a new deposit occurring north of the Burra Mine on the prolongation of the fault zone where it is concealed by a shallow thickness of alluvium and detrital material. The persistence of the mineralization for some considerable distance to the north of the Burra Mine is suggested by the occurrence of copper carbonates near the railway quarry approximately 3,000 feet north of the Burra open cut.

Because superficial deposits cover the area to the north, Mr. Dickinson has recommended a geophysical survey as a means of prospecting the area. The area to be covered by such a survey would depend on how far to the north the principal structural control, namely the fault zone, extends. The Kingston fault, which bounds the fault zone on its western side, appears to be a strong feature. Mine workings have proved its existence over a length of approximately 3,000 feet and its continuation northward for a similar or even greater distance seems to be a definite possibility. It will be appreciated, therefore, that the area which might be covered by such a survey as is recommended by Mr. Dickinson might be large and the time required for such a survey correspondingly long. It was decided, therefore, that before any extensive geophysical survey be undertaken, a series of tests be carried out to test the reaction of the various geological formations and structural features to geophysical methods and in this way to decide whether or not the more extensive geophysical survey would be justified.

* Bulletin No.20, Geol. Sur. S.A.

This report deals with the results of such a test survey which was carried out in the vicinity of the Burra mine between March 4th and 13th, 1942.

B. GEOLOGY AND NATURE OF THE GEOPHYSICAL PROBLEM.

The geophysical problem may be briefly stated in the form of a question. If a copper deposit similar in character to that which has been mined at Burra exists beneath superficial deposits to the north of the Burra Mine, could it be located by geophysical methods? The geophysical tests were carried out to provide, if possible, an answer to the question.

It is therefore desirable at this stage to examine closely the nature of the known ore occurrences and to deal briefly with the geological conditions associated with the Burra copper deposit. For a fuller discussion of these conditions, however, reference should be made to Dickinson's report. A geological plan by Dickinson of this portion of the Burra area which contains the Burra ore-body is shown on Plate 1.

The Burra ore-body occurred in the hanging-wall of the Kingston fault. It consisted of a large cigar-shaped mass of secondary copper minerals, chiefly carbonates, in limestones and shales. Its centre of gravity was situated approximately at ground water level and its maximum dimensions were 800 feet in length, 250 feet wide and 300 feet thick. At the 180 feet level (40 feet below present water level) the mineralization became more or less confined to fissures in which numerous small and disjointed ore-bodies were present. These small ore-bodies within the fissures appear to represent the character of the primary copper mineralization. They do not constitute payable ore occurrences.

No description of the ore outcrop has been preserved but Samuel Higgs, a former manager of Wallaroo Mines, in a report dated 27th October, 1877, refers to the surface ores as occurring as great "bunches." These "bunches" probably were rounded masses of various sizes containing carbonates, oxides and possibly chalcocite. Their copper content was probably 20-30% (dressed ore averaged 22%) and they were enclosed in broken and twisted country rock consisting of "cherty siliceous formation, crystalline white and grey limestone, blue slaty shales and argillaceous sandstones."

The Burra ore-body appears to have been essentially an oxidation enrichment in which the migration of copper in solution probably played a major part. The oxidation products from the numerous small and low grade primary ore-bodies have accumulated in the region of the ground water table which has evidently maintained a fairly constant level over a great period of time. Copper in solution has evidently invaded the previously unmineralized country rock adjacent to the original primary mineralization, the zone of deposition being centralized at the ground water table.

It must be assumed, therefore, that if any new deposit exists in the area recommended for geophysical survey to the north of the original ore-body, it will consist of such an accumulation of secondary copper ores in broken and twisted country.

None of the geophysical tests carried out could determine whether or not such a deposit would respond to geophysical methods of prospecting for the obvious reason that the original deposit of this nature has been completely mined and no part of it remains on which geophysical tests could be conducted.

What geophysical reactions would be obtained over such a deposit is a matter for pure speculation. The writer can find no reference in previous literature to geophysical surveys over a similar deposit so that there is no precedent to guide the following discussion. However, there are certain physical conditions involved which suggest that such a deposit might be located geophysically.

In the first place, such a deposit would almost certainly be more electrically conductive than the surrounding rocks. To what extent it would differ in this respect from the surrounding rocks can only be guessed because the writer can find no reference in the literature to the resistivity of secondary copper ores such as comprise the Burra deposit. However, from general considerations such as the occurrence of much crushed and shattered material in the presence of secondary copper minerals, and the aqueous solutions derived from such minerals, it seems a reasonable assumption that the conductivity of such a deposit might be many hundred times greater than that of the altered limestones and massive dolomites which lie on either side of the original deposit. On the other hand, the conductivity of a calcareous shale band which lies between the two rock types mentioned above and in which the Burra ore-body occurs may not differ greatly from the conductivity of the ore-body itself. Anticipating the results of the tests, which will be discussed in detail later in the report, it was found that, in tests conducted at the southern end of the Burra open cut, the conductivity of this particular bed increased rapidly as the open cut was approached, i.e., it increased as the original ore-body was approached. This increase is probably due to the combined effects of an increase in the shattering and distortion (or of the fault zone with which the ore-body is associated being more intensely developed) and of the increase in mineral content of the included water as the position of the original ore-body is approached. This suggests that the ore-body would be much more conductive than the calcareous shale band in its normal condition.

As regards other methods of geophysical prospecting, the self-potential method might be a suitable one. Dickinson lists chalcocite as possibly occurring as a secondary copper mineral in the Burra ore-body. If this mineral should occur in any appreciable quantities, its oxidation might lead to the generation of a self-potential effect. The surface conditions (loamy soil) on the area recommended for geophysical survey should be suitable for the preparation of satisfactory electrical contacts and the results obtained from such an area should be reasonably free from contact effects, which have frequently made interpretation of results impossible in other areas. Under the favourable conditions presented in the area it is a reasonably safe assumption that any measured self-potential effect, however small, could be attributed to the oxidation of secondary or primary copper sulphides. This assumption would be based on the knowledge that accumulations of metallic sulphides do not exist in the area outside the limits of the known ore-bodies.

The foregoing discussion dealt with what might be called the direct method of approach, i.e., the possibility of locating an ore-body such as the Burra one by means of its own intrinsic physical properties. There is, however, a second line of approach which aims at the location of such an ore-body indirectly through mapping the geological structures with which such an ore-body is associated. It was in order to gain knowledge of the usefulness, or otherwise, of geophysical methods for this indirect approach that the tests herein reviewed were carried out.

(1) <u>Structure</u>. In order to fully appreciate the following discussion of these tests it is necessary to briefly outline the structures which Mr. Dickinson has mapped and which appear to have

been the controlling factors in localizing the copper mineralization at the site of the Burra mine.

Although Mr. Dickinson's report will be freely quoted reference should be made to his full text and to the plans which he has prepared.

> "The Burra ore-body is located in a fault zone on the steep east limb of the regional anticlinal fold and is some distance east of the main regional fault. The fault zone is bounded by the two main breaks, Kingston's and Tinline's faults, the former being the more prominent structure. Between these faults, there are other minor fractures (not shown on plan), such as Sanders' fault, along which movements have also taken place. In places these dislocations have smashed the rocks into breccias which appear to be localized in competent limestone or dolomite beds where the faulting engages a relatively wide band of such competent rocks in contact with incompetent ones. The more massive limestones and dolomites are broken into fragments and tend to become enwrapped by "plastic" calcareous shales, a condition which possibly facilitated the spreading of the mineralizing solutions. In other places highly crumpled folding has brought about relief of stress.
>
> One structural control of the Burra ore-body is therefore the intersection of the fault zone with the contact between series of calcareous shales and massive dolomites. This is evident from the fact that mineralization has been found both north and south of Burra in this bed; which has been coloured distinctively on the mine plan on this account. Furthermore, the longitudinal section of the Burra mine suggests that pitch may also influence ore occurrences. The shape of the lower limit of profitable ore outlined on the longitudinal section may be easily correlated with the pitch changes shown by the folds adjacent to the ore-body. This possible ore control is supported by the structural conditions at the Princess Royal (a small ore-body located approximately 8 miles south-east of the Burra ore-body), which can be confidently related to the dome structure mapped at that locality."

An examination of the geological plan which accompanies Mr. Dickinson's report reveals another feature which appears to be intimately associated with the Burra ore deposit. This is the highly buckled appearance of the favourable horizon, namely, the calcareous shale band which is referred to above, in the vicinity of the Burra open cut.

It will be observed that this shale band has been mapped over a length of 10,000 feet to the south of the Burra mine to where it engages the Kooringa fault. Over this length the outcrop has a slightly sinuous character. In contrast to its general appearance, however, that part of it which coincides in position with the Burra ore deposit has an extremely buckled appearance which might be ascribed to the cross-folding which is evident from the nature of adjoining beds to the immediate north of the open cut.

The coincidence of the ore-body with the place where the Kingston-Tinline fault zone engages the buckled calcareous shale band suggests to the writer that this buckling may have been one of the factors governing the localization of the ore-body at the place where it was found.

It would appear from the foregoing discussion of the structural controls that the principal features are :-

(i) Kingston-Tinline fault zone.

(ii) The intersection of the above fault zone with the contact between series of calcareous shales and massive dolomites.

(iii) The ore deposits favour a particular calcareous shale band.

(iv) Possibly the intersection of the fault zone with intensely buckled calcareous shale band.

(2) <u>Nature of the geophysical problem from the structural point of view.</u> From the geophysical point of view it would seem that if the fault zone, or principal members of it such as the Kingston and Tinline faults, could be located by geophysical methods and, further, if the position of the favourable calcareous shale band could be mapped it should be possible to determine whether the favourable geological conditions which are associated with the known ore occurrence are repeated in the covered area to the north. For the purpose of the following discussion it will be assumed that a repetition of such conditions would be favourable to an ore occurrence similar to that already worked.

Mr. Dickinson, however, stresses the fact that structural ore controls cannot be slavishly used for ore prediction purposes because the Burra ore-body is largely an accumulation of secondary copper minerals which have not necessarily been localized solely by structural controls.

C. RESULTS OF THE TESTS.

Geophysical tests were made at the southern end of the main open cut and covered an area extending 500 feet north to 300 feet south of Morphett shaft and extending laterally for 500 feet east and west of that shaft. The area so covered crosses the Kingston-Tinline fault zone and the favourable calcareous shale horizon.

In addition to the tests on the area described above, a small amount of testing was carried out on two traverses at the northern end of the Burra open cut. The following methods were used in the tests :-

(i) Potential ratio (electrical).

(ii) Electromagnetic.

(iii) Magnetic.

(iv) Self-potential.

(a) <u>Morphett Shaft Layout.</u>

(i) Potential Ratio Method - The results of this test are shown on Plate 1 in the form of a logarithm - potential-gradient contour plan while the potential gradient profiles are shown on Plate 2. The logarithms of the potential gradients are so closely related to the resistivities of the rocks involved that the plan may be regarded as a resistivity contour plan. The geological features as mapped by Dickinson have been added to the plan. Some difficulty was experienced in fitting the position of shafts, dumps, etc., as shown by Dickinson with the positions as mapped on the geophysical layout but the fitting shown on the plan is regarded as being the most likely.

It will be observed that the potential gradients, and hence the resistivities, are generally high on the western half of the area. This area is occupied by limestones which have been brecciated and recemented in part and generally altered to impure marbles.

Between traverses 100N and 370N and approximately 150 to 200 feet south of the base line is a zone in which the gradient values fall to 1.2 from the prevailing high values (1.5 - 1.6). The axis of the zone coincides in plan position with the outcrop of the Kingston fault and it is reasonable to presume that the decrease in potential gradient values is due to this feature. Other zones of low values on the western side of the layout are due to causes unknown but there is evidence of considerable folding of the beds in the vicinity of 350W/300S which may have produced structural weakness responsible for the low value obtained at the place.

Potential gradients and hence resistivities are generally low over the eastern half of the layout which is occupied by banded dolomites and calcareous shales.

The calcareous shale band which apparently provides the favourable ore horizon coincides closely at its northern and southern ends with a zone of low values which show a marked tendency toward very conductive conditions as the northern end of the layout, and hence the original ore-body, is approached. This tendency towards better conductivities has been discussed earlier where the belief was stated that this tendency is due to an increase in the shattering or shearing of the rocks accompanied by an increase in the conductivity of the included water as the ore-body is approached.

In the centre of the layout, particularly between traverses 100S and 200N, the gradient contours show a marked divergence in trend from the trend of the calcareous shale band as mapped. It is suggested that the geological mapping may here be slightly in error. A geological interpretation of the geophysical results is suggested in Figure 2, Plate 1. This interpretation is based on the position of the conductive zone which is believed to correspond to the calcareous shale and the interpretation is supported by the trend of a strong resistive zone of narrow width which lies to the immediate east of the calcareous shale band on the southern edge of the layout and extends to 100N. This zone is probably due to the presence of a narrow band of dense dolomite and its trend is parallel to that assumed from the electrical evidence to be that of the calcareous shale band. The interpretation shown is further supported by the results of a magnetic test which gave a series of weak indications, apparently arising from some narrow band of rock with a high magnetic susceptibility within the calcareous shale band. The trend of the magnetic indications is the same as that assumed for the calcareous shale band from electrical evidence.

The conductive zones on the far eastern side of the layout are probably due to additional shaly bands within the zone mapped by Dickinson as containing predominantly banded dolomites.

To what extent the conductivities measured in the favourable calcareous shale band are due to the influence of the Kingston-Tinline fault zone can only be guessed but, as already pointed out above, the increase in conductivity as the open cut is approached may be due partly to an increase in shearing or shattering as the ore-body is approached.

Faults of strike similar to the Kingston and Tinline faults have been mapped at a number of places in the upper limestone group of rocks to the east of the Burra mine. These faults like the Kingston and Tinline fault have evidently been mapped from the evidence provided in openings such as quarries, their surface outcrop apparently being obscured by soil.

It therefore seems within the bounds of possibility that undiscovered faults and perhaps even zones of faulting may exist in the eastern side of the test layout and that the zones of generally good conductivity found there may be due partly or wholly to such causes.

(ii) Electro-magnetic Method - Electromagnetic tests were carried out on this layout on traverses 100S, Zero and 100N but the results were poor and the method cannot be recommended as a suitable one for the area.

(iii) Magnetic Method - Tests with the magnetic method gave a number of small anomalies which are shown on Plate 2, together with their corresponding geological sections. As mentioned earlier in this report, the trend of these indications is the same as that of the electrical indications, each, however, differing slightly from the trend of the calcareous shale and dolomite bands as mapped. It is suggested that the geological mapping may be in error. The cause of the magnetic anomalies could not be determined but it is tentatively assumed that they are due to the presence of a narrow band of rock of high magnetic susceptibility within the calcareous shale band.

Magnetic readings in the vicinity of Morphett shaft were greatly disturbed by the presence in the shaft of a great number of massive mild steel pump rods.

(iv) Self-potential Method - The results of self-potential tests on the layout are shown on Plate 2.

The curves have a tendency towards high values at either end but this is attributed to surface causes rather than to any deep seated effect.

No anomalies which can be correlated with the known mineralization are present. The general smoothness of the curves in their centre sections, obtained in spite of the extremely dry surface conditions, suggests that under more favourable conditions such as might be expected during the winter months on the well soiled area to the north of the mine, little disturbance can be anticipated from surface causes.

(b) Northern Layout.

In addition to the tests on the layout described above a limited amount of testing was done on two traverses at the northern end of the Burra open cut. Potential gradients were determined on these traverses as well as self-potentials. Magnetic intensities were determined for one complete traverse and part of the other one.

The results are shown on Plates 3 and 2. On Plate 3 are shown potential gradient contours while self-potential, potential gradient and magnetic profiles are shown on Plate 2.

(i) Potential Ratio Method - An examination of the potential gradient contour plan shows three zones of relatively good conductivity crossing the traverses. The centre one coincides with a line of potholes and shallow shafts which have apparently followed the course of a fault or fissure along which some mineralization has occurred.

The conductive zone which crosses the traverses between 200W and 300W may possibly represent the continuation of the calcareous shale band which has been mapped to within 200 feet of the traverses on the southern side.

The geological significance of the conductive zone between 300E and 400E is not known - it may, however, be due to the presence of a relatively conductive shale band.

More detailed geological mapping is evidently necessary to establish beyond doubt the relationships between the geophysical results and geology on this layout.

(ii) Magnetic Method - The magnetic profiles (shown on Plate2) show a number of minor anomalies - one near 300E being located on the two traverses. Their geological significance is not known but it is believed that the anomalies arise from narrow bands of rock which have a relatively high magnetic susceptibility. The axis of the magnetic anomaly at 300E is parallel to the strike of the conductive zone between 300E and 400E.

(iii) Self-potential Method - The results of the self-potential tests are shown in the form of profiles on Plate 2. The profiles show considerably more disturbance than do the profiles obtained on the Morphett shaft layout. The disturbances are apparently due mainly to surface causes. However, the persistence of low values on the eastern end of the traverses may be due to the presence of oxidizing sulphide minerals at depth. The low values in the vicinity of 400E correspond roughly with the prolongation of the Tinline fault and may be due to sulphide mineralization within such a feature.

D. CONCLUSIONS.

The geophysical problem at Burra is that of locating large masses of secondary copper ore - if such should exist - in the covered area to the north of the existing workings.

The geophysical tests herein reviewed were carried out with the object of determining, if possible, whether such a problem was capable of solution by geophysical methods.

A critical examination of the project shows that there are two ways in which the problem might be tackled.

Firstly, there is the possibility of discovering such bodies by measuring directly physical properties - such as electrical conductivity or self-generated potentials - which are intrinsic properties of the body. This might be called the direct approach.

Tests to determine whether or not the direct approach was possible could not be made because the original deposit had been completely extracted and no other deposits of similar kind were known to exist. It is believed, however, from purely general considerations, that this method of approach might yield useful results.

The second method of approach to the problem is that of mapping geological structures with which the known ore-body is associated on the assumption that repetitions of the favourable structural set up would favour a recurrence of the ore-body. This does not necessarily follow, however, for, as Dickinson points out, the original ore-body was in nature an accumulation of secondary copper minerals and was not necessarily localized by structural controls alone.

The principal structure appears to have been the Kingston-Tinline fault zone and it is suggested that conditions favourable to ore deposition occur when the fault zone engages the contact between a calcareous shale band and more competent dolomites. It also appears that one particular calcareous shale horizon may have been favourable to ore deposition.

It would seem therefore that if geophysical methods could map the course of the fault zone and also map the position of the favourable calcareous shale horizon any repetition of the favourable structural conditions occurring in the covered area to the north of the Burra Mine would be immediately apparent.

The geophysical tests gave a weak indication of the Kingston fault near Morphett shaft and of other minor faults at the northern end of the open cut. They were not, however, strong indications and the existence of similar features in unknown ground would probably only be recognized if the indications differed appreciably in strike from the strike of the country rocks.

As far as the favourable calcareous shale horizon is concerned, the geophysical tests indicate that it should be possible to map the position of such a band in an area of unknown geology providing its occurrence was known at at least one place for purposes of correlation.

It would seem therefore that the application of geophysical methods for prospecting the area to the north of the Burra Copper Mine could be expected to yield interpretable results. Whether or not such a survey is justified would seem to depend largely on how favourable, from a purely geological point of view, are the chances of a new ore-body existing in the area on which such a survey is contemplated.

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