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Mineralization in the Cobar-Nymagee Province and its Significance

by

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I. SUMMARY.

L.C. Graton (12)≠ has recently remarked "the out-standing unfilled need lying ahead is the discovery of new mineralized districts". In this connection he speaks of "the all-important standpoint of genetic understanding". As a contribution towards filling this need, the following points are here presented for consideration :-

1. That the Cobar Nymagee (N.S.W.) copper-gold metallization is intimately related to synchronous or concordant granite and quartz-felspar porphyry exhibiting strong evidence of replacement origin.

2. That the metallization is closely connected with the porphyritic phase of the synchronous granite, which tends to form near the top of granitic cupolas.

3. That the subsequent, crosscutting Erimeran granite, which is probably only slightly later in age than the concordant granite, shows little relationship to ore deposition.

4. That a chain of important ore deposits extending from Cobar to Nymagee occurs close to the axis of a faulted anticlinal fold; there is good reason to believe that the younger formations composing this fold are concordantly granitized, and that the ore deposits thus overlie an inverted V-shaped mass of granite.

5. That along this anticlinal structure, mineral fields occur in the vicinity of anticlinal crossfolds and are thus associated with domes in the sedimentary rocks. There is evidence that these domes also correspond to cupolas in the underlying granite. Just as the whole Cobar field is associated with an anticlinal crossfold, each ore deposit within the field is associated with a similar minor structure. It is suggested that these may correspond to the position of minor cupolas in the underlying granitic rock.

6. That there is a zonal arrangement of the ore deposits at Cobar which strongly supports the conception of their origin from a granitic mass which pitches with the bedding. Evidence is presented showing the possible vertical range over which ore deposition has taken place at Cobar.

7. That some prospecting targets can be suggested on the basis of the above evidence.

8. That the metalliferous province is co-extensive with a particular group of beds and that the metals have been concentrated during the granitization of these beds. This is suggested by the association of the ore with the synchronous and not with the subsequent granite and also by dithizone tests.

≠ The numbers in parentheses refer to bibliography at end of paper.

9. That the Cobar-Nymagee findings have a general application in mineralized districts related to granitic rocks, e.g. in the Broken Hill, Kalgoorlie-Coolgardie and Bendigo areas.

II. INTRODUCTION.

Situation, Climate, Topography.

Cobar is situated 464 miles by rail W.N.W. of Sydney, N.S.W., and is at the head of a branch line from Nyngan on the Sydney-Bourke railway. It is situated in the midst of sheep-grazing country, the average rainfall being approximately 15 inches per year. The area is one of very low relief; the broad plain around Cobar is only 800 feet above sea level. A number of low ridges composed of the more resistant rocks rise to heights of 100 to 400 feet above the plain.

History.

The Cobar mining field was discovered in 1870, since when production has been almost continuous. To the end of 1947, the field had produced approximately 130,000 tons of copper, over 1,000,000 ounces of gold, and approximately 2,000,000 ounces of silver. At current Australian prices, this production would be valued at approximately £A.27,000,000. In addition to this, the mine at Nymagee has produced some 23,000 tons of copper, and production from the Mount Boppy Mine at Canbelego has been over 400,000 ounces of gold. Mining at Cobar has reached a maximum depth of 2,000 feet (New Occidental); three other mines are over 1,000 feet deep. (See Plate C.3).

Three mines, the New Cobar, the Chesney, and the Occidental, are at present being operated by New Occidental Gold Mines, N.L., the rate of production being approximately 130,000 tons of ore per annum.

Size of Deposits.

The major deposits at Cobar yield from 500 to 2,000 tons of ore per vertical foot, and persist very strongly in depth. The New Occidental orebody is known, from drilling results, to extend for 3,000 feet below the surface, without any substantial change in the type of mineralization.

Previous Investigations.

The district has previously been described in some detail by E.C. Andrews (1). A.C. Lloyd (19), during the years 1935-1939, carried out considerable reconnaissance mapping in the Cobar-Canbelego-Nymagee-Mount Hope metalliferous province and published a number of plans. Mulholland and Rayner (24) of the Department of Mines, New South Wales, carried out further investigations in 1945, and, at the same time, the writer, assisted at various times by Messrs. W.B. Dallwitz, K.R. Fleischman, J.F. Ivanac, E.K. Sturmfels, and others, commenced an investigation which has continued until the present time. An interim report (31) on the detailed structure of the Cobar mines has been issued to interested parties and is now to be published.

Two large mining companies, the Commonwealth Bureau of Mineral Resources, and the Department of Mines, New South Wales, are jointly carrying out an exploration programme in the Cobar province in the hope of finding previously unknown ore deposits. The writer is in charge of the Commonwealth Geological investigations in the area and gained his present knowledge as a result of these investigations.

The geochemical work mentioned in the paper was carried out under the supervision of V.P. Sokoloff, of the United States Geological Survey, who came to Australia in 1948, under the joint auspices of the Zinc Corporation Ltd. and the Bureau of Mineral Rescources. The geochemical investigations carried out in the Cobar-Nymagee province were of a reconnaissance nature and demonstrated that the dithizone method (26) of copper detection may be of considerable importance in prospecting. The results of this and other geochemical work performed in Australia in 1948, are now being prepared for publication.

111. GEOLOGICAL HISTORY OF AREA.

Map Compilation.

Plate C. 1 shows, in outline, the general geology of the district, as it is now known. The map has been compiled by the writer from information gained jointly by him and by E. K. Sturmfels. Some observations have been taken from the geological maps of Andrews, Lloyd and Mulholland and Rayner, and data supplied by the geologists of Zinc Corporation Limited, have also been incorporated in the plan.

The map covers an area of approximately 2,000 square miles and only a portion of it is at present covered by aerial photography. Because of the general scarcity of outcops, mapping in this district is properly regarded by all geologists acquainted with it as being most difficult; in many parts of the district, air photographs yield no information because of the deep alluviation; in other parts, only faint trend lines are visible. However, elsewhere, the photography shows most valuable information and large-scale structural mapping would be most difficult without it. The mapping is being carried out on a scale of 4 inches to the mile and, on the present compilation (scale 1 inch to 2 miles), it is possible to show only the salient features. As the investigation is still proceeding, the map must be regarded as being only tentative. Most attention has been paid to the belt of rocks in which the Cobar-Queen Bee-Nymagee ore deposits lie, and much information remains to be gathered in the remainder of the area.

Although a small proportion of the information has been taken from other sourches, the structural mapping is almost entirely new, and the author alone is responsible for the interpretation of this data shown on the sections (Plate C.2).

Summary of Historical Geology.

Accounts of the general geology of the Cobar-Nymagee District have been given by Andrews (1) and Lloyd (19), and, as this paper must be of limited length, the present author's view of the stratigraphic and tectonic history of the area are briefly tabulated below:-

(a) Ordovician. (?) Deposition of Cobar-Nymagee-Canbelego tuffaceous sandstones (4,000-6,000 feet), followed by the deposition of a much greater thickness (30,000 feet?) of tuffaceous muds. No fossil evidence for the age of these beds has been found, but it is not impossible that they correspond to the Ordovician beds found near Tallebug (25) which appear to lie on the southern continuation of the Cobar-Nymagee belt.

(b) Silurian. The Upper Silurian was marked by the deposition of the Weltie and Ballast groups (the latter lying to the east of the Canbelego line of lodes). The Weltie beds consist of fossiliferous limestone and chert with interbedded claystones and sandstone. Volcanic activity was widespread in Upper Silurian times and the Baninda volcanics consisting of tuffs, volcanic breccia, rhyolite and amygdaloidal basalts, interbedded with fossiliferous sandstones, belong to this period.

At the close of the Silurian there was intensive folding on axes trending N.N.W. - S.S.E. During the folding, high-angle reverse faults developed close to the axial planes of a number of anticlines. Such a fault can be traced almost continuously from the vicinity of the Cobar township to south of Mount Nurri and shows a close relationship to ore deposition. Its position has been determined by the junction of competent and incompetent rocks.

(c) <u>Devonian.</u> Lower Devonian times were marked by the depression of the Silurian beds and the deposition of considerable (but unknown) thicknesses of sandstones and claystones known as the Ampitheatre beds. It is probable that the Alley and Water Tower beds to the west of Cobar also belong to this period though fossil evidence obtained to date is of doubtful value. The Shume beds (quartzites) in the Nymagee-Wirlong area may also belong here. At the close of Lower Devonian time, the Tabberaberan orogeny developed and resulted in folding along N.E.-S.W. axes. This had the effect of causing pitch changes in the Silurian folding and also caused buckling of the axial plane faults mentioned above. During this time granitization of large masses of tuffaceous sediments occurred which resulted in the concentration of copper and gold materials, especially above the high-points or cupolas of the granitized mass. The supposedly Devonian beds are not themselves "intruded" by granite, but, to the west of Cobar and in the Canbelego area (3) they contain low-grade copper and gold metallization. It seems then, that the lode-shears were formed and that the ore was deposited, at the close of Lower Devonian time. At Cobar the shears were localized by the pre-existing fault, but unlike it, they are quite unfolded. There appears to have been no large-scale tectonic disturbance since the deposition of the lodes, though this event seems to have been followed by the deposition of some Upper Devonian beds such as the Shenandoah beds mapped by Lloyd to the south of Shuttleton.

<u>IV. THE NATURE AND SIGNIFICANCE OF THE GRANITIC ROCKS.</u>

In a previous paper (30), the author suggested that the Cobar orebodies were not genetically related to granite because, at that time, no granite had been found bear the field and because a regional line of weakness appeared to have had a decisive influence on ore localization. As a result of the extension of mapping to the Nymagee District (some 50 miles to the south of Cobar) and of the discovery of a small, previously unrecorded granitic mass near Cobar itself, it now seems quite clear that the Cobar-Nymagee ore deposition is, indeed, intimately related to granite. The former conclusion emphasises the danger of confining studies to mines and their immediate surroundings if one wishes to understand ore genesis and localization.

The granitic rocks shown on Plate C 1 are of two distinctive types :-

<u>1. Synchronous Granites.</u>

The granite immediately to the east of Nymagee township is of the synchronous type (30). Structurally, it generally conforms to the bedding though in some instances, its boundaries appear to cross the bedding for a short distance, in most cases, along lines of weakness such as joints. This granite outcrops in two distinct masses which will be described separately :-

(a) <u>The Northerly Mass.</u>

This mass of rock, although all shown on the plan as granite, is by no means homogeneous. It consists, for the most part, of medium to coarse-grained quartz-microcline granite, some with abundant biotite and some with little ferromagnesian mineral content. Within the granite, and quite undisturbed structurally by it, are beds of tuffaceous sandstone in all stages of alteration to granite and, in some instances, to granite-porphyry. Where the road from Nymagee to Canbelego crosses this granitic range, the author collected a number of specimens for further study. Within a single sandy bed, it is possible to observe, over a distance of 15 feet along the strike, progressive alteration from a comparatively fresh-looking sandy schist to an almost completely granitic rock. Microscopic examination by J.F. Ivanac showed that the sandy schist consists mainly of elongated anhedral quartz grains, with small amounts of potash felspar and muscovite. There is a groundmass of sericite and quartz. The granitic phase is a quartz - orthoclase - muscovite - biotite rock in which a good deal of sericite has been developed by secondary processes.

Several specimens collected from this area, even though granitic in appearance, are abnormally high in free silica and may be described as partly felspathized sandstones. In the intermediate stages of felspathization, the alteration is normally selective to thin laminae within each bed; this gives rise to a lit par lit structure.

Within the generally granitized mass, hills of solid granite are aligned parallel with the bedding of partially granitized sediments occurring on either side. To the east of the main northerly mass, discontinuous, spotty, granitization occurs. A number of small copper and gold deposits are closely associated with this granitization. The major Nymagee copper deposit occurs immediately to the west of the northern synchronous granitic mass.

(b) <u>The Southern Synchronous Granitic Mass.</u>

This mass occurs on the same strike as the northern one and exhibits similar replacement characteristics; texturally, however, it is a good deal different. It consists of perhaps 70 per cent granite-porphyry and contains large phenocrysts of quartz, orthoclase, and microline with some biotite, in a fine groundmass of quartz and felspar. However, throughout the mass, the porphyry is found to grade into medium-grained granite which, in many instances, either contains dark bands parallel to the bedding found near the boundaries of the granitic mass, or is "interbedded" with actual sediments - now mainly quartz-sericite schist. This mass thus exhibits the close field relationship which exists in this area between granite and porphyry. The nature of this relationship will be discussed later, as it appears to be intelligible only after the structure of the district has been understood. The point it is desired to make here, is that the two masses of granitic rocks occurring immediately to the east of Nymagee exhibit strong evidence of replacement-origin and generally conform closely to the bedding of the surrounding rocks. These granites may have been formed in the position in which they are now found (30).

(c) <u>Other Synchronous Granitic Outcrops.</u>

In the vicinity of Wirlong and Shuttleton (Plate C.1) two small outcrops, varying from quartz porphyry to quartz-orthoclase porphyry and orthoclase porphyry, occur. At Wirlong, chalcopyrite ore has been mined from a shear zone occurring within the porphyry. In the vicinity of the mine, the "igneous" rock is approximately 700 feet wide and the western 200 feet contains much evidence of former bedding structure. In the field this rock was called "porphyritized sediment".

At Shuttleton, copper ore has been mined from slates, in close association with a small mass of quartz-felspar porphyry, showing evidence of replacement and granitization.

Recently, as a result of information supplied by C. St. J. Mulholland, weathered granite and granitized sandstone was discovered on the dumps of the old Cobar Lucknow shafts, situated 6 miles east of Cobar (Plate C.1), where gold was mined over 50 years ago. It was not possible to inspect the actual occurrence underground.

2. Main Subsequent Granites.

(a) Erimeran and Gilgunnia Granites.

The Erimeran granite, shown in the southern part of Plate C.1, is in the writer's opinion, a good example of a subsequent granite (30). It is a cross-cutting, truncating, type and it must have extended to a stratigraphic horizons much higher than that reached by the top of the synchronous granite occurring to the east of Nymagee. It does not contain the bedding remnants and replacement characteristics of the Nymagee granite, but is massive and more or less homogeneous. Most important of all, from the point of view of the present study, it shows little relationship to ore deposition. Similar remarks apply to the mapped portion of the Gilgunnia granite.

(b) Queen Bee Granite-Porphyry.

Two interesting plugs of granite-porphyry outcrop approximately 1 mile south of the Queen Bee Mine. These have transgressive boundaries and show little indication of replacement or granitization. They are not immediately related to any known ore deposition and may perhaps be described as small granitic masses of a subsequent rather than a synchronous (30) type.

Significance of Types of Bathyliths.

In a previous paper (30) the relationship between synchronous and subsequent granite bathyliths has been examined in some detail. Briefly, the argument is that if the formation of granite be regarded as a process of alteration leading from sediments to schist, thence to gneiss and granite, the deposition of ore would be expected towards the close of the period of granite formation and would show a close relationship to the distribution of granite which had not moved after its formation. The synchronous type of granitic bathylith is held to correspond to this case. If, as postulated by Dunn (6), the granite may subsequently become magmatic and move to higher horizons, it would form crosscutting bathyliths which would not be expected to show the same relationship to ore deposition.

The work at Cobar and that at Brock's Creek (29) strongly suggest that a recognition of the varying significance of granitic outcrops is of first-rate importance in the search for mineralized districts. In the future, regional structural studies should be linked with the study of the distribution of synchronous granitic masses.

A consideration of the difference between synchronous and subsequent granite may also help to explain many apparently anomalous relationships. Thus, at Spargo's Reward Gold Mine (28), 28 miles south of Coolgardie, the writer found that pegmatite dykes cut the gold-pyrite-arsenopyrite replacement orebodies and seam the surrounding rocks. Obviously the pegmatites are post ore and they have very little effect on the deposits. Ellis (7) noted the same phenomenon in the Yilgarn gold-field and, partly on this basis, concluded that there were two periods of intrusion, but that both originated in a common "magma chamber". Ellis (7, p. 14) states :-

"The extent of the granite shown on previous geological maps has been considerably reduced, and some of the gneissic rocks of granitic composition have been recognised as migmatites and replacement gneisses; these latter resulting from the process of regional granitization.

"The intrusive granite which has been assumed to have provided the gold-bearing solutions, is a medium-grained usually non-porphyritic biotite granite, probably intruded during two periods of intrusion, but having its origin in a common magma chamber."

Matheson and Hobson (23, p.22), speaking of the same area, state however :-

"In this reference (Ellis), it is concluded that there are probably two periods of granitic intrusion, but it is not beyond possibility, that one period of granitic intrusion could have produced the same results. The granite which is responsible for the auriferous quartz was intruded simultaneously with, or subsequently to the folding. The regional granitization of the country was brought about by the intrusive granite ------

"Numerous instances or pegmatite dykes intruding auriferous quartz reefs, and pegmatite dykes occupying faults which have displaced auriferous quartz reefs, are recorded. Whether or not this is evidence for two periods of granitic intrusion, is problematical."

The present writer ventures the opinion that the conflict of ideas indicated here arises from traditional thinking regarding the origin of granite. The formation of Ellis' migmatites and replacement gneisses probably came first and was accompanied by ore deposition. Subsequent mobilization of portion of this material and its upward movement under tectonic pressure is evidenced by the intrusion of gold-bearing lodes and reefs by pegmatitic dykes. These dykes are conspicuous by the fact that they do not in any way affect ore deposition.

There are numerous examples of similar relationships in various parts of the world.

V. GEOLOGICAL STRUCTURE.

As emphasised previously, the present knowledge of the geology of the Cobar-Nymagee area is incomplete, and, largely on account of the scarcity of outcrops, may remain so for quite a long time. However, Plate C. 1 and the three accompanying sections (Plate C. 2) indicate some broad relationships which seem to be indicated.

North-South Anticline. The two masses of synchronous granitic material lying to the east of Nymagee occupy the axial position of an anticlinal fold which has been traced continuously from Cobar. Most of the Cobar orebodies occur close to a discordant (faulted?) junction between slaty and sandy rocks, which lies a little to the west of this anticlinal axis. The cross-section A-B (Plate C. 2) illustrates this relationship. The anticlinal axial plane and the faulting associated with it, both of which are believed to be of Silurian age, have been folded (probably at the time of the Amphitheatre - Lower Devonian orogeny), and it is believed that the Queen Bee-Nurri line and the Cobar line (Plate C. 1) are really continuous, being linked by a fold which occurs to the south of the Peak Mines. The persistence with which ore occurs along this faulted anticlinal axial plane over a distance of approximately 25 miles is quite remarkable and renders it a valuable guide to prospecting.

The reason for the localization of the ore along this line is suggested on the two cross-sections and on the longitudinal section (Plate C. 2). On the latter it is postulated that the concordant granite to the east of Nymagee forms an anticlinal ridge which pitches beneath the Cobar-Nurri ore line. The evidence for this assumption is as follows :-

1. The granitic masses to the east of Nymagee occupy the same anticlinal fold in which the Cobar-Nurri deposits occur.

2. All available pitch information indicates that the granite has replaced stratigraphic horizons lower in the sequence than those in which the Cobar-Nurri deposits occur.

3. The granite in question, where it has been mapped, conforms closely to the bedding of the enclosing sediments and can logically be expected to do so where it does not outcrop.

4. Up to 8 miles north of the most northerly outcrop of the Nymagee synchronous granite, patches of sericitized rock, similar to those associated with granitization to the southward, occur close to the axial plane of the anticline. (Plate C. 1).

5. Two plugs of granitic porphyry outcrop approximately 1 mile south of the Queen Bee Mine, exactly on the same anticlinal axis along which the Nymagee concordant granite occurs, but 27 miles north of the most northerly outcrop of this granite.

6. The granite and granitized sediments recently discovered at the Cobar Lucknow Mine, 6 miles to the east of Cobar, are significant as shown on Section A-B (Plate C. 2).

7. The copper-gold mineralization at Cobar is very similar to that closely associated with the synchronous granite at Nymagee.

Cross-folding.

As shown on the plan and longitudinal section (Plates C.1, C.2), ore does not occur haphazardly along the anticlinal axis, and, the Cobar field for example forms a very distinctive unit. The pitch information collected to-date indicates that the pitch lines of the bedding across the axial plane of the anticline are as shown on the longitudinal projection. The axes of change of pitch trend approximately 50 degrees magnetic, and are closely associated with folding of Amphitheatre (Devonian ?) age. The amphitheatre anticlinal cross-fold impinging on Cobar is a major feature which, mapping by C. St. J. Mulholland (Department Mines N.S.W., Min. Res. No. 39/1940) suggests, persists for 80 miles south-west of Cobar. The mineralized fields occur close to the elongated dome-like structures in the sediments and it is suggested that these domes correspond to the position of cupolas (8, 9, 29) in the underlying concordant granite. Areas overlying these are well-known as being favourable for the occurrence of ore deposits. The association of mineralized fields with dome-like structures is held to apply at Cobar, Queen Bee, Nymagee, Wirlong, Shuttleton and, probably, at Canbelego. The N.W.-S.E. alighment of the Shuttleton, Wirlong and Nymagee mines (Plate C. 1) is quite striking.

A very interesting fact is that the individual mines at Cobar have long been known to be associated with "bends" or folds in the discordant contact between slaty and sandy rocks, the folds being in the nature of cross-structures. These relationships are illustrated in plane on Plate C.3. This cross-folding is accompanied by an anticlinal change of pitch - e.g. to the north of the New Cobar Mine, the pitch is $50^{\circ} - 60^{\circ}$. south but in the vicinity of the main shaft, the pitch is steeply north to No. 3 level, then approximately 80° south to No. 9 level (31). A steppening of the pitch was also mapped at the New Occidental Mine. Thus, in effect, each mine at Cobar is a replica of the whole field and may overlie a minor cupola in the south-pitching flank of the major cupola which, it is postulated, underlies the Cobar field (Longitudinal Projection, Plate c. 3).

Formation of Channelways.

It is not desired to imply that this is the full "story" of ore localization in the Cobar mines. The presence of favourable openings depending on the well-known factors of lode dip, intersection of shears, type of rock intersected by shears, etc., governs the detail of ore distribution within the various mines. These factors have been intensively studeid ≠ by a number of investigators whose work is largely unpublished. The present writer has written an extensive report (31) on these details, which is accompanied by plans of all levels in the accessible mines.

Figure I, p. 10, shows the writer's interpretation of the same development of favourable openings in the New Cobar Mine. The same pair of forces (of Devonian age ?) which caused the buckling of the discordant (faulted ?) contact of Silurian age, gave rise to the development of two sets of fractures, one set trending parallel to, and being localized by, the north-south portion of the discordant contact, the other, of a tensional type, being parallel to the north-west - south-east trending portion of the contact. Both sections of fractures tend to parallel the Silurian axial plane cleavage, which has been bent in the visinity of the later folds. The intersection of these two sets of fractures, which pitches steeply northward with the pitch of the orebody, has given rise to a pipe-like mass of fractured rock which was favourable fore replacement. The mineral grain elongation also pitches with the orebodies and approximately at right angle to this, a large number of tension joints have been developed.

Ore tends to form on the more flatly dipping portions of the lode shears, in which movement has beeen of the reverse type. These are unproductive in sandy tuff but have been highly productive in slaty rock.

The empirical structural approach would tend to accept these various factors as sufficient in themselves to explain the occurrence of an orebody, but it is contended here that the broad district relationships suggest otherwise and that the pitch changes in the vicinity of the mines closely duplicate, on a small scale, the broad domal structues found to influence the occurrence of the mineralized fields themselves.

The possibly vital significance of anticlinal pitch changes will be further discussed in the chapter dealing with the application to other fields of the concepts which are considered to apply at Cobar.

≠ Since this paper was written, the author has seen a paper by H.C.J. Conolly (Aust. Inst. Min. and Met. Proc., N.S. No. 143, PP.156-187, 1946), in which the role of elongated pip-like masses of rock in the localization of the Cobar orebodies is emphasized. The Cobar orebodies do pitch with the mineral grain elongation, which however within the lode shears, is not usually parallel to the pitch of the folds in the bedding, but to the direction of movement within the lode shears. (See Fairbairn, H.W., 1942 : Structural Petrology of Deformed Rocks, Addison-Wesley Press, Cambridge, Mass. pp. 79, 94-96).

This paper is typical of the current empirical structural approach to ore-finding.

FIGURE I.

VI. HYDROTHERMAL DEPTH-ZONING AT COBAR.

A zonal arrangement of the Cobar orebodies appears to constitute a rather striking confirmation of the structural and genetic interpretations given above. The salient features of this zoning, together with their possible interpretation are shown on the longitudinal projection (Plate C.2). On mineralogical evidence, there is a gradual fall in the temperature of ore deposition from north to south.

The Great Cobar deposit (production 3,400,000 tons of ore, 2.8 per cent copper, 1.4 dwt. gold, depth 1,500 feet) contains quartz, pyrrhotite, magnetite and chalcopyrite. A silicate mineral, tenatively regarded as ekmanite, was recorded by Andrews (1). The deposit is of the high temperature type and belongs to Lindgren's hypothermal class. The next important deposit going south is the New Cobar (production 1,000,000 tons, 5 dwt. gold, 1.4 per cent copper, depth 1,270 ft.). The main gangue mineral is quartz with minor dolomite and calcite. The sulphides in order of abundance are pyrrhotite, chalcopyrite, pyrite, galena, sphalerite and bismuth sulphide.

The Chesney deposit (production 400,000 tons, 2.5 dwt. gold, 2.5 per cent copper) consists of quartz, dolomite, pyrrhotite, and chalcopyrite with minor galena, sphalerite and gold.

Both of these deposits may be classified as hypothermal though they are of a lower temperature type than the Great Cobar and do not contain appreciable quantities of magnetite or of the silicate minerals e.g. ekmanite.

The New Occidental deposit (production 1,600,000 tons, 5.0 dwt. gold; depth 2,000 feet) is in marked mineralogical contrast with the mines described above. The ore consists of mainly fine-grained quartz containing relatively small quantities of pyrite and pyrrhotite with minor chalcopyrite galena, sphalerite and gold. The fineness of the gold is approximately 840 (10). There is not enough copper present to interfere with gold extraction by cyanidation. The deposit is considered to be of the mesothermal type. Drilling indicates that essentially similar ore persists for 3,000 feet below the surface.

The deposits in the Peaks Area consist mainly of sheared slate and sandstone containing pyrite, together with gold and silver. Disseminated pyrrhotite has recently been obtained in diamond drill cores. From the records, it was found that the average fineness of the gold obtained by amalgamation was approximately 600 (10). The area is relatively rich in silver the Blue, Brown and Conqueror lodes having produced - in addition to 19,000 ounces of gold - 236,400 ounces of silver from 28,000 tons of ore treated, an average of 8.5 oz. silver per ton. One parcel of 483 tons from the Peak Silver Mine averaged 26 oz. silver per ton. It is considered that the Peak area mineralization is epitherman to mesothermal in type.

Low-grade concentrations of copper, lead and zinc have also been found in the Peaks area, but to-date, gold and silver production have predominated. Geophysical findings, at present being tested, suggest the hope that overlapping of temperature zones has allowed the deposition chalcopyrite-pyrrhotite ore within mining depth, but it is not unlikely that the Peaks is an example of a very fine structure, containing ore only at considerable depth (Plate C2).

It will be noted that the zonal arrangement of the Cobar ore deposits, fits in very well with the conception of the south pitch of the field and with the idea that the ore has been deposited within certain beds at a relatively constant distance from a concordant granitic mass (Longitudinal Projection Plate C.2).

The projection also suggests that the whole range of Cobar ore deposition would amount to approximately 30,000 feet; this is an interesting basis for comparison with the ranges suggested by L.C. Graton (11), who thought that ore deposition might take place over a total vertical range of some hundred thousand feet. It is to be expected that this range will vary from field to field, depending on the local structural, chemical and temperature-pressure conditions.

The evidence at Cobar, strongly suggests that at a structurally favour able position, such as The Peaks, the present outcropping deposits would be successively underlain by ores of the New Occidental, Chesney, New Cobar and Great Cobar types. Unfortunately, the depths to which mining can be economically undertaken are limited, and this is one of the important factors handicapping the mining geologist as compared with the oil geologist

VII. ASSOCIATION OF ORES WITH PORPHYRY.

Lloyd (19) has made particular mention of the close association which exists in the Cobar-Nymagee province between granitic porphyry and ore. In some cases, e.g. at Mt. Hope (19) to the south of Nymagee, and at Wirlong, copper occurs in porphyry. This has led to a consideration of the possibility of the discovery in this district of "porphyry copper" deposits of the Utah and Nevada types.

In many quarters it was assumed that the monzonite stocks of the South Western United States were the direct source of the metals contained in the "porphyry coppers". Monzonites were assumed to be rich in copper owing to "magmatic differentiation". However, after careful study, C.D. Hulin (18) concluded that at Ely, Nevada and at Grass Valley, California, for example, the mineralisation was later than the monzonite stocks and had been derived from some underlying source. The stocks had merely provided a suitable structural environment for the localization of the ore.

This hypothesis was tested to some extent by the present writer at Wirlong. Here chalcopyrite occurs in two faults or shears, situated within a band of porphyry 700 feet wide, which has been traced, at intervals, over a distrance of 3 miles. Eleven samples were cut across the strike of porphyry in the vicinity of the mine and were tested by dithizone (20, 26) for copper content. This reagent is believed to be capable of detecting, under the conditions of the experiment, the presence of 0.02 parts per million of extractable copper; however only three samples, all of them in or near the known copper-bearing shears, gave positive tests.

These results indicate that the porphyry itself is relatively barren of copper and contains only the metal which has been introduced after the formation of the porphyry and its subsequent fracturing.

It is considered that the relationship between porphyry and ore in the Nymagee district is to some extent explained by the longitudinal projection and by the cross-section from Nymagee to Shuttleton (Plate C.2). The longitudinal projection shows that the mass of porphyry, granite and granitized sediments, outcropping to the south-east of Nymagee is close to the top of a theatre of granitization. Similarly, the cross-section indicates that the Wirlong and Shuttleton porphyries occur at, or above, the tops of cupolas. The association of ore with the tops of granitic cupolas has been stressed by Emmons (8, 9) and has previously been discussed by the present author.

Origin of Replacement Porphyries.

The abundance of replacement textures and the general field relationships of the porphyries occuring to the south-east and north-east of Nymagee, suggest that in these localities, the porphyries were formed practically in situ and this also applies to the Wirlong occurrence. Lloyd (19) has described the "interbedding" of porphyry with sediments in the Mount Hope district to the south of Shuttleton. Backlund (4) has suggested that small granitic apophyses form towards the margins and over the top of granitized masses, partly owing to the presence of the abundant volatiles which are held to collect in these areas during granitization.

Backland (4, pp. 114-115) writes as follows :-

"The question of the formation of minor granitic intrusions may next be reviewed. All previous investigations indicate that the metamorphism of sediments is attended by an important loss of volatiles and their compounds ---- the higher the grade of metamorphism the more complete is the loss ---- when complete granitization is effected the volatiles are vigorously expelled from the granitized rock, the final rock, the "normal" fresh granite, containing only small quantities of the volatiles ----. Consequently, in front of the theatre of granitization a "cloud" of volatiles is concentrated.

"There are three effects to be expected from this state of affairs. (1) The marginal parts of the granite in statu nascendi become enriched in occluded volatiles (including H_2O); the "intergranular film" becomes significant, and the granite becomes more and more like a liquid in its behaviour although still at a relatively low temperatuse. (2) The tension in the rocks above the granite steadily rises and thus prepares the roof for injection by the expansion of fissures and joints. (3) The pressure within the upper part of the region of granitization becomes a hydrostatic one pari passu with the increasing liquidity of the granite. These border conditions create extra steep gradients of energy differences (PT), which favour a particularly rapid advance of the "granitization front", so that small "intrusions" are formed at the higher stratigraphical level".

Trangressive Porphyries.

According to Barth (5), the solution of water in molten rock is an exothermal reaction. The high back pressures of volatile materials existing at the top of areas of granitization might force a certain amount of water back into the partly liquidfied granite, thus causing a rise in temperature, in some cases sufficient to completely liquefy small portions of the newly formed granite. These high temperature fractions would be suitable for forcing their way through the weakest sections of the sediments overlying the granitic cupolas. On reaching a region of lower pressure, the sudden escape of the occluded volatiles would cause a rapid fall in temperature, resulting in the fine-grained groundmass of the porphyritic rocks. This supplies a possible explanation for the origin of the small, transgressive plugs and dykes of porphyry.

Summary of Ore - Porphyry Relationships.

The evidence seems to suggest that during the process of granitization, there forms above the cupolas, or high points in the granite, an accumulation of volatile materials, and also of the metallic ions which have not been accepted into the crystal lattices of the granite-forming minerals. The "hydrothermal solutions" themselves have small penetrative power, however, and always require the presence of channelways, before they are able to move. This is a matter of common experience. "Magmatized" granitic material is more capable of forcing its way through the overlying rock and in so doing, prepares the way for the accumulated "hydrothermal solutions". Further, it seems likely that the agencies which cause granitization must themselves have considerable penetrative power as compared with "hydrothermal solutions" and in some cases, e.g. at Wirlong, it appears that they may have prepared above the main theatre of granitization, what may be called a channel of porphyritization, through and around which, generally after some further movement, the dammed up "hydrothermal solutions" were able to escape and deposit their load of metals. The words "through and around" are used because at Canbelego (3) and at Shuttleton, the ore occurs near the edge of porphyritic masses. Fractured or brecciated porphyries are most likely to contain disseminated ore minerals; the massive, unsheared porphyries are likely to be barren.

In general, it is believed that the association of ore with porphyritic rocks has not been fully understood and warrants careful study. The association is of considerable economic importance in Australia, particularly, perhaps, on the West Coast of Tasmania, where major ore deposits are commonly associated with rocks of this type.

VIII. SOURCE OF THE COPPER AND GOLD.

Possibly, the prospecting value of the relationships between ore occurrence and other geological factors described in preceding chapters is independent of the ultimate source of the copper and gold at present found in the orebodies. Nevertheless, this question has considerable economic importance, as has any evidence which may lead to a better understanding of ore genesis. This basic understanding is essential to a true assessment of the prospects of future discovery, an assessment, which, it is submitted cannot be adequately made on the basis of present knowledge.

It is suggested then, that copper and gold may have originally been dispersed in the younger formations of the Cobar group which have now been converted in granite. This is suggested by the following evidence :-

1. The Cobar-Nymagee metalliferous province is a very distinctive one, containing, for the most part, copper, gold, or copper-gold deposits. It is co-extensive with a particular group of beds.

2. In particular, the available evidence indicates that only certain formations have been converted into granite and as these were deposited under similar conditions (and, incidentally, during a period of volcanic activity), they would be expected to have somewhat the same trace-element content.

3. The ore is associated with the concordant granite and not with the subsequent, cross-cutting granite. This is to be expected if it is concluded that the synchronous granite formed in its present position and if the metals were previously dispersed in the sediments from which the granite was formed. It would be at

the time of formation of the granite that the accumulation of metals would take place, not after the subsequent magmation and movement of the granite. If the granite represented material coming from unknown depths, bringing the ore with it, no special relationship between ore and type of granite would be expected (30).

4. During the course of reconnaissance geochemical testing in the Cobar-Nymagee district 110 samples were taken of which 89 represented material of sedimentary origin, mainly from the Cobar-Nymagee group, and 21 were from granitic rocks (granite and porphyry). Apart from the three positive samples taken near lode-sheare in the Wirlong porphyry, only one sample of biotite-muscovite granite gave a very faint positive test after fusion, all other samples giving negative results for copper. Thus 4 of 21 samples, or 19 per cent, of granitic rocks gave positive tests for copper. This was in spite of the fact that granitic samples were first tested by leaching with dilute H_2SO_4 then tested after roasting and, finally after fusion. Of the samples of sediment 64 per cent gave positive tests for copper. It is not by any means claimed that the above testing is conclusively as the number of samples taken was relatively small. However, the results indicate that the granitic rocks are not rich in copper, and rather suggest that the copper of the orebodies was formerly dispersed in the tuffaceous sedimentary rocks and was concentrated during the granitization of the sediments.≠

This gives a logical explanation for the occurrence of metalliferous provinces which are usually co-extensive with certain granitized sedimentary or volcanic rocks (e.g. the Western Australian gold province is practically co-extensive with the greenstones, or with areas where greenstones may logically be inferred to be present below other rocks) and also implies the possibility that in areas such as the Broken Hill District, where an isolated orebody occurs in a distinctive group of rocks (the Willyama Series), there is a change of finding other orebodies wherever this particular group of rocks extends, provided other conditions are favourable.

≠ Since writing the above, the author has received a communication from W.G. Garbutt and J.J. Murais of Northern Rhodesia, in which they supply extensive evidence for the pre-copper age of the Rhodesian granites, to which the ore has previously been attributed. The extensive work of these geologists indicates a syngenetic origin for the copper of the region and hence, suggests, that the existance of sedimentary " beds" for copper is not unlikely.

IX. PROSPECTING TARGETS.

COBAR-NYMAGEE.

In accordance with the principal purpose of this paper, attention will be directed mainly to the possibility of utilizing the geological relationships described above to find other fields of the Cobar type. The factors governing localization of ore within the Cobar field itself have been discussed in previous reports by the writer (31) and by others (24) and the exploration of this field is now being vigorously prosecuted.

The most obvious locus of metallization so far mapped is the axis of the Cobar-Nymagee anticline. As a result of geological mapping, geophysical investigation of this axis from the Peak Mines to a little south of the Queen Bee Mine is now proceeding. Owing to the presence of magnetite and pyrrhotite in many of the orebodies, the magnetometer has proved exceedingly useful in the Cobar District. Self potential, and gravimetric methods have also been used with valuable results. Geophysical investigation has, to-date, proved the most useful method of localizing drilling targets within areas, in may cases extensive, suggested as being favourable on geological grounds.

The regional plan (Plate C. 1) and the longitudinal section (Plate C. 2) suggest however that along this anticline an area of maximum interest is centred approximately two miles south of the Nurri Trig Station. From Plate C.1, it will be seen that a comparatively large cross-fold, similar to the smaller folds which localize ore deposits at Cobar, occurs in this region. It is considered that this is an anticlinal cross-fold along which the Baal Gammon and Boppe (Canbelego) mines occur. The Canbelego deposit has been relatively important (production over 436,000 ozs. gold) and the intersection of this fold with the Cobar-Nymagee anticlinal axis must be regarded on geological grounds as a good prospect. Reconnaissance mapping has disclosed the existence in this region of a considerable number of quartz reefs and gossans, but there is a large soil cover to the south of the cross-fold and the area would be difficult to prospect by ordinary means. The area of interest will be mapped on air-photographs enlarged to a scale of 1 inch to 400 feet. This mapping will guide subsequent investigations such as geophysical and geochemical studies. Drilling of promising areas would follow.

Geophysical techniques are well-known and have proved their worth, but geochemical prospecting though showing very considerable promise, is still in a developmental stage. However, the dithizone test for copper is very satisfactory and it is possible for a single chemist to make up to 60 field tests per day. Reconnaissance testing of soils and rocks strongly suggests that there is a regional copper anomaly in the country rock of the Cobar field itself and, if this is confirmed by more detailed work, the testing of areas such as that south of Nurri Trig Station by dithizone should yield most valuable direct evidence of the favourability or otherwise of the area for the occurrence of copper. It was found also, during preliminary testing in the Cobar-Nymagee district that the dithizone tests will probably be of considerable assistance in the interpretation of various limonite products in leached outcrops.

In addition to the Cobar-Nymagee anticline, the Wirlong and Shuttleton folds are worthy of futher attention as is the anticline to the west of Cobar, mapped by B.P, Thompson of Zinc Corporation Limited. As indicated in section A-B (Plate C.2), the outcropping rocks here are unfavourable for ore and they are only weakly mineralized even in favourable areas - e.g. at Canbelego (3). However, along parts of the Western Anticline (as the anticline to the west of Cobar is called) there are interesting accumulations of massive dark borown to lack limonite, underlain by leached sandstone. These limonite outcrops contain no voids after sulphides and do not represent the outcrops of sulphide lodes of the Cobar type (i.e. they are not true gossans). However, they may indicate areas of weak sulphide mineralization, overlying ore deposits in the favourable Cobar slates which should occur below. Dithizone tests indicated that, in and around one such limonite accumulation, there is a marked concentation of copper.

There is thus a chance that the Cobar field is repeated at depth below the western anticline, but suggestions as to whether it would be likely to occur within range of mining must await further geological and geophysical evidence.

The mapping to-date has been most detailed in the vicinity of the Cobar-Nymagee, Shuttleton and Wirlong anticlines and the present paper is largely an examination of the first-mentioned structure. However, there is a number of other ore-bearing lines in the district e.g. the Canbelego anticline, and each of these warrant a thorough search. Prospectors with considerable knowledge of ore occurrence have combed this district fairly thoroughly and the modern scientific prospector has no easy task ahead of him. The results obtained at Cobar to-date, indicate however, that with patience, skill and luck (still an important factor in prospecting) there is a good chance of finding new deposits of worthwhile dimensions.

X. GENERAL APPLICATION. ≠

Broken Hill.

Attention has previously been called by the writer (30,31) to the possible importance of the application of these concepts to the Broken Hill District, N.S.W. where ore occurs in an elongated sheared dome in an area of synchronous granitization. The basic change in approach from that generally accepted, is inherant in the postulate that the lead-zinc lodes are one of the results of the re-arrangement, during the process of granitization, of materials already existing within the Willyama Series. It is considered that the whole of this series, which, according to existing maps, crops out over an area of approximately 2,000 square miles, should perhaps be regarded as a potential source of lead and zinc deposits.

To test this hypothesis, it would first be necessary to study geochemically, the distribution of minor elements, particularly lead and zinc, in the rocks of this district. If unusually high quantities of these elements are found, particularly in certain sedimentary or volcanic beds as compared with the granitic rocks, valuable confirmatory evidence of the hypothesis would be gained. The information concerning the distribution of the ore-elements in the various horizons would also be most valuable from the viewpoint of prospecting.

≠ In writing these notes, the author is fully aware that others have far greater knowledge and experience of Broken Hill, Kalgoorlie and Bendigo geology than he has, and that information may be known to private companies which invalidates sections of the published maps. The comments throughout this paper are based on available information and are made in the belief that basic knowledge of ore-genesis, which will ultimately be of great economic importance, remains to be discovered. Any new interpretations are suggested in a spirit of scientific enquiry.

If the evidence obtained from the geochemical work was satisfactory, the oil-field approach could then be applied to the district. This would involve the elucidation of the stratigraphy, with particular reference the horizon which carries the present lodes and to any horizon previously found to be rich in lead and zinc. Geochemical methods would be used to sample these horizons throughout the district. The geochemical work, in conjunction with ordinary field mapping and microspopic study, should also provide valuable data for the correlation from place to place of the various stratigraphic horizons. At present, on account of intensive folding, shearing and faulting, this is quite a difficult task on many mining fields - particular where fossils are absent - and is in marked contract to the relatively simple structural problems confronting the oil geologist.

Due account would need to be taken of the significance of the elongated domal structures for the occurrence of mineral fields. It is considered that in the Broken Hill area, these must be regarded initially as having the best chances. Within these structures, the best chances of finding ore must lie in the beds which carry the known lodes. However, allowance must be made for the more or less unpredicatable factors such as the presence of transgressive plugs (8 p. 183) pre-ore faulting, brecciation, etc., which could give the ore access to beds other than those in which the known lodes are found.

The Bendigo Field.

The Bendigo Field is a good example of the occurrence of ore in domal structums. The maps supplied by Herman (15) show clearly how the maximum concentration of ore occurs at the crest of elongated domal structuses (See Figure 2). A map published by Thomas (32) indicates that the whole Bendigo Field is situated in a complex domal structure. It has also been known for many years that the maximum production has been obtained from the Bendigo stage of the Ordovician system. Bendigo thus satisfies the general conception of the occurrence of the ore on domal structures within a limited stratigraphic range.

The Victorian Mines Department had kindly shown the author unpublished maps of this district which show the complicated domal structuse very clearly. These maps also indicate that the Harcourt granite at the southern end of the field is cross-cutting and completely truncates the structure. It is considered, however, that this fact does not invalidate the conception that the ore is genetically related to granitization. It is hard to imagine that the ore has originated from the granite while it was in its present position - an idea previously suggested by Stone (27)*. The known orebodies show no relationship to the distribution of this granite. In accordance with the concepts outlined earlier, this granite is probably of the subsequent type and must have reached its present position after becoming magmatic. Most of the ore deposits would have formed when the actual granitization took place, probably at a much greater depth than that at which the granite is now found. The subsequent magmation (6) and movement of the granite has apparently had little effect on ore deposition.

It may be significant that, as noted by Harris and Thomas (14), a large proportion of the Victorian goldfields occur on domal structures.

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* Stone (27, p. 893) states: "A mine that is good at one level, is apt to be good at deeper levels, but an adjoining mine may be poor throughout.

"This vertical repetation and also the distribution of product in plan make it improbable that the source of the ore solutions was the outcropping Harcourt Bathylith, but suggest that the source was a separate offshoot of a great underlying regional bathylith [illegible]

offshoot lies below the centre of the district."

FIGURE 2.

Kalgoorlie - Coolgardie, Western Australia.

The following comments are based on information supplied by R.S. Matheson, who has recently written a paper (21), pointing out a relationship between ore occurrence and regional structures in this region and suggesting the Hannans Lake area as worthy of prospecting. The present author was kindly given an advance copy of this paper. Plate K-1 is Matheson's map. The elongated domal structure at Kalgoorlie was discussed by Gustafson and Miller (13) and a cross-section after these authoris is reproduced as Figure 3. The reader is especially referred to a recently published valuable study by Matheson (22) of the Coolgardie area, in which it is shown that gold deposition is related to domal structures and also that it tends to occur within a limited stratigraphic range.

The two sections (plates K-2) and K-3) illustrate the writer's tentative interpretation of the geology of the area. The Coolgardie granite (plate K-1) is generally concordant to the surrounding country rock and has the characteristics of a synchronous (formed in situ) granite mass. It occupies a domal structure, but probably the most favourable part of the structure has been eroded away.

Referring to plate K-2, it will be seen that the upper limit of granitization at Coolgardie is some 25,000 feet stratigraphically below the contact of the Black Flag sediments and the underlying Kalgoorlie series. If the upper limit of granitization is assumed to follow the geological structure in the surrounding sedimentary and volcanic rocks, as it does, approximately, in other instances investigated, the position of the granite would be somewhat as shown in Plate K-2. As argued in a previous paper (30), the occurrence of albite-porphyry dykes at Kalgoorlie strongly suggests that the mining field overlies a granitic cupola and most geologists have assumed that the ore deposits there are of granitic origin. The granitic mass lying eastward of Trig. Station HK.2, and that to the west of Mount Marion, have reached a relatively high stratigraphic horizon and appear to be examples of the "explosion vents" of Emmons material, derived from the granitized mass below.

It is worth noting that the Kalgoorlie ore deposits occur at a stratigraphical horizon comparable with that in which the mines of the Coolgardie district are found. A second point of interest is that to the west of the Kurrawang syncline, there is an anticlinal structure in which the greenstones are brought close to the surface, though, along the line of section, they are overlain by the blanketting Black Flag slates and other sediments. This anticline could be of value as a producer at or near the top of its crest line.

Plate K-3, which is a longitudinal section along the Kalgoorlie anticline, is based, for the most part, on pitch information given by Gustafson and Miller and by Matheson. According to the latter authors, a reversal of pitch occurs at Kalgoorlie and hence the most productuve portion of the field occurs on the southern flank of an elongated dome. The quartz-dolerite-greenstone has been eroded from the top of the dome and this may account for the relative scarcity of ore deposits there. This rock has produced a very large proportion of the gold obtained at Kalgoorlie, probably owing to its physical character; under stess, it yielded along well-defined planes, which formed suitable openings for ore localization. Much gold occurs on the northern flank of the domal structure, though, in general, it has not been so conveniently localized for mining. However, the Mount Charlotte property, on Hannans Hill, which is in the northern flank of the dome, promises to be one of the most important mines at Kalgoorlie. The fracture-pattern in the northern portion of the field is quite different from that in the productive southern portion and this may be the reason for the smaller production of the northern portion - not a lack of gold-bearing solutions.

FIGURE 3.

Gustafson and Miller (13) showed that the Australia East crossfold, which is a minor structure on the southern flank of the Kalgoorlie dome, has had an important influence on the occurrence of gold. They suggest that "this knot in the country apparently allowed shearing stresses to find their fullest expression about it, much as the splitting of a pine board is influenced by knots in it. In time, ore solutions found this a region of easy access".

However, the structural arrangement at Kalgoorlie is quite reminiscent of the Cobar picture and it is suggested that this cross-fold may have a more basic significance - viz. that it overlies a minor cupola in the granite underlying the Kalgoorlie dome.

Consideration of the possible genetic significance of the domal structure at Kalgoorlie leads to important conclusions. It has often been assumed, for example, that since the favourable quartz-dolerite-greenstone pitches southward underneath the blanketting Black Flat slates and porphyry (plate K-3) there is good reason to expect non-outcropping gold deposits to occur for an indefinite distance south of the known field. This may, or course, be so, but just as at Bendigo (figure2), gold deposition falls off on the flanks of the domal structure, this is also likely at Kalgoorlie. (This remark also applies to the Broken Hill lode which, perhaps, should not be expected to extent indefintely away from the centre of the arch).

An understanding of the significance of the domal structures may also warrant closer attention to the vicinity of the crest of the Kalgoorlie-dome. The rocks outcropping over this crest consist of the unfavourable "calc schists" which underlie the favourable quartz-dolerite-greenstone. There appears to be little knowledge, however, concerning the variations of rock types which may occur below the outcropping calc schist. A number of very important ore shoots including the Oroya Shoot and a shoot on the North Kalgurli Mine occur at the flatly pitching junction of the calc schist and the quartz-dolerite-greenstone, essentially, it is thought, precisely because this is the junction of two dissimilar rock types along which movement, in many instances facilitated by the presence of a thin slate band, has occurred. The shoots are usually localized in minor folds in the contact. If there are similar junctions of different rock types stratigraphically below the present outcropping calc schist, particularly in the vicinity of the crest of the dome, there would be a good chance for the occurrence of similar ore shoots. It is also not impossible that, below the present outcropping calc schist, other sill-like masses of quartz-dolerite-greenstone, suitable for the production of tabular lode systems, occur.

On structural grounds, Matheson (21) has suggested that the Hannans Lake area should receive attention for the possible occurrence of a field such as that already found at Kalgoorlie. On plate K-3, a reason is given in support of this suggestion, viz. that this area probably lies above a domal structure in the granite. Probably, the Kalgoorlie anticlinal structure should be traced both north and south as it may localise gold deposits in the vicinity of any domal structure in granite.

If, eventually, the whole of the Western Australian gold-fields are linked up by a series of geological maps and sections, taking into account the occurrence of synchronous granitic masses and of suitable source-beds among the greenstones, it might be possible to locate a number of fields which, owing to the presence of deep soil cover, or of rocks which tend to blanket ore deposits, have not been found by ordinary prospecting methods.

Follows from p. 22

XI. CONCLUSIONS.

In the recent past, geologists have been inclined to confine their study to the structural traps and openings which localize individual ore shoots and have tended to neglect most other features, including considerations of ore genesis. L.C. Graton (12) describes the emphasis on "structural control" as follows :-

"Just as the arteries, veins and capillaries are no more important to the human system than is the character of the blood that flows through them, or than the subtle re-actions of so many kinds that contribute to the total physiological process, so the attention to channelways, re-opening and preparatory "ground-conditioning", to channelway details as by contouring attitudes or wisths, to relative fracturability of different rocks, represents a most one-sided and partial approach to the problem as a whole. It is an unsound approach only in that it tends to neglect, if not indeed to discourage, other important and necessary adjuncts."

In the present paper, there is no attempt to minimize the importance of structural studies, but an effort has been made to come a little closer to Graton's (12) "all-important standpoint of genetic understanding". Favourable openings will not localize ore deposits, if no source of ore is available.

As a contribution to a fuller understanding of the problems involved in the search for new mineralized districts, the following points are suggested for consideration :-

(1) Ore deposits show a general relationship to concordant, synchronous, granite, which may have formed approximately in the position in which it is now found; but do not appear to show the same relationship to those large bodes of subsequent, cross-cutting granite, which appear to have moved very considerable distances. Frequently, however, small plugs of granitic material force their way through rocks overlying synchronous granitic masses and become important localizers of ore.

(2) The frequently noted association between granitic porphyries and ore seems to be related to the fact that porphyries tend to form above threatres of granitization. In some instances, they occur as transgressive plugs, formed from actual magma derived by the liquefaction of granitized material; in other instances, the porphyries appear to be of replacement origin, and may have been formed along the lines suggested by Backlund (4). It appears that the major role of both the transgressive plugs of actual magma and of the "channels of porphyritization" is to allow the escape of the ore-forming materials which tend to collect above the high-points of theatres of granitization. The oprhyries themselves do not appear to be the source of the ore.

(3) In regions where granite forms in concordant, sheet-like masses, the occurrence of domal structures in the overlying sedimentary and/or volcanic rocks is of the utmost importance, because these structures may overlie cupolas, or high-points, in the granite. It is in these positions that ore is likely to occur. Any means that may serve to indicate the contours of non-outcropping granite are believed to be of great importance - e.g. consideration is being given to the possibility of checking by geophysical means, the postulated outlines of the non-outcropping granites shown in the sections on plage C - 2/

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