COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Fourth Empire Mining and Metallurgical Congress

Session C - Modern Methods of Prospecting -

MINERAL EXPLORATION IN AUSTRALIA

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FOURTH EMPIRE MINING AND METALLURGICAL CONGRESS

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I. INTRODUCTION.

The scientific search for ore[/] in Australia is still in an early stage of development, because, until recently, a sufficient supply of metals was available from concentrations readily detectable by ordinary prospecting methods. Now the whole mineral supply position is changing and the rate of discovery of new deposits by prospectors in the present century has been quite discouraging. To bring out this position more clearly, the history of metal discovery in Australia is outlined below :-

HISTORY OF DISCOVERY. (See Raggatt, 1947 and 1949)[ø]

The main episodes ~~(Raggatt, 1947) ø~~ in Australian mineral discovery are as follows -

(a) The copper discoveries, chiefly in South Australia, beginning in 1842.

/ The paper refers only to metalliferous ores

ø List of References at end of paper.

(b) The gold discoveries in New South Wales and Victoria, beginning in 1851.

(c) The discoveries of copper, tin and lead-zinc of 1870 to the late 1890's, including ~~Mt. Lyell 1870~~, Mt. Bischoff 1871, Broken Hill lode 1883, and Mt. Lyell, 1890.

(d) The gold discoveries in Western Australia beginning about 1884, including Coolgardie 1892, and Kalgoorlie 1893.

The period of discovery coincides with the era of land settlement and exploration. In general, in any given mineralized district, one or two ore deposits formed prominent topographic features and were readily detected, even by those comparatively untrained in prospecting. News of any discovery led to a "rush" of experienced prospectors who quickly combed the surrounding country. So thoroughly did these men do their work that, since the late 1890's, the only important surface discoveries have been those of/Mount Isa, Queensland, in 1923, and Aberfoyle, Tasmania (tin-tungsten) in 1926.

King Island (Scheelite) about 1912,

DEPLETION. (See Raggatt 1947)

The results of the above are indicated by the following facts :-

(1) The average age of producing mines has progressively increased since 1898.

(2) Excluding coal, 84 per cent of the mineral production for 1938 was derived from deposits discovered prior to 1900.

(3) In the period 1873-1882 (except for two years) Australia held first place among tin-producing countries with an output of approximately 11,500 tons per annum. In 1947, output was 2,371 tons of refined tin, not quite sufficient to meet domestic requirements. From 1842, copper production mounted to a maximum of approximately 45,000 tons per annum for the period 1911-13 then gradually fell and in recent years it has been in the vicinity of 20,000 tons per annum which does not meet Australian requirements. In regard to other essential metals, such as lead, zinc, tungsten (derived from King Island) Australia is in a much more fortunate position, and is able to supply

substantial proportions of world requirements. Gold production is important and large supplies of zircon and rutile are available (Baggatt, Nye, Fisher, 1946).

CORRECTIVE MEASURES.

The Australian Governments and the Australian mineral industry have recognised the need for mineral exploration both to supply home requirements and to assist in overcoming ~~the problem of~~ world shortages, ~~and~~ the present high prices for base metals have created ~~a favourable atmosphere~~ conditions in which the work can be carried out.

Commonwealth Government.

In order to help meet the position, the Commonwealth Government has adopted two measures :-

(a) Taxation Reform.

In 1947, as a result of advice tendered by the Mining/Industry Advisory Panel, of the Secondary Industries Commission, ~~a group of prominent executives concerned with various aspects of the industry,~~ substantial reforms, favourable to the industry, were introduced into the Commonwealth Taxation Act. These new provisions are too long to quote in full but, in effect, they provide that :-

(i) Income derived by a bona fide prospector (person or company) from the sale of rights to mine gold or one of a long list of other metals now in short supply, shall be exempt from taxation.

(ii) Expenditure incurred by a taxpayer on exploration or prospecting (with some minor exceptions) shall be an allowable deduction from income. The definition of "exploration and prospecting" is very wide and makes provision for the use of all modern scientific methods.

(b) Formation of Bureau of Mineral Resources, Geology and Geophysics.

This Bureau was created in 1946 and now has an establishment ~~approved for the employment~~ of approximately 60 geologists and 60 geophysicists. It also includes small sections devoted to mineral economics, petroleum technology and mining engineering.

The Bureau is designed to take an active part in mineral exploration and, to date, programmes have been co-ordinated with those of major ~~exploration~~ companies engaged in mineral exploration. The Geophysical Section of the Bureau is the only organization of its kind in Australia and

has been responsible for the major portion of the geophysical exploration undertaken to date in this country, including that carried out on mining leases held by various companies.

A diamond drilling group is now being formed, the initial equipment consisting of two heavy drills capable of penetrating to 3,000-4,000 feet, 2 medium drills for holes up to 2,000 feet and two light, portable drills. The~~se~~/heavier drills may be hired ~~loaned~~ to private companies. //The formation of a small geochemical section has begun.

Para

The formation of such an organization cannot be accomplished quickly, and full staffing has not yet been attained.

State Governments.

The ~~various~~ State Governments have ~~tended to~~ expanded their geological surveys in recent years and are actively assisting ~~with the~~ in mineral exploration ~~programme~~.

Mining Companies.

The changed taxation policy, the high ruling prices for copper, lead and zinc, and the favourable long-term outlook for base metals, particularly lead, have had a most marked effect on the exploration policies of the major Australian base-metal companies. Prior to World War II,

these companies normally examined hopeful prospects brought to their notice, but did not actively seek properties outside of their own territory. Since the end of the war, the Broken Hill lead-mining companies have embarked on the most active exploration policy ever conducted in Australia.

Two major companies are scouting for gold prospects in Western Australia.

In the following chapter, the more notable work carried out by mining companies in the past will be briefly described and current activities will be outlined.

II. EXPLORATION BY REPRESENTATIVE MINING COMPANIES.

(A) PROSPECTING 1930-1940.

In Australia, prior to 1930, there was little organised scientific prospecting, and geological work generally was not directed towards ore-finding. However, in the decade 1930-1940, this work received considerable impetus as the following examples show :-

WESTERN MINING CORPORATION LTD.

This is primarily a gold-mining company which, during the years 1933-35, set out to find orebodies by geological means. A number of geologists with good reputations abroad, as well as some Australian geologists, were assembled in Western Australia with the objective of finding orebodies on a basis of structural geology.

Initially it was thought possible to find entirely new deposits by studying regional structures on a basis of air-photography, and considerable money and effort were expended in this direction. The immediate results of the work were disappointing.

The other side of the work by this Corporation consisted of the geological examination of old mines in the light of the then modern structural ideas. This type of investigation led to the establishment of three mines, each with an output of approximately 10,000 tons of ore per month. These are Gold Mines of Kalgoorlie, established on formerly abandoned leases on the eastern side of the Kalgoorlie field; the Triton Mine, which exploited a known, but previously unworked, deposit, which improved rapidly with depth; and Central Norseman Gold Mines, where non-outcropping shoots, whose existence was suspected on geological grounds, were proved by diamond drilling and by underground development.

A. See p.10

The same company conducted extensive geological surveys as well as a considerable underground exploratory campaign at Bendigo, Victoria, in the hope of finding substantial new gold deposits on that field, but the search was unsuccessful.

Western Mining Corporation performed a considerable service to Australian geology by introducing a number of prominent men from abroad whose ideas and techniques have now been absorbed into Australian geology. The Corporation was also the first to demonstrate to Australia the difficulties in wait for those seeking to find ore away from known deposits and, at the same time, it showed that much valuable ore occurring near well-known lodes, may have been missed in the past. Since that time, the exploration by

A. Seems

Since that time, a number of Kalgoorlie companies have re-studied their properties and have proved the existence of more than 10,000,000 tons of ore on ground previously considered to be virtually exhausted.

CENTRAL GEOLOGICAL SURVEY, BROKEN HILL.

During the years 1936-1939, the Broken Hill Companies jointly employed a group of geologists to study the field as a whole. This study, in conjunction with geophysical surveys carried out by J. M. Rayner, then of the Department of Mines, N.S.W., indicated that the ore-bearing structure continued unbroken to the southward of the known mines and also that a flattening of the pitch might occur which might bring the mineralized horizons within mining range of the surface. These deductions would be simple enough in some areas, but the Broken Hill rocks consist, for the most

part, of schist and gneiss, and 85 to 95 per cent of the critical area is covered by sand.

New Broken Hill Consolidated is now working the large orebodies discovered when these geological and geophysical deductions were followed up.

The fundamental ore-controls discovered during the survey form the basis of current operating mining geology at Broken Hill, and the information thus gathered is also being used in the search for entirely new deposits.

OTHER COMPANIES.

The development of the Big Bell property in Western Australia was the result of exploration activities by the companies controlling Mt. Isa Mines Limited.

These companies later formed an exploration company, Anglo-Queensland Pty. Limited, which examined a number of prospects brought to its notice, mainly in Queensland and New South Wales, but no orebodies were discovered which warranted exploitation. An important development at Mt. Isa, however, was the discovery and exploitation of a large non-outcropping copper deposit in the hanging-wall of the Mount Isa lead-zinc orebody. During the recent war, copper was produced from this deposit at the rate of 10,000 tons per year.

B. PROSPECTING 1941-1949.

ZINC CORPORATION LTD.

In 1946, this Corporation, (in conjunction with other interests,) formed a special exploration company known as Enterprise Exploration Ltd., which, under the general supervision of a Director of Exploration, employed, in 1948, an average of 6 engineers, 10 geologists, 12 geophysicists and 34 diamond drillers. Many A number of its geophysical examinations were carried out jointly with the Bureau of Mineral Resources and it also shared with that organization, the services of ~~an American~~ P. Sokoloff, geochemist, of the United States Geological Survey A considerable number of the Company's geophysicists were recruited from South Africa by the Company's geophysical consultant, Mr. O. Weiss. An airborne magnetometer has now been brought into operation by this organization.

~~A staff chart of the company is shown below :-~~

The work of the company may be divided into :-

(1) Examination of known prospects.

(2) Exploration of known metalliferous provinces for entirely new orebodies.

(3) Sundry testing - e.g., of beach sands.

(4) In association with established oil companies, Enterprise Exploration Ltd. is also carrying

out a search for oil and natural gas, but this phase of the work is outside the scope of the present article.

(1) Examination of Known Prospects.

This has been the most immediate objective of the company, and, since 1946, approximately 40 base metal prospects have been examined in some detail. The usual procedure has been examination of records, detailed geological examination using structural concepts of ore localisation, followed by diamond drilling where considered warranted. In the course of this work, some 15,000 feet of diamond drilling have been carried out.

The most promising prospect uncovered by these methods is a lead-zinc deposit, aggregating approximately 5,000 tons of ore per vertical foot containing probably 2 per cent lead, 8 to 12 per cent zinc and 2 oz. silver. The ore is graphitic. This prospect had previously been recommended by the North Australia Survey (Noakes, 1937; Rayner and Nye, 1937).

Most previously recorded mineral occurrences have proved disappointing when drilled and, after three years' work, difficulty is being experienced in maintaining the tempo of the campaign, because of the lack of prospects considered worthy of detailed examination.

(2) Exploration for New Orebodies away from Known Mines.

This type of work requires more imagination and courage than that described above, and some very interesting work in this category is being carried out by the company.

Important studies will be described under locality headings :-

Broken Hill, N.S.W.

The stimulus for exploration here derives from :-

(a) The immense size and richness of the known lead-zinc deposit; and

(b) The fact that the known ore is largely confined to certain beds which, in longitudinal section, are bent into a broad arch; in cross-section the structure is that of a ruptured anticline. Only the top of the arch was exposed and, with 1,500 feet less erosion, very little ore may have been found at the surface. The hope is that non-outcropping deposits may occur.

Large portions of the district are covered by wind-blown sand and the rocks of the area are schists and gneisses so that the deciphering of the stratigraphy and structure is difficult. Nevertheless, much has been achieved. The basis of the exploration programme is geological mapping, based on aerial photographs (scale 1 inch = 400 feet) tied to an accurate ground survey. It has been possible to divide the various metamorphic rocks into distinctive horizons and the magnetometer has been utilised in following key beds. Large areas have been covered by detailed magnetometer survey and considerable gravimetric studies have also been undertaken.

The basic concept of the search is that another lode may occur in any structure similar to that which contains the present orebody. Other anticlinal structures have been mapped and on these certain "indicator" minerals, such as gahnite and a peculiar green felspar, which are characteristically associated with the Broken Hill lode, have been found. Small quantities of lead and zinc sulphides have also been detected.

To date, 31,000 feet of diamond drilling have been carried out by Zinc Corporation Ltd. in connection with this project, and other Companies have drilled 35,000 to 40,000 feet with a similar object in view.

A small amount of preliminary geochemical work has been undertaken by the Bureau and it has been found possible to detect the presence of small quantities of lead and zinc in various rocks of the district. This fact may have prospecting significance.

The current Broken Hill work has been in progress for approximately three years and is likely to continue for some time. An air-borne magnetometer is now being brought into operation with the objective of speeding up some sections of the investigation.

Wallaroo-Moonta, South Australia.

This was/~~a rich~~ an important copper-producing district but no large-scale mining has been undertaken there for many years. Geological study and diamond drilling were carried out by the South Australian Mines Department and geophysical investigations - mainly self-potential - were undertaken by the Bureau of Mineral Resources.

Further geological study and considerable diamond drilling were carried out by Zinc Corporation Ltd. but no worthwhile orebodies have yet been intersected.

V. P. Sokoloff of the United States Geological Survey, who was in Australia in 1948, under contract to Zinc Corporation Ltd. and the Bureau of Mineral Resources, carried out extensive geochemical studies in this area (Sokoloff and others, 1949) and used dithizone (Sandell, 1944) to detect copper dispersed in the deep residual soils of the mineralized district. This work indicated the presence of copper anomalies which are being tested by drilling.

(3) Sundry Drilling.

Drilling by the company has proved the existence, in beach sands, of very large reserves of zircon, rutile and ilmenite.

ELECTROLYTIC ZINC LIMITED, ROSEBERRY, TASMANIA.

This organisation has a staff of three geologists and two geological assistants and is examining an area of approximately 300 square miles surrounding its properties in Western Tasmania. Much of this country is covered by extremely thick scrub and, in some sections, Tertiary glacial tillite obscures the mineralized Palaeozoic rocks.

The company uses air-photos as a basis for mapping. These reveal much of the geological structure, in spite of the dense forests - in fact, they reveal much that cannot be seen at close quarters.

Besides the geological department, the company has a small staff of diamond drillers under an exploration engineer. Much use is made of a light diamond drill, made in portable sections, which yields an E X core and is capable of penetrating 200 feet. Heavier drills are available for deeper testing.

The Company's programme is still in the initial stages and to date has been confined largely to the testing of old prospects, now overgrown by dense bush. High zinc prospects were not of great interest to prospectors in the past and these are now being sought by the company.

A point of interest is that the company is taking steps to establish a small geochemical unit for testing outcrops. Initially it is intended to use dithizone techniques, which were demonstrated in the region last year by the Bureau geochemical party.

NORTH BROKEN HILL LTD.

This company is very active in the exploration field and maintains a staff of 5 to 6 geologists, which number is likely to be increased as graduates become available from the universities.

At Zeehan, Tasmania, an effort is being made to revive the old lead-zinc field. The exploration is based on geological studies supplemented by geophysical work carried out by the Bureau of Mineral Resources. Diamond drilling gave promising results and underground development is now proceeding.

On the basis of air-photography, a considerable proportion of the highly mineralized belt in the West Coast District of Tasmania is being mapped, and an attempt is being made to use this mapping for prospecting on a regional basis.

A similar regional prospecting campaign is being carried out in the Nymagee district of New South Wales. The Bureau of Mineral Resources is collaborating with the mapping and is also ~~performing~~ conducted the geophysical surveys.

WESTERN MINING CORPORATION LTD.

The work of Western Mining Corporation Ltd. from 1933-35 has already been mentioned. At present, the Company maintains a staff of seven geologists, three of whom are

permanently engaged on mine operational work. The remaining staff is employed on geological studies associated with the exploration of abandoned fields or is accorded to one of the mines for special studies related to major exploration projects.

The company now tends to confine its activities to well-known mineralized areas and to the examination of new deposits discovered by prospectors, but is also interested in more speculative ventures. Thus, an examination is being made of a deep alluvial area to the south of Kalgoorlie with a view to finding gold eroded from the Kalgoorlie lodes. The Bureau of Mineral Resources carried out gravimetric and seismic surveys with the hope of locating buried channels, and the seismic survey gave promising results on which drilling by the company will be based. The company is also seeking a complete repetition of the Kalgoorlie field itself (gold production, 27,000,000 oz.) by following the Kalgoorlie structures southward to where, it is hoped, a favourable juxtaposition of rock-types and structure may have led to ore deposition of the Kalgoorlie type in areas now covered by deep soil or by lake deposits.

ANGLO-WESTRALIAN MINING PTY. LTD.

This is another prospecting company which is backed by ample venture capital. Essentially, its work has consisted of the geological study of old mines with a view to determining the possibility of repetitions, and the examination of new prospects. Aerial photography is used, when available, and, in one case, the geological mapping of an area surrounding a mine was based on photographs enlarged to a scale of 1 inch to 150 feet.

In addition to the detailed structural studies of known deposits, this company is proposing to engage in regional mapping of areas up to 200-300 square miles in an attempt to correlate and understand deposits outcropping on these regions. The hope is, of course, that this understanding will lead to discoveries. This company is closely associated with Big Bell Mines Ltd., which successfully operates a gold deposit which averages 2.9 dwt. per long ton. Output is 450,000 tons per annum.

SUNDRY VENTURES.

As an example of current ventures may be quoted the recent formation of a company to drill the deeps of the Great Fingal Mine at Cue, Western Australia. The

The deposit was worked to a depth of 2,500 feet and yielded over 1 million ounces of gold, but was poor at the bottom and the mine has been under water for many years. A contour study (Conolly, 1936) showed a relationship between gold occurrence and vein structure and led to a hope of repetition at depth. The company proposes to drill six deep holes to test the repetition prospect. It may be noted here, that the finding of extension and repetition gold deposits by geological study and diamond drilling has been relatively successful, especially in Western Australia, and a number of companies there have very hopeful prospects which they are investigating. The present unfavourable price/cost relationship is the greatest deterrent to the opening up of new mines (Raggatt, 1949).

General.

The contour method of studying metal distribution and vein structure introduced by H.J.C. Conolly (1936) is still popular, particularly in Western Australian gold fields. In general, for the past 20 years, exploration companies have put their faith in detailed studies of the structural geology in regions of known mineralization. This method of investigation was a big improvement on the techniques previously employed and has been responsible

for finding much ore. However, this technique is very empirical in conception (Sullivan, 1946; Graton, 1947), and does not represent a comprehensive approach to exploration.

III. EXPLORATION BY GOVERNMENT AGENCIES.

(A) THE DECADE 1930-1940.

NORTH AUSTRALIA SURVEY.

Perhaps the most significant attempt at prospecting by Government agencies during the period is represented by the work carried out by the Aerial Geological and Geophysical Survey of Northern Australia. This organization was supported by the Governments of the Commonwealth and those of Queensland and Western Australia.

It operated during the period 1935-1940 and, at its time of maximum activity, employed twelve geologists and the same number of geophysicists. The Royal Australian Air Force photographed a considerable number of separate areas up to 200 square miles in extent. The areas chosen were mainly those surrounding known mineralized districts.

The objectives of the survey were to assess discovered mineral resources situated north of the 22nd parallel of latitude and also to attempt to find new deposits by scientific methods. The Survey's assessment programme was largely achieved and attention was drawn to the probable value of several important deposits, but it cannot be claimed that any spectacular discovery

away from known deposits resulted from the first use in Australia of combined geology, geophysics and air-photography; in this, the experience was similar to that of Western Mining Corporation already cited. However, this survey was probably the most important single factor in introducing to Australia geophysical techniques and air-photo geological mapping, two factors which are now considered to be practically indispensable to any major investigation. It was also the first organization to attempt geochemical studies in Australia.

STATE GEOLOGICAL SURVEYS.

During this period, the work of the State geological surveys was not generally directed towards the finding of metalliferous mineral deposits though many important studies carried out led to a fuller understanding of individual orebodies.

(B) CURRENT ACTIVITIES.

AUSTRALIAN BUREAU OF MINERAL RESOURCES.

At present the Bureau has six geologists who can be said to be engaged in the search for vein - and lode-type metalliferous deposits though an equal number are employed in testing beach sands, bauxite deposits, and in similar projects. Approximately 12 geophysicists assist with Bureau mineral prospecting projects and supply a wide

The New South Wales Mines Department proved the existence of 15 million tons of aluminous laterite containing from 34 per cent to 45 per cent Al_2O_3.

variety of services to prospecting companies and State Governments. A small geochemical team is in process of formation and ~~also~~ a diamond drilling unit is being organised. Examples of work being carried out by the Bureau are :-

Tennant Creek, Northern Territory.

The field occupies an area of approximately 1,500 square miles. The deposits consist of massive hematite with which gold is associated.

Regional mapping based on air-photography (scale 1 inch = 1 mile) together with mapping on larger scale photographs, indicates that the lines of orebodies occur along the sheared axes of anticlinal folds and that the field is limited in depth by a semi-concordant granite. The hematite bodies are lenticular in shape and many of them do not outcrop. Magnetometer traverses along the fold axes detect most non-outcropping deposits, because there is a considerable proportion of magnetite associated with the hematite. Some thoroughly oxidised lenses are not magnetic, but their high specific gravity renders them susceptible to detection by gravimeters. However, a large proportion of the hematite bodies carry no gold, and, to date, no satisfactory method has been found of determining whether a non-outcropping hematite mass is auriferous or not ~~has been found~~. In many instances,

hometite bodies apparently barren of gold at the surface have yielded ~~very~~ rich shoots when explored at depth. Detailed geological mapping has shown that these shoots are associated with certain structural conditions, but the presence or absence of these conditions, cannot, in many instances, be predicted for the non-outcropping leases detected by the magnetometer.

Experiments are now proceeding in the use of a modified dithizone (Sokoloff and others, 1949) technique to detect the presence of very small quantities of gold above the hematite masses. Tests are also being conducted for the field detection of dispersed bismuth, because the gold is intimately associated with this metal. Where detailed studies have been made in known mines, it has been found that gold distribution is related to post-hematite shearing; accordingly, any shears or other structural planes which, from their attitude, can be expected to intersect the non-outcropping hematite masses, are to be tested for traces of bismuth and gold.

Final Success with this type of work would be of great importance at Tennant Creek. The detection of the hematite bodies presents no great difficulty (Rayner & Nye, 1936; Richardson, 1936, 1937); if the probability of

of gold occurrence within the hematite bodies can be determined, it would probably be feasible, within the space of a few years, to prove by drilling a large proportion of the ore deposits on this field.

Cobar-NYmagee District, N.S.W.

This metalliferous province contains copper-gold deposits. Cobar is the major field and has produced approximately 130,000 tons of copper and 1,000,000 ounces of gold. The district is being investigated by the Bureau of Mineral Resources in collaboration with Zinc Corporation Limited, North Broken Hill Limited, and with the Department of Mines, New South Wales, which has also carried out considerable previous work in the district. (Andrews, 1911, 1913; Mulholland and Rayner, 1947).

An area of 2,000 square miles has been photographed on a scale of 1 inch to 1,250 feet. The photographs are plotted by slotted template or simply by mosaic compilation to reconnaissance standard.

Reconnaissance mapping carried out to date has shown that one important ore line (which includes Cobar itself) is confined to a series of shears occurring a little to the west of the axis of a regional anticline which has been traced in a north-south direction for 50 miles.

At the southern end, the core of the anticline is occupied by concordant granite, surrounded by small ore deposits of the type found ~~at Cobar~~ at the northern end. Half-way along the anticlinal axis two plugs of granite porphyry outcrop and from this and other evidence, it has been inferred (by the writer) that the ore deposits occurring along the anticline overlie more or less concordant granite. (Sullivan, 1949).

The mining fields occurring along the anticline are associated with major anticlinal pitch changes and the individual deposits at Cobar, for example, are associated with minor cross-folds, producing the same type of pitch change. It is postulated that these anticlinal pitch changes correspond to the occurrence of cupola-like forms in the underlying granite - hence the occurrence of mineral fields. The small cross-folds, with which the individual orebodies are associated, are minor duplications of the major structure.

The area close to the "ore-line" is being carefully mapped on photographs enlarged to a scale of 1 inch to 400 feet. Magnetometer surveys carried out jointly by the Bureau and by Enterprise Exploration Ltd., are being used to ~~follewing down~~ trace the sheared limb of the north-south anticline and, in particular, geophysical work is

being concentrated in regions of anticlinal cross-folding. The magnetometer is most useful on account of the association of pyrrhotite with a considerable proportion of the orebodies, and the Cobar field itself has been almost completely covered by megnetometer surveys sited almost independently of the geological mapping. The geophysical surveys themselves have suggested sites for ~~successive studies~~ further investigation. The first drilling of a magnetic anomaly at Cobar disclosed the presence of a relatively small pyrrhotite-copper deposit of economic grade but other drilling has intersected disseminated pyrrhotite mineralization with a low content of valuable metals.// The drilling in the Cobar district is being carried out by Enterprise Exploration Ltd.

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Limited self-potential and gravimetric surveys have been made and consideration is being given to the possibility of determining by geophysical means, the outline of the postulated underlying granite. This latter project is still in a very speculative stage.

The regional work in the district is still in the initial stages, but already a number of promising magnetic anomalies have been found, and are being drilled. There are ~~a number of~~ several ore loci in this metalliferous province, each with similar structural and genetic associations. Many of these lines remain to be studied for geological detail and ~~to be searched out~~ tested by geophysical, geochemical, and drilling methods.

In the Cobar-Nymagee province (and in many other metallifferous provinces for that matter) a detailed knowledge of the stratigraphy is necessary because the ore deposits tend to be related to stratigraphic horizons.

The Brooks Creek District, Northern Territory.

Results of a geological study of this gold district have been described by the author (Sullivan, 1947). Of 22 formations mapped in the area, the gold occurs only in or around No. 9 formation. In particular, the ore deposits occur in this formation where it is found in domal and anticlinal structures. The deposits are related in distribution to graphitic schists and hematite-rich beds, which, in two deeply eroded dome structures in the district, are seen to surround masses of concordant granite. From this and other similar evidence, it has

been inferred that when these metasomatic rocks and associated orebodies occur in less eroded domal structures elsewhere in the district, they overlie cupola-like masses of granite.

Prospecting is planned for an area of about 5,000 square miles in this district, using the known relationship between stratigraphy, metasomatism, structure and ore, but has not yet been undertaken because of the remoteness of the area and the lack of trained personnel and drilling equipment.

Sundry Testing.

In addition to this relatively long-range work, the Bureau has carried out a number of testing programmes. Prior to 1945, the known deposits of bauxite of satisfactory metallurgical grade in Australia were small. Testing by Australian Aluminium Production Commission, under the supervision of a Bureau geologist, has proved the existence of 9 million tons of bauxite of which 6½ million represents previously unreported deposits. Exploration of the known deposits generally indicated lower economic reserves than had been estimated formerly.

At King Island, Bass Strait, geological study and diamond drilling proved over 3 million tons of open cut ore containing 0.6 per cent WO_3.

A rather extensive survey of the zircon-rutile-monazite

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A rather extensive survey of the zircon-rutile-monazite

content of the beach sands of the eastern coast of Australia is being conducted in association with other public authorities and private companies.

STATE GEOLOGICAL SURVEYS.

In the present decade the Geological Survey of Western Australia has fully embraced the doctrine that structural studies are the key to ore-finding, and considerable mapping has been carried out in the difficult terrain of the Pre-Cambrian Shield (Ellis, 1939; Matheson, 1948). Banded iron formations have frequently been used as marker horizons.

Two major principles appear to have emerged from this mapping. These are :-

(1) Ore tends to occur at approximately the same horizon in the greenstones, even in widely separated fields. The West Australian geologists regard these horizons as being "favourable" for structural reasons.

(2) Major deposits are associated with intersecting regional fold axes.

Some ore has already been found as a result of the application of these principles.and, in addition, the regional mapping has been of considerable assistance to mining companies carrying our more detailed investigations in limited areas.

The South Australian Mines Department maintains an efficient diamond drilling organization and has carried out a number of searches for specific metals on the basis of structural geological study and diamond drilling. ~~The Bureau of Mineral Resources has supplied geophysical services to South Australia and to other States.~~

The Victorian Mines Department has made the major contribution to our knowledge of the gold-fields of that State and their work at Bendigo still forms the soundest basis for exploration. Similar contributions have been made by other States in accordance with their technical resources and with their commitments in other directions.

As already mentioned the New South Wales Mines Department and the Bureau have a cooperative programme at Cobar and the Geological Survey of that State is also contributing to the intensified exploration programme at Broken Hill.

The Queensland and Tasmania geological surveys have, in recent years, carried out general and structural studies of a number of mineral deposits occurring in their respective States.

IV. SUMMARY OF ORE-FINDING EFFORT.

In an attempt to summarise the forces brought to bear on the problem of ore-finding in Australia during the past 20 years, the following approximations are suggested :-

During the period 1930-1940, there may have been an average of 20 geologists actively engaged in the search for ore in Australia, and from 1935 to 1940 they were assisted by 10 to 12 geophysicists. These do not include all geologists and geophysicists practising during this period, but only the comparatively rare workers whose investigations were consciously directed to the problem under discussion.

It is estimated that, at present, there are approximately 60 geologists and 20 geophysicists actively engaged in metalliferous geology in Australia. However, of the geologists more than half are concerned chiefly with routine surveys or operating mining geology and cannot be said to be engaged in exploration for new orebodies. Considering the difficulty of the task and the amount of work to be done, this is a relatively small force which would not be expected to achieve a vast amount of work in the search for oil; and the finding of new orebodies will probably be even more difficult than the finding of new oil pools.

As a further index of the amount of exploration proceeding in Australia, it is estimated that during 1948, some 70,000 feet of diamond drilling may have been carried out in the search for new mineral deposits; a much greater footage is, of course, drilled annually for the purpose of outlining known deposits ahead of development and by way of lateral prospecting in blocks of well mineralized ground - e.g., at Kalgoorlie. Deep "venture" drilling is still in the early stages of development in Australia, but is being increasingly undertaken by mining companies in the search for repetitions close to known deposits.

It is noteworthy that the discoveries made to date have been almost entirely at or near points where important outcropping mineralisation had previously been found by ordinary prospecting methods. The task of extending search away from known mines has commenced only in the very recent past and the possibility of the extension of known mineralized structures below thin non-mineralized rock cover is only now being considered. The possible significance of areas of weak mineralization along structures containing outcropping payable deposits has not been fully evaluated.

V. RE-ASSESSMENT OF PROBLEM OF MINERAL EXPLORATION.

At the beginning of this paper, it was stated that the scientific search for ore is still in an early stage of development, and it is believed to be very necessary to remember this fact when attempting to assess the chances of finding new deposits. Twenty to thirty years ago, with some notable exceptions, the average geological study carried out in Australia was generally not of direct assistance in finding new deposits, but aimed, rather, at a scientific understanding for its own sake. Those geologists with an ore-finding outlook ~~were limited by the lack of~~ did not have available to them the techniques which we have today. //Then came the empirical structural approach, the protagonists of which found quite a lot of ore and also developed a very considerable disdain for any type of geological investigation except "structure"; all else was tellingly labelled "academic", a term sufficient to discourage anyone venturing off the chosen path. An idea seems to have grown that a favourable structural trap is in itself a self-sufficient explanation for the occurrence of an orebody; problems of genesis have been relegated to the depths of the earth, a zone of little interest to those seeking mineral riches. Following this tendency juniors with little or no geological training have been

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elevated to the post of mine geologist, and one prominent Australian consulting exploration geologist affirms that geology has little to di with ore-search and that it is mainly a problem of geometry and diamond drilling.

NEW CONCEPTS CONCERNING GENESIS AND LOCALIZATION OF MINERALIZED FIELDS.

In spite of these current rather extreme ideas, it is considered that unless the fundamentals of ore-genesis and localization are fully understood, the problem of ore-search cannot be fully appreciated.

During recent years, the writer (Sullivan, 1947, 1948, 1949) has found evidence to support the hypothesis that for ores related to granitic rocks (which form a very large proportion of all orebodies), regional mapping indicates in many cases that the ore is genetically connected with concordant granite - and not to the same extent with subsequent, cross-cutting granite masses, which in some instances, appear to be later than the period of ore-formation. ~~If the concordant granite masses are projected parallel with the structure of the surrounding~~ to

If the outcrops of concordant granite in some districts are projected down-dip, parallel to the folding in the surrounding rocks, it is seen that the mineralized fields appear to occur in areas overlying the high points or cupolas of the underlying concordant granite mass.

The fields themselves occur in elongated domal structures in the sediments and other rocks, concordantly overlying the granite. In detail, individual deposits within the mining fields are commonly associated with minor anticlinal pitch changes.

Consideration is being given to the possibility of outlining, by geophysical means, critical sections of the granite lying below metalliferous districts. This would delineate areas in which mining fields could occur, would indicate the rock-bottom below which search would be useless, and would give some indication as to whether ore is likely to be found within mining range of the surface, even if favourable structural traps exist. One of the big disadvantages under which the metalliferous geologist works as compared with the oil geologist is the limited depth to which mining can be conducted.

Thus, during the Cobar-Nymagee study, a particularly favourable "structure" for ore localization was mapped by the present writer (Sullivan, 1948) and geophysical work was recommended. This work resulted in the outlining of a large magnetic anomaly as well as a self-potential anomaly. Some small shoots of payable gold-silver ore outcrop at the surface. The regional study suggests however that the concordant granite which appears to have been responsible

for this mineralization may be 35,000 feet below the surface at this point, and that the first zone of large-scale payable mineralization may be 10,000 feet below the surface. These suggestions were made before any drilling was undertaken and the drilling to date has revealed only 2 per cent pyrrhotite mineralization. Further drilling is being undertaken as these concepts are still of a tentative nature only, and there are many unpredictable factors in ore-deposition. Nevertheless, in the Cobar-Nymagee province and in the Brocks Creek District, Northern Territory, the granite responsible for ore deposition can be identified, and when it is treated as a semi-stratigraphic unit and its sub-surface position is interpolated, some very suggestive results are obtained.

There is a growing recognition in Australia, also, of the tendency, in a regional sense, for ore to occur at about the same lithological horizon. This may be related to several features, thoug, in the past, it has been assumed to be an indication that particular horizons are "structurally favourable", i.e., amenable to fracturing, etc. (Miles 1949). Actually, in some cases, ore deposits may be regarded as part of a contact aureole surrounding more or less concordant granite, similar in origin to the other types of metasomatism which, in many cases, surround these granites.

The writer suggests also that, for instance, the Western Australian gold deposits may tend to occur at about the same horizon in the greenstones, because the gold has been concentrated from gold-rich horizons in the old lavas, during the process of folding and granite-formation. Under this concept the process of granite-formation leads to the concentration of some elements formerly dispersed in volcanic and other rocks from which the granite were formed. (Sullivan, 1948, 1949).

Work now being carried out by John Bradley (1949) on the West Coast of Tasmania, shows that a close association exists between the distribution of a group of tuffs and flows, known as the Read-Rosebery volcanics, and the occurrence of ore deposits. The work indicates that within the volcanic group, the ore deposits occur close to regions where the rocks have undergone a type of mineralogical reconstitution, resulting in the formation of felspathic porphyries, in many of which the bedding of the original tuffs is preserved.

Steps are now being taken by the Bureau to determine by spectroscopic and other trace-element techniques, the minor metal content of rocks in metalliferous districts.

It is hoped to build up this knowledge concurrently with ordinary geological work. This basic research has considerable economic significance, e.g., in coming to a decision as to whether further orebodies of the Broken Hill type are likely to be found within the 2,000 square miles of Willyama Series outcropping in that district, the problem of genesis is most important. If the known deposit is believed to have resulted from the happy conjunction of favourable openings and a supply of ore solutions of unknown, but very deep-seated origin, the warrant for a repetition search is simply the hope that if another favourable opening is found, some more solutions may have been available. If it can be shown, however, that the source of the lead is close at hand, perhaps even within the Willyama Series itself, that it has been concentrated during the formation of the concordant granites which characterize the district, that the concentrating granite can be identified and that the ore tends to occur at about the same stratigraphic horizon in elongated ruptured domal structures overlying this particular granite, a reason for search is provided and a technique suggested.

It is added that no such mode of origin has yet been proved though the present writer believe it is entirely possible and could be tested by known trace-element and other techniques.

CONCLUSION.

The scientific search for ore in Australia has arisen in the past 25 years. Its main successes have resulted from the geological study of known deposits, followed by diamond drilling. In the past decade, geophysical investigation has become indispensable and air-photography is used for regional geological mapping wherever possible. Geochemical studies are only now beginning in Australia but initial work suggests that this science will add greatly, both to fundamental knowledge of ore genesis and to the techniques of actual search. Venture diamond drilling has not been common in Australia, but there are indications that its use is increasing fairly rapidly.

At times in the past there has been, in the writer's opinion, some undue optimism concerning the ease with which ore might be found in "favourable structures" in areas removed from known deposits. This optimism was based, to some extent, on a lack of knowledge of ore-genesis and it is believed that fundamental knowledge in this respect remains to be built up in the forthcoming years. In particular, current work suggests that there may have been a lack of appreciation of the importance of the depth-factor.

The writer knows one large company in Australia, which has ample financial and technical resources, but which is now speculating as to what it can do further in the search for base metals, even though it is quite prepared to spend money where legitimate chances seem to exist. Its very energetic programme carried out over the past few years has yeilded rather disappointing results, though the Company utilized all modern methods of attack, and the work was based, generally, on structural geology.

This feeling of uncertainity underlines the views expressed by L. C. Graton (1947) that there is a great need for fundamental knowledge concerning the origin and localization of mineralized fields or districts. Until such knowledge is available, exploration is likely to be initiated with a rather vague feeling of optimism and may end up in rueful ~~resentment~~ disappointment. In the long-run, basic research into ore genesis and localization, and into detection techniques will pay good dividends. Even if basic theoretical and field studies merely lead to the conclusion that, in reasonably prospected areas, most mining fields of the vein-and lode-type occurring within mining depth of the surface have been discovered, this conclusion itself will be valuable.

As against this somewhat negative conclusion, the work of the geological parties which are looking for ore will, in the future, be far more sharply oriented towards the main purpose than it has been in the past. ~~Parties of Bureau geologists are being equipped with light portable diamond drills, and prospectors are being attached to parties working in relatively unsearched areas. A team study of given areas by groups of specialists in various branches of geological and geophysical science is being developed where possible, the limiting factor in Australia at present being lack of trained staff.~~

Finally, it must be stated that, in spite of the wide recognition of the need to find new deposits, the actual force being brought to bear on field investigations and on improvements in techniques is comparatively small, though that force has been expanded very considerably in the past ten years.

Acknowledgements and Explanations.

Australian mining companies generally have been most generous in supplying information for this article and special thanks are due to Mr. M. A. Mawby, Director of Exploration, Zinc Corporation Ltd., who has been extremely helpful. Wherever possible, the mining companies referred to have been consulted, but in one or two cases,

owing to the distances involved, and to shortage of time, this has not been possible. If any inaccuracies have been introduced, this has been done unknowingly, and without malicious intent. Every attempt has been made to avoid such inaccuracies, which however, tend to occur in a summary of this nature.

Lastly, it is emphasized that the author alone is responsible for the views expressed in this article. The subject of mineral exploration is quite controversial, and the ideas outlined - particularly those of a speculative nature - by no means correspond, in every given case, to the views of those leading the various private and public organizations whose work the author has attempted to summarize.

(Sgd.) C.J. Sullivan.
23/3/1949.

Canberra, Australia,
March, 1949.

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