1953/40
Copy 2

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

1953/40

REPORT ON TOUR ABROAD

July-December

1952

by

C.J. Sullivan

The information contained in this report has been obtained by the Department of National Development as part of the policy of the Commonwealth Government to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus or statement without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

CONTENTS.

	Page.
INTRODUCTION.	1
INITIAL JOURNEY	1
SYDNEY-JOKARTA-SINGAPORE-BOMBAY-NAIROBI.	
SOUTH AFRICA.	4
SOUTH AFRICAN GEOLOGICAL SURVEY.	4
Shortage of Staff.	4
Level of Training.	5
Organisation of Survey.	5
Geophysics.	5
Water Supply.	6
Lessons for Australia.	7
ATOMIC ENERGY COMMISSION.	8
UNION CORPORATION.	9
Regional Prospecting.	9
EAST GEDULD MINE.	10
Mining Data.	10
Type Section.	11
Ore Shoots - Genesis.	12
Type of Geological Work.	12
WESTERN REEFS MINE.	13
Section.	13
Structure.	13
Mining Methods.	14
DIAMONDS.	14
THORIUM.	15
STEEL.	16
COAL.	16
NORTHERN RHODESIA.	16
GENERAL.	16
GENERAL GEOLOGY.	18
ORE GEOLOGY.	21

	Page.
Primary Mineralization - Genesis.	21
Oxidation and Leaching.	22
MINES.	23
Mufulira.	24
Roan Antelope.	24
Nkana.	25
Baluba.	27
BELGIAN CONGO.	27
KIPUSHI.	27
JADOTVILLE.	28
Copper-Cobalt Plant.	29
Geological Laboratories,	29
GEOLOGY OF KATANGA.	30
MINERALIZATION.	31
Origin of Mineralization.	33
MINES OF KOLWEZI AREA.	35
Musonoi.	35
Ruwe.	36
Mupini.	37
Fungarume.	37
KASAKELESA MANGANESE.	38
DIAMONDS.	39
DRILLING IN CONGO.	40
BELGIUM-FRANCE-NORTH AFRICA.	40
NINETEENTH INTERNATIONAL GEOLOGICAL CONGRESS, 1952.	42
EXCURSION CROSSIERE.	42
FORMAL SESSIONS.	43
VISIT TO GELLIDGA.	45
ENGLAND.	46
BRITISH GEOLOGICAL SURVEY.	47

	Page.
CANADA.	48
CANADIAN GEOLOGICAL SURVEY.	48
ALBERTA OIL FIELD.	49
GOLD-FIELDS REGION, BEAVERLODGE LAKE.	50
General Geology.	51
Ore Deposits.	52
Genesis of Ores.	54
VISIT TO TORONTO.	55
Ventures Ltd.	55
The University.	55
Provincial Survey.	56
SUDBURY, ONTARIO.	57
Ore Deposits Output.	57
Geology.	58
Genesis of Ore.	59
Geological Techniques.	61
NORANDA, QUEBEC.	62
KERR ADDISON, ONTARIO.	65
Geology.	65
Genesis of Ore.	67
UNITED STATES OF AMERICA.	68
WASHINGTON, D.C.	69
MARQUETTE RANGE, MICHIGAN.	71
General Geology.	71
Genesis of Ores.	72
Ore-Search Techniques.	73
KEEWENAWAN COPPER DEPOSITS.	73
BONNE TERRE LEAD DEPOSITS, MISSOURI.	75
Geology.	75
Genesis of Ores.	76
Mining Notes.	77
Geochemistry and Geophysics.	77
CLIMAX, COLORADO.	77
Geology.	78

	Page.
URANIUM DEPOSITS, FRONT RANGE, COLORADO.	79
Copper King Mine.	79
Caribou Mine.	80
Central City District.	81
COLORADO PLATEAU URANIUM PROVINCE.	82
General Geology.	82
Mines Visited.	84
(1) Outlaw Mine.	84
(2) Happy Jack Mine.	85
(3) Monument No.2 Mine.	86
(4) Lukachukai Mountains, Arizona.	87
(5) Mines near Gallup, New Mexico.	88
(6) Gay Eagle Claim, Grants, New Mexico.	89
(7) F.O.Manoel Claim, Grants, New Mexico.	89
(8) Santa Fe Claims.	89
(9) Blue Peak Mine, Grants.	90
(10) Poison Canyon Claims, Grants.	90
Genesis of Plateau Ores.	91
OTHER URANIUM DEPOSITS, U.S.A.	93
Marysvale, Utah.	93.
Deposits of Jefferson County, Montana.	94
(a) President Woodrow Wilson.	94
(b) President George Washington.	95
PORPHYRY COPPER DEPOSITS OF SOUTH WESTERN U.S.	96
Santa Rita, New Mexico.	97
Morenci, Arizona.	99
San Manuel, Arizona	101
Ray, Arizona	102
Miami - Inspiration, Globe Arizona	104
Bingham Canyon, Utah	105
Bute, Montana	106
CONCLUSIONS AND RECOMMENDATIONS	109
ORE POSSIBILITIES FOR AUSTRALIA	109
Diamonds in Australia	109

	Page
Rhodesia - Congo and Rum Jungle	109
Gneiss and Uranium	109
Criteria for Porphyry Copper Deposits	109
Big Mines for the Future	109
Geology, Geophysics and Watersupply	109
Criteria for Copper in Basalts	109
TECHNIQUES OF ORE SEARCH	110
Importance of Drilling	110
Integration of Geology and Geophysics	110
Geochemistry, Coming Science	110
Rock Alteration	110
Comprehensive Approach	110
SUGGESTIONS FOR BUREAU	110
Introduction	110
Geology and Geophysics Not Integrated	111
Level of Australian Training, Low	111
Chemistry Needed	111
Water-Supply Neglected	112
Availability of Plans and Reports	112
ACKNOWLEDGMENT	112

REPORT ON TOUR ABROAD

5.7.52 - 13.12.52

C.J. SULLIVAN

INTRODUCTION

The object of this tour was to study ore deposits and methods of exploration in Africa and North America as well as to attend, as Official Delegate of the Commonwealth of Australia, the 19th International Geological Congress held at Algiers in September, 1952.

A considerable amount of information was gained concerning ore deposits in the countries visited and this information should be of assistance in the search for further metal deposits in Australia.

At the International Congress useful work was achieved and contact was made with a large number of geologists in various parts of the world. These contacts will facilitate the exchange of information between Australian and foreign geologists.

The itinerary followed the attached as an Appendix to this report.

INITIAL JOURNEY

SYDNEY - JOKARTA - SINGAPORE - BOMBAY - NAIROBI

I left Sydney by Qantas Empire Airways on the evening of 5th July, 1952, and after touch-downs at Darwin and Jokarta we spent the evening of the 6th in Singapore.

Passengers were accommodated at Raffles Hotel and there was an opportunity during the afternoon of the 6th to see the thriving and cosmopolitan city which is still expanding rapidly; new steel and concrete buildings being put up in numerous places. Australian currency is accepted in Singapore where the standing of the Commonwealth is apparently fairly high.

On 7th we flew to Bombay touching down for a couple of hours at Colombo. As there was no transport from Bombay to Nairobi, Kenya, until July 10th, two days were spent in Bombay. A considerable portion of this time was spent in discussing geological problems and methods of developing mineral resources with the branch of the Indian Geological Survey which has headquarters in that city.

The Indian Geologists appear to be cordial and were very helpful in supplying information. The level of training of the Indian geologists encountered did not appear to be high and they themselves considered that the standards within the Indian universities in general were not as high as those in Australia. The Survey is attempting to maintain the levels of geological work established by the Indian Geological Survey under British direction, but one got the impression in Bombay that the English technicians and administrators were being missed. Educated Indian men and women encountered socially appeared, in some cases, more English than the English, their accents being strictly Oxford and their aim being to be like the British pukka sahib.

Nevertheless the Indians were imbued with a new enthusiasm to develop the country, increase secondary production, and improve the standard of living. This is undoubtedly a very long range task as the system whereby each man does very little work is deeply ingrained in the Indian character. For example there were four servants attached to my room at the Taj Mahal Hotel and, even so, it was not considered that any of these should demean themselves by carrying the bags from the lobby to the room and vice versa; these tasks were reserved for the more humble "bearers".

On the 10th July I flew from India to Nairobi, Kenya. There was no plane to Johannesburg until the 13th and the intervening time was spent in discussing geological exploration with the Kenya Geological Survey and in inspecting such items of geological interest as the Rift Valley.

Geological work in Kenya is carried out by approximately 16 geologists who are paid by The Kenya Administration but are under the general direction of the Colonial Geological Survey which lays down policy. The basis of work is regional mapping, based on air photography which is supplied by the Royal Air Force. The techniques used are somewhat similar to those employed in Australia, but, in my opinion, are inferior to the procedures which have been developed by the Geological Section of the Bureau of Mineral Resources in Canberra.

The air photography itself is generally poor and is not sufficiently clear for high-grade geological work. In addition, there are no suitable maps compiled in time for use by the geological staff. There is a central organization in London whose responsibility it is to prepare maps but this is very much behind with its work and the geologists work merely from the air photographs making their own compilations. No preliminary photo-interpretation maps are made, which we know in Australia, is a distinct disadvantage.

The geologists employed in Kenya are mostly from 25-30 years of age and are very good types of men, apparently very well trained. One man works alone mapping about 900 square miles in a six months safari. The maps being produced appear on the whole to be of a good standard but as only a small area of Kenya is likely to contain important metal deposits, the Geological Survey is labouring under difficulties in attempting to improve the metalliferous production of the Colony. A considerable proportion of Kenya consists of eroded pre-Cambrian gneisses similar to those exposed in Central Australia in which metalliferous deposits are not to be expected. An additional large area is covered by Tertiary lava with which no ore deposits are associated.

In the north-east corner of Kenya there is an area of Jurassic rocks in which it is possible that oil exists. There are also some Karoo (Permo-Carboniferous) rocks which contain very thin coal seams.

The philosophy of ore search in Kenya is that of geological mapping and hoping for the best. There is not much sign of a direct "pay-off" in terms of mineral production.

As is well-known from the press reports, there is a certain amount of native unrest which is causing considerable worry to the Colonial Administration. On the whole, the natives appear cheerful, but there is a deep impression that large groups of them are fundamentally unhappy. Owing to the development of towns such as Nairobi considerable numbers of natives have moved to these centres where those employed are paid about 50/- per month. The aggregation of poorly paid natives in towns usually leads to trouble. In addition, the English are settling in Kenya,

in the same sense that they and other foreign races settled in South Africa. As it is impossible in the modern age to kill all the Africans, the inevitable problem arises of the co-existence of a white proletariat and a black proletariat. This problem is very evident throughout Africa and appears to be fundamentally insoluble. The Mau Mau secret society had begun carrying out murders at the time of my visit, and even in Nairobi, white people, especially women and children, do not take many risks. Property is kept strictly under lock and key and windows in all hotels are barred.

The natives are still in a semi-savage state and will be quite incapable, for many generations, of running the country at European standards. The number of natives is increasing, as the British have improven the production and distribution of food, have installed medical services, and have prevented the wars which were formerly an important factor in reducing the population.

SOUTH AFRICA

I arrived in South Africa on the 13.7.52 and was very well received by the local authorities who put me through Customs and Immigration with the minimum delay and maximum courtesy. This was owing to the fact that Mr. Nel, the South African High Commissioner in Australia, who is the brother of the Director of the South African Geological Survey, had sent previous word of my coming.

I spent one week in the Union during which time I visited the Geological Survey at Pretoria, inspected one of the large mines held by Union Corporation and studied their methods of exploration; and visited mines held by the Anglo-American Corporation in company with their Chief Geologist, Dr. B.B. Brock.

SOUTH AFRICAN GEOLOGICAL SURVEY

Dr. Lewis T. Nel met me at the Railway Station in Pretoria and was most helpful during my visit to this capital. He took me to lunch with the Acting Secretary for Mines, Mr. Rothmann, and Dr. Haughton, previous Director of the Survey who is now in charge of radioactive material resources of the Union.

Shortage of Staff

The Geological Survey of South Africa has carried out some very

high-grade work and it is possibly unnecessary to say that many of its past geologists have had international reputations. At the present time, Dr. Nel is finding it difficult to retain staff on the salaries paid by the Government and during the past year he has lost five of his senior geologists to mining companies. Geologists are in high demand in South Africa and there is a shortage of experienced men both for company and Survey work.

Level of Training.

Dr. Nel would like to have only men with doctorates on his staff and tries to insist at least on an M.Sc. level of training. A number of South African geologists are being sent abroad by the leading mining companies to carry out post-graduate studies, especially in North America.

It appears to me that Australian levels of academic training are low by world standards in that the average student does not spend long enough time in obtaining basic training at the University. We should encourage the development of Ph.D.courses within our universities, as the Australian D.Sc. degree does not really answer the problem.

Organization of Survey.

The Survey is organized as follows:

Under a Director and Deputy Director there are five principal geologists who are partly, or even largely, administrative, and are in charge of the following sections:

1) Regional geology
2) Economic geology (including exploration for metals)
3) Fuels (coal and oil)
4) Underground water, which includes most of the geophysical staff and those engaged in engineering geology.
5) Mineralogy and petrology.

There is also a drawing office, museum, library and an extensive editing and translating section. By law it is necessary that all official publications are in two languages - English and Afrikaans - which greatly complicates the problem of publication.

Working under the Principal Geologists are Senior Geologists, Geologists, Junior Geologists, all of whom are graduates.

Geophysics.

A striking feature of the organization is the way in which geophysics is employed. Dr. Nel does not employ any pure physicists.

all members of the staff are called geologists and all have had at least a degree course in geology. There is the closest possible liaison between geology and geophysics, and this applies also to the mining companies operating in South Africa.

In no country in the world have I seen such respect for geophysics as in the Union of South Africa (although there are exceptions such as the large Anglo-American Corporation), and in few countries also did I encounter such a complete marriage between geology and geophysics. The geologists know the geophysical properties of the main rock groups on the Rand just as well as they know their quartz and felspar content. Additionally, the people using geophysical instruments are very well acquainted with the geological problems under investigation.

Water Supply.

A second factor in which the South African Survey differs from the Bureau of Mineral Resources is in connection with the search for water. The search for water in the Union is regarded as of prime national importance and to assist in this, the Government maintains 263 drilling plants and has spent £35,000,000 in the development of water for farms in the Union. Drilling by the Government plant is only carried out if approved by the Geological Survey.

The Survey devotes a very large proportion of its resources to the search for water, and 80% of the geophysical work is in this connection. The man in charge of the section, Dr. Jansen, took a degree in geology and the specialised in geophysics during his post-graduate course. In areas where the geology is known, technical direction of drilling has raised the percentage of successes from 45 per cent to 80 per cent. The cost of geology and geophysics is about £30 per site or about 10 per cent of the average cost of boring. Research is proceeding on methods of exploration for water in areas in which it is difficult to find, and the officer-in-charge expects a considerable increase in the percentage of successes. The demand from farmers for assistance in the search for water is more than the Survey can cope with. The government drills the bores on the basis of no water/no charge but the cost of Government bores is a little higher than that of private boring.

Eight parties are in the field at the present time. The parties consist of one geologist and one technical assistant to read geophysical instruments. The technical assistant, who is not generally a graduate, may continue his training with the assistance of the Survey and the University Authorities.

The geophysical methods most in use are the magnetic methods and resistivity measurements. Much of the water in the Union occurs on the walls of doleritic dykes which can be detected by the use of magnetometers. The resistivity measurements are used to calculate porosity and permeability. High resistivity indicates a very low porosity, low resistivity indicates a low permeability. The medium resistivity is considered the most favourable, suggesting that the rock has porosity and permeability. In addition to the neighbourhood of basic dykes a good deal of water is found in weathered pockets in granitic rocks.

Within the Transvaal dolomite, which is a very important aquifer, electric potential methods are used in the search for water. Dr. Jansen told me that a small portable seismic plant is being developed for the study of dam sites.

Considerable research is being carried out on the depletion of the underground water supplies in the Union which is considered to be a serious problem and is under the control of the Survey.

Lessons for Australia.

It appeared to me that the main lessons to be learned by Australia from The South African Survey are :-

(a) High level of training

(b) Near fusion of geology and geophysics

(c) Attention given to water supply with profitable results.

It is believed that we could learn a considerable amount from the South African Survey in connection with developing small supplies of water in arid areas at depths of 50-300 ft. and I discussed with Dr. Nel both in South Africa and at the meeting in Algiers of the British Commonwealth Conference on Geology and Mineral Resources, the possibility of exchanging geologists in connection with these and similar problems; undoubtedly the South Africans could also learn something in Australia.

Dr. Nel stated that his Government was extremely loth of spending any money on this or any other project, and that therefore he might find it difficult to send geologists to Australia. He stated, however, that every possible assistance would be given to Australian geologists who cared to study the methods of the Survey, and I am sure from the reception given to me this would be so.

ATOMIC ENERGY COMMISSION

Dr. Haughton, previous Director of the Geological Survey, is now in charge of the search for and assessment of uranium resources on behalf of the Government. Although he is housed in the Survey building he is head of a small separate establishment which functions as a type of Raw Materials Division of the Atomic Energy Commission and consists of Dr. Haughton, one Senior Geologist and two other geologists as well as perhaps ten drafting and clerical staff who are largely engaged in assaying of samples and tabulation of results.

Samples representing all headings and boring in the areas favourable for uranium are forwarded to Pretoria by the mining companies and these are assayed very rapidly by an ingenious plant which makes radioactive determinations of samples at the rate of 8 every 2 minutes. The assaying is handled by a staff of two. A native clerk prepares the samples and slides them in the machine, and the second clerk reads the meters and records the results. These results are then passed to the drafting staff which consists largely of women. The samples are occasionally tested by radiometric means to determine whether the ore is in equilibrium or not. Ore from the oxidised zone and from near fissures is not always in equilibrium.

The equipment was developed by the National Physics Laboratory of South Africa, with help in the way of special gear from the similar laboratory in England.

Radioactive logging of drill holes is very important, both in the search for ore and as a means of correlating the different formations being encountered in drilling, especially in the Orange Free State. The laboratory of the Survey has developed some special gear for this which consists of a single piano wire from which a 1" cylinder containing a Geiger tube is suspended. Results are

recorded on a revolving drum and both the survey staff and geologists of the mining companies have told me that the information obtained is of great value. For some time there was considerable difficulty in correlating the various formations encountered in drilling in the Orange Free State.

During the course of my discussions with Dr. Haughton and with others concerned I obtained some information on the uranium resources of South Africa and this information will be given in a separate report on the Uranium deposits seen by me in South Africa, Rhodesia, the Congo, Canada and the United States.

UNION CORPORATION.

The Chief Geologist of Union Corporation, Dr. A. Frost, to whom I had a letter of introduction from Mr. M.A. Mawby, was most helpful in showing me the methods and results of geological work carried out by his large company in South Africa. I spent a day in the Central Office, Johannesburg (a huge steel and concrete skyscraper), studying the general methods and then visited the East Geduld Mine, one of the group controlled by this corporation.

Regional Prospecting.

Frost and Weiss claim most of the credit for the discovery of the Orange Free State goldfields (Frost, McIntyre, Papenfus and Weiss, 1946), and although this claim is strongly disputed by the geologists of Anglo-American Corporation which now controls a large proportion of the Orange Free State area - good evidence in itself - Frost and Weiss undoubtedly carried out some very brilliant work in this area and may have missed the boat partly on account of the lack of support by the directors of their company. I have reason to believe that work by this team has recently uncovered a large new basin containing Lower Witwaters rand gold-bearing rocks, under a deep cover of Karoo, well to the west of known deposits; it seems possible that this discovery may be almost as important as that of the Orange Free State. A good deal of drilling has already been carried out by Union Corporation. This work and the results obtained are still regarded by the Corporation as secret and confidential, partly because they feel that they failed to cash in on the previous work they did in the Orange Free State.

Frost and Weiss are very old friends and work in the closest collaboration.

The geophysical deductions are largely based on the generalization that the Witwaters rand and sediments are light and non-magnetic, that the Ventersdorp lavas are heavy and magnetic and that the Jeppestone shales which underlie the Lower Witwaters - rand are highly magnetic. It is largely on the basis of this last factor that it was possible to unravel the complicated structure in the western part of the Rand and to predict the position of the ore-bearing Elsburg and Witwaters rand series under big thicknesses of dolomite and Ventersdorp lavas. By this means important mines such as Western Reefs, 120 miles west of Johannesburg, have been brought into production and the recent discovery by Union Corporation to the West again of this has also utilized the magnetic properties of the Jeppestone shale. The work which led to the discovery of the Western Reefs group was largely ground magnetometer survey but the recent investigation of Union Corporation has been based on closely spaced airborne magnetometer surveys at 500 ft. altitude // From the results obtained cardboard and plaster models of the magnetic anomalies were constructed and from geological and geophysical interpretation of these anomalies it was possible to find the payable reefs of the Witwaters rand.

EAST GEDULD MINE

The East Geduld Mine near Springs, Transvaal was visited in order to look at underground exposures and to see the operating office of the Geological Department of Union Corporation which is situated here. As in most parts of the world the search for new ore deposits on the Rand is more interesting than is the study of the geology of the operating mines, and requires a higher degree of geological ability, but some interesting information was obtained at East Geduld.

Mining Data

The mine has a capital of 1.75 million pounds; ore reserves are 12 million tons containing 5.6 dwt. per ton and production is approximately 1,200,000 tons per year. Overall annual profit is approximately £4,000,000; overall costs are 27/- per ton.

From all employees, including natives, a production of 2 tons per man-shift is obtained and the average advance is 0.84 ft. per man-day.

Levels are driven 200 feet apart vertically; this is equivalent to 600 feet horizontally and yields 700 feet of backs. The main raises are 800 feet apart. Between each level and two adjoining raises, about 120,000 tons of ore are developed.

About 51 per cent of the driving and raising is in payable ore.

Driving is carried out on contour levels and in many levels haulage is by means of the endless rope system. All drilling, bogging, trucking etc., is done by African Natives and it has been found that it does not pay to have mechanical boggers in the faces as this work is done cheaper by the natives. They are paid approximately 3/- to 5/- a day. A party of 4 to 5 Africans is under the charge of a white "miner" who tells them where to put the holes and lights the charges. The white "miner" draws £50 or more per month. It is not permitted to call the Africans "miners" any more than it is for them to become carpenters or members of any other skilled trade. This is part of the battle of the white African working man against the African working man and explains much of the support received by nationalist-racialist parties such as those of Dr. Malan.

Type Section

A type section in this area is as follows:-

0-97 feet	Karoo. Sandstones, shale, coal		
97-1168 feet.	Dolomite and chert, some dolomitic sills.		Transvaal System
1168-1197.7. ft.	Black reef quartzite with reef at base carrying pay ore in some mines. The Ventersdorp lava is missing.		
1197-7-1855 Ft.	Kimberley = Elsberg quartzite	Elsberg.	Witwaters-rand Upper
1855-1955 ft.	Upper Kimberley reefs (3) being worked.		
1955-2118 ft.	Kimberley Quartzite.		
2118-2364 ft.	Upper Kimberley reef zone (grade with some payable bands) 5 payable reefs.		
2364-2496 ft.	Kimberley Quartzite.		
2496-2587 ft.	Payable reef zone.		
2587 feet	May reef		

2587-2967 ft.	Quartzite and reefs	
2967-3327 ft.	Kimberley shale	
3327-3557 ft.	Main Bird quartzite	
3557-3706 ft.	Bird amygdaloidal lava	
3706-4336 ft.	Main Bird quartzite. Main reef (most productive in area)	
4336-4725 ft.	Jeppestone shale. The principal production is coming from the Main Reef, May Reef and from the Upper Kimberley Reefs.	Lower Witwatersrand.

Ore Shoots - Genesis.

After many years of mining, extensive plans showing the old stopes on the East Geduld mine are available and these give a very good indication of the gold distribution. The gold is arranged in shoots which show a close relationship to the folding structures as outlined by the contour drives. The geologists on the mine and indeed most geologists on the Rand consider that the gold is of detrital origin and that it is distributed in relation to former stream patterns and alluvial valleys. Without entering into a long discussion and covering ground that has largely been covered before, I record that I consider also that it is most likely that the gold is of detrital origin and that the uranium which is associated with it in some places is also syngenetic. The uranium has probably been precipitated from solution, however, and is unlikely to be strictly detrital.

Type of Geological work

The work of the operating geologists on the mines consists, in the early stages of the identification and correlation of the various formations and reefs intersected, thus solving the faulting and folding patterns; and in making sure that no payable ore is missed.

When a mine is fully developed the geologist watches all reefs in drives and makes sure that development is kept on the favourable formations. The Rand geologist is very adept at recognising favourable reefs, and appears able to tell within close limits the gold content of the various types of conglomerate. The favourable conglomerate is well sorted and consists of boulders generally 1" to

2" in diameter. Rich ore may contain a high percentage of pyrite in the form of "buckshot" or coarse rounded crystals. Generally speaking, gold distribution shows a close relationship with the degree of abrasion by water action of conglomeratic material.

Probably the most remarkable feature of the Rand gold deposits is their well-known persistence over very large areas, and three to four drill holes which intersect ore are commonly considered to provide sufficient evidence for the expenditure of large sums of money on the development and equipment of mines.

WESTERN REEFS.

These mines, situated approximately 120 miles west of Johannesburg, were visited in the company of Dr. B.B.Brock, Chief Geologist of the Anglo American Corporation which controls a large proportion of the gold mining as well as the whole of the diamond mining in South Africa. It is also a large holder in the Rhodesian copper belt.

Section.

A generalised section in the Western Reefs area is as follows:-

0-800 ft.	Dolomite. (Transvaal)
800-3800 ft.	Ventersdorp lavas. Unconformity. Contact reef (producer)
3800-6000 ft.	Elsberg, mostly sandy sediments.

Near the base of the Elsberg, the Vaal reef containing payable gold and uranium is found. The Contact reef and the Vaal reef are the main producers in the Western Reefs area.

As outlined above, the Western Reefs deposits were found as a result of geological and geophysical work, by means of which the Jeppestone shales and overlying formations were traced to the westward from Johannesburg under the cover of Transvaal dolomite and Ventersdorp lavas.

Structure.

The structure in this region is extremely complicated owing to the presence of large folds and of faults with vertical displacements amounting in some cases to 3,000 ft.

In the Western Reefs Mine there are three systems of faults and in the early stages of drilling geologists had difficulty in making correct correlations; it was only after considerable

development had taken place that some of the answers to the faulting problem were obtained.

A permanent staff of six geologists was employed on this mine and they were fully occupied with mapping the mine openings and attempting to solve the faulting problems. They have intimate knowledge of the stratigraphy of the area, and, indeed, throughout the Rand, geologists appear to be able to recognise various formations with the greatest facility. Rand geological problems are largely stratigraphic.

Mining Methods.

The complicated faulting makes mining difficult and in order to cope with this problem a somewhat special technique has been developed. The Main Shaft is sunk to intersect ore in the deeper positions and twin contour drives are run to the fault at the level at which the upthrown reef is known to occur. The presence of the two openings enables the drive to be successfully ventilated and also provides for rapid haulage of waste or ore. Jumboes and mechanical boggers are used in this work and rates of advance up to 600 feet per month (working three shifts) have been obtained. Once the fault is passed, the twin tunnel is used as a means of access on ore on the up-throw side of the fault and a good deal of vertical shafting is avoided.

DIAMONDS.

The diamond mines of South Africa are owned either by the State or by the De Beer's Corporation. These two bodies co-operate closely in the marketing of the product. The operation of the De Beer's mines is under the control of the Anglo-American Corporation of whom Dr. B.B. Brock is Chief Geologist. Dr. Waters, an American, is the expert for diamonds in the Anglo-American Corporation and I had some conversations with him but unfortunately was not able to visit the deposits.

Dr. Brock believes that the occurrence of diamond pipes is related to certain tectonic conditions. The favourable conditions are sinking sedimentary basins commonly provided by faults- the type of structure classified by Kay (1951) as a traphrogeosyncline. This type of structure is associated with Rift valley faulting.

Brock also considers that the former Gondwanaland has some significance for the occurrence of diamonds.

The area which immediately comes to mind in Australia is the Fitzroy Basin, Kimberley Division, and which contains plug-like intrusives associated with much breccia. The igneous material in these intrusives has been classified by Wade & Prider (1940) and others as nephelinite in contrast to the more basic Kimberlite which contains the diamonds of South Africa, but it is by no means certain that a complete study of the intrusive plugs of the Kimberley, Western Australia, has been made. Perhaps some of the Nullagine basins also offer possibilities for the occurrence of diamonds.

The Kimberlite pipes of South Africa contain breccia associated with ultra-basic dykes or plugs. The favourable ground is characterised by the occurrence of chrome diopside, ilmenite and pink garnet.

It is doubtful whether Australia has been adequately prospected for diamonds and possibly the Kimberley oil parties should collect a good suite of specimens from the plugs.

Diamond prospecting requires a few special techniques and special equipment which are adequately described in text books on the diamond mines of South Africa.

The Orange River deposits which are now owned by the Government are of course extensive alluvial and beach occurrences. The first geologist to recognize their possibilities was Merensky to whom the Government granted 100 claims, each about 15 ft. by 30 ft. He was not permitted to peg any more ground which was simply appropriated by the Government.

THORIUM.

An apparently important deposit of monazite was discovered just prior to my visit to South Africa. The ore is said to contain about 50 per cent monazite and fills a shear in granitic gneiss. Dr. Haughton of the Atomic Energy Commission indicated that about 100,000 tons of monazite had been outlined and that the deposit was to be exploited by a large mining company which expected to obtain £100 (South African) per ton of monazite. Specimens of the ore seen by me were virtually pure monazite.

STEEL.

A steel plant has been erected at Pretoria and it is expected shortly to produce approximately 1,000,000 tons of steel per year.

COAL.

Supplies of coal are obtained from the Karoo (Permo-Carboniferous) near Pretoria but much of it is non-coking. This coal is blended with good coking coal obtained from Natal.

NORTHERN RHODESIA.

GENERAL

I flew from Johannesburg to Ndola, Northern Rhodesia, and was met there by a representative of the Roan Antelope Mine which is one of a group controlled by Selection Trust, London. The mine is managed by Mr. J. Thompson. The Mill Superintendent is Mr. Goldick, an Australian. Geological study is under the gene ral supervision of Mr. W. Garlick, Consulting Geologist, Selection Trust, and Mr. J.J. Brummer, Chief Geologist, Selection Trust. Two resident geologists look after the general mapping of the Roan mine.

Garlick is about 42 and Brummer 35. They head the exploration organization of Rhodesia Selection Trust which is engaged in an extensive survey for new deposits. Their organization consists of approximately 30 geologists at present and it is intended to increase the staff to 60. In line with the age of the top men, most of the rest of the staff are quite young and have not had a great amount of experience. Neither Brummer nor Garlick have had any experience to speak of outside Rhodesia but nevertheless they know this country and its geology very well and appear to me to be carrying out a very keen search.

The field staff spend virtually the whole year in the field and receive their leave every three years. Engagements are on a three yearly basis. Geologists are paid £110 per month plus a copper bonus (up to 60% of salary).

Bancroft, who directed much of the pioneer investigations in Rhodesia, had most of the country covered by traverses at ½ mile intervals. Rhodesian Selection Trust is now covering the country by traverses spaced 1,000 feet apart, the basic survey control being established by theodolite and the remainder being filled in by tape and compass. Pegs are put in every 200 feet and S.P. Stations are

established every 50 feet. The geologist walks along the line of traverses while 3 to 4 "hammer" boys range out on either side of the traverse line looking for outcrops. The rocks collected by the "hammer" boys are brought to the geologist for determination. A large proportion of the country is covered by air photographs but as much of it is ~~over~~ a peneplain with deep soil cover and intensive vegetation, only a comparatively small amount of information is obtained from the photographs as compared, for example, with the information which can be obtained from the air photographs of the more arid regions of Australia. However, the photographs are still extremely useful, and by showing up vegetation patterns for example, they are of considerable assistance in interpreting ~~of~~ results from the traverses. It is found that different tree patterns occur on different formations and this knowledge is widely used. Over the mineralisation, vegetation is commonly relatively sparse, the sparse areas being referred to as "clearings".

An individual party usually consists of one surveyor, two geologists, two geophysicists and three instrument observers. Pitting and geochemical investigation follow the work of the geologists and geophysicists, The surveyors usually move ahead of the geologist and have the base maps constructed for his use. It costs about £20,000 per annum to maintain a party of this type in the field.

Mapping scales are 1 : 2,000 for regional work. Mine working plans are 1 :500 and 1 :200. At present 4 drills are in operation. They average about 400 ft. per month - similar to results at Rum Jungle. Core recovery is poor.

Once the geologist establishes the approximate stratigraphical position of key formations, pits are sunk at 1,000 ft. intervals along the strike and at 50 ft. intervals across the strike. These pits which are approximately 30 inches in diameter, are put down by hand by the African natives and remain accessible for indefinite periods. Pitting is necessary on account of the extensive lateritization, soil cover and deep weathering which will be discussed more fully below.

Some geophysical prospecting has been employed in Rhodesia to test for bodies of sulphides and geochemical prospecting, first suggested to the Rhodesia Selection Trust by this Bureau, is being used extensively. The laboratory for this purpose has been established at Mufulira.

GENERAL GEOLOGY.:

The general geology of Rhodesia has been described by D.M. Davidson (1931), Anton Gray (1930), and recently by Garlick and Brummer (1951). There is still considerable disagreement on the classification of stratigraphy and readers interested in going into this matter further are referred to these papers.

A typical section at the Roan Antelope Mine, Luanshya, is shown on the accompanying figure.

At the base occurs the Muva Schist which consists of black quartz-biotite schist, crystalline schists and quartzites. This basement complex is contorted and is intruded by granite. All investigators prior to Garlick and Brummer considered that this granite also intruded the overlying Lower Roan which contains the most important ore deposits, but these two authors consider that they have established that the Roan rests unconformably on the eroded surface of the granite. In the Roan Antelope Mine, I observed numerous felspathic (pegmatite) dykes within the Lower Roan, but these are considered by Garlick to be due to metamorphism, which seems probable (to me). However, Garlick thinks the dykes quite unrelated to the ore. But within the granite, which in part forms the footwall of the Roan orebody, I observed foliation planes parallel with the bedding of the Lower Roan. This suggested to me that the granite may be younger than the Roan, a view taken by investigators prior to Garlick.

On top of the Muva Schist there is an unconformity and above this are 100-350 ft. of rocks known as footwall quartzites, because they generally form the footwall of the beds carrying ore at the Roan Mine. They constitute the oldest formation of the Lower Roan. These rocks consist of conglomerates, arenaceous and argillaceous quartzites, as well as re-crystallized felspathic quartites.

The rocks are characteristically cross-bedded and appear to be of aeolian origin; the crossbedding is used to determine the direction of the shore lines. The upper most (hanging wall) conglomerate is used as a marker bed; the lowest is the basal conglomerate which rests conformably on the basement schist.

Reaction rims occur in the conglomerates. Above the footwall quartzite occurs argillite which carries the ore in the Roan mine. It is 50-75 ft. in thickness and consists essentially of dark grey, fine-grained argillite with sandy particles. The base of the formation is described as black micaceous schist.

Above this is a thickness of 150-250 ft. of sediments known as the hangingwall quartzites. These consist of dark grey-black fine-grained compact quartzites and siliceous shale interbedded with fine-to coarse-grained white to buff felspathic quartzites which are lenticular and cross-bedded.

The next formation is called the green shale and dolomite which is 25-50 ft. thick. It is a fine-grained calcareous shale at the top, passing into schistose talcose dolomite. At the b ase, a chert breccia may occur.

Above this is 400-500 ft. of arkose and arkosic quartzite. It is generally pink in colour and is massive. There are some fine or medium sandstones and thin bands of silty shale. Ripple marking is common. This is the top of the Lower Roan which is also known as the Mine Series and is considered to be equivalent to Serie Des Mines which carries the important copper,cobalt and uranium ore deposits in the Belgian Congo.

The Upper Roan, which rests conformably upon the Mine Series or Lower Roan, is divided into two formations, the bottom one being approximately 100 ft. thick and consisting of calcareous shale and sandstone. The shales are described as dark grey and green and are poorly sorted. They are inter-bedded with fine sandstone and in places contain copper oxides.

Above the calcareous shale is a thickness of 200-300 ft. of dolomitic limestone consisting of red, white and blue rock which is in places altered to serpentine.

calcareous shales and fine sandstones. It contains pyrite in some places.

Overlying the Upper Roan Group is the Mwashia Group (banded carbonaceous and pyritic shales), which is again overlain by the Kundulungu Series - a name derived from the Congo. Tillite is found both in Rhodesia and in the Congo. An important formation in this formation in the Kundulungu is the Kakontwe limestone, which contains pyrite and also disseminated galena. In the Congo, it contains the famous Kepushi mine near Elizabethville, which produces 1 million tons of ore annually yielding 10% Cu and 15% Zn.

Maps showing the distribution of these formations in the Roan Antelope-Muliashi districts and also a general map of Northern Rhodesia are attached at the end of this report.

There is no stratigraphic break from the Lower Roan to the Upper Kundulungu. A folding movement, The Lufira Orogeny, occurred at the end of the Kundulungu.

Such uranium-lead determinations as have been made indicate that, in age, the Lower Roan, the Serie Des Mines of the Congo and the Witwatersrand of South Africa are all of much the same age. These rock groups are all of Pre-Cambrian age, hence there is no fossil evidence. In the Congo, the Lower Roan (Serie De Mines) is more calcareous than in Rhodesia.

The Lower Roan Group which contains all the important ore deposits in Rhodesia is considered by Garlick and Brummer to have been deposited in comparatively shallow seas, and at the Roan Mine at least the ore deposition is considered to have taken place close to a shore line. Some evidence for this is considered to be the occurrence of cross-bedded aeolian sandstones, the presence of the arkosic material, and the manner in which the mineralization is controlled by lithology. The climatic conditions were believed to be semi-arid in type, and some evidence for this exists in the presence of casts after anhydrite. Arkosic crossbedded sandstones of epicontinental (Red Bed) type carry copper in the Permiam and Mesozoic sediments of Russia and in South Western U.S.A.(Bastin 193

There is considerable evidence of slumping in the beds at Roan and Mufulira and it is believed that this could also occur on a shelf. Photographs showing some of this evidence are attached.

ORE GEOLOGY.

Primary Mineralizarion - Genesis

The primary mineralization in Rhodesia in general consists of chalcocite, bornite, chalcopyrite and pyrite with some carrollite (cobalt-copper sulphide) linnaeite and uraninite. The grain size of the copper minerals is commonly in proportion to the grain-size of the rocks. In places, however, aggregations of metallic minerals, believed to be due to metamorphism, are found. Fine particles of chalcocite in shale are difficult to detect, even if the ore assays up to 5% Cu. Specularite is common in beds close to the ore zone.

Garlick considers that these minerals, at least at the Roan Antelope, are arranged in a zonal pattern which is illustrated in the accompanying diagram. This pattern, according to Garlick's idea, corresponds with the deposition of the various sulphides by H_2S under sapropelic conditions and hence he believes that the ore is syngenetic. The syngenetic idea was anticipated by Hans Schneiderhohn who considered that this was likely when he visited Africa during the International Geological Congress of 19 . However, the idea is strongly opposed by men like Anton Gray and Bancroft who both spent many years in Rhodesia and found much ore for their respective companies.

In my opinion Garlick may be at least partly right, the evidence being the general lack of gangue minerals such as quartz and carbonates; the disseminated nature of the ore; the presence of chalcocite to depths of 2,000 to 3,000 ft; the scarcity of pyrite; the strict lithological control of the ore deposition and the apparent lack of relationship of ore deposition to present structure (this point is disputed by Anton Gray). Another point which in my opinion may be significant is the metal association - copper-cobalt-uranium. This association is not characteristic of ore deposits concentrated under magmatic conditions and the association copper-uranium is characteristic of areas such as the Colorado Plateau which appears to be essentially syngenetic in type.

The cross-bedded arkosic sediments are related to the occurrence of possibly syngenetic copper in Russia and in South Western United States.

The metal association copper-uranium is, of course, also characteristic of the Rum Jungle field in which the concentration of ore appears to be clearly related to granite. Nevertheless, it is considered that there may be a syngenetic component in the Rum Jungle-Brocks Creek district and the work so far carried out in these two areas suggested that there is a marked relationship between the black slate group and ore occurrence. Much of the mineralization found in the Brocks Creek area is of a pyritic type which when interpreted in the light of Garlick's hypothesis may have significance. This also applies to the pyritic sandstones found near Dysons deposit and to the hematite-bearing quartzites which are still lower in the sequence at Rum Jungle.

Garlick's sequence is as follows:

1) Near the shore line occur sandstones and shales, barren of sulphides.
2) In the absence of acid - i.e. under reducing conditions, the uranium zone is developed.
3) Entering the stagnant water zone the shales contain disseminated chalcocite and bornite and also a small amount of bismuth.
4) Bornite with higher bismuth content.
5) The cobalt zone appears with chalcopyrite; in addition to carrollite some bornite occurs as well as sphalerite (at Chambishi and Mufulira).
6) Further from the shore bornite diminishes leaving chalcopyrite and bornite dominant.
7) Pyrite appears and chalcopyrite diminishes.
8) The deepest and most extensive zone contains mainly pyrite.

Oxidation and Leaching

A very complete removal of copper and cobalt together with leaching and alternation of the country rock extends to a depth of 200 feet although present water table is commonl y at 40 to 50 ft. below the surface. The deep weathering is possibly connected with the Miocene lateritization which is wide-spread. Removal of copper from outcrops is also believed to be related to the occurrence of arid climate (as in S.W. United States) and it is possible that deep weathering in Rhodesia is related to the desert climate,

which produced the fossil Khalahari Desert which is now being covered by tree growth. In place there is an enrichment of uranium in the ferruginous zone of the laterite, a fact which could probably be utilized in airborne scintillometer surveys.

As is known in a general way, outcrops of the copper-bearing lodes are either non existent or extremely uninteresting-looking, taken as a whole. At the Mufulira Mine where the ore is mainly in quartzite and greywacke, virtually no copper is seen at the surface. It is well-established in Rhodesia that the coarser grained rocks are more completely leached. The presence of copper-bearing lodes at Mufulira was suspected owing to the occurrence of copper-bearing springs, near Mufulira Stream, which has cut down through the old Miocene peneplain. It is in the vicinity of these modern streams, which result from a new cycle of erosion, that the copper-bearing outcrops or other signs of copper mineralization are usually found. This may also be the case in the Rum Jungle district, Northern Territory.

Geochemical testing has shown that at Baluba, 0.05% cobalt and 0.1% copper found at a depths of 30 to 50 ft. below the surface represent primary ore containing 0.20% cobalt and 3.5% copper. The copper and cobalt are in the form of black oxides which are sufficiently similar to manganese or iron oxides in appearance as to enable them to be missed if geochemical testing is not carried out. These black oxides appear to be typical products of weathering in a non-calcareous environment under tropical conditions. Minerals found have the appearance of black wad which contains copper, cobalt and manganese. A common secondary cobalt mineral is heterogenite which is black and sometimes nodular; occasionally pink staining is associated with this black material.

A geochemical indication of 1 unit intensity in quartzite is more important than one of 20 units intensity in dolomite.

MINES

Typical mines visited are briefly described below -

Mufulira.

The following are some salient features of the Mufulira Mine controlled by Rhodesian Selection Trust.

The ore occurs as a replacement of quartzite and greywacke in contrast to the finer-grained Roan shale which is mined at the Roan Mine, Lunanshya. Possibly on account of the coarse texture of the rock, surface leaching at Mufulira was virtually complete although faint copper stains can be seen in places in the sparse outcrop of the ore-bearing quartzite. This is especially so when the quartzites are broken up.

Ore occurs in three beds which have been called the A, B, and C orebodies respectively. In the past these deposits have been mined separately, and maximum mining width has been 120 ft. Preparation is now being made to mine the three orebodies in one caving operation which will result in mining widths of 200 ft.

The grade of ore mined in the past has been 3.3 per cent but an increased width of mining will result in a grade of approximately 2.8 per cent. In 1950-51, 3,355,143 tons of ore were mined of an average grade of 3.3 per cent Cu. There is a small amount of cobalt in this ore but it is not recovered at the present time.

The mine yields 20-35 tons of ore per foot of driving and the production per man-shift, including Africans, is 2.28 tons. There are ten or eleven Africans for each European and African wages average one twelfth of European rate. Mining costs per ton in 1949-50 were 10.74 shillings.

The ore from a number of shafts is transported by conveyor belt to a mill where it is ground and treated by flotation. Smelting and refining are carried out on the property.

Roan Antelope Mine.

It is estimated that, during 1952, this mine will produce 4,679,698 tons of ore averaging 3.3 per cent Cu. Mining is by caving and is generally comparable to that outlined above for Mufulira.

The main ore minerals are chalcopyrite, chalcocite and bornite, most of the chalcocite being considered primary and

Section of Mine	Cu	Fe	P	Bi	Cu	Ni	Pb	Te	Se	As.
E.End	40.49	7.1	15.4	0.010	0.004	0.004	0.007	Tr	0.003	0.001
W.End	42.89	16.0	23.8	0.018	0.018	0.002	0.014	Tr	0.005	0.052
Roan Ext.	36.69	17.8	23.2	0.019	0.020	0.004	0.013	Tr	0.003	0.002

being shiny in appearance, the secondary chalcocite is of the sooty type. Small amounts of carrollite ($CuCo_2S_4$) and linnalite (Co_3S_4) are also present but the amount of cobalt is small, as shown by the following analysis of concentrates.

ANALYSIS

The Roan ore occurs in shale, specimens of which from both the oxidised and sulphide zone, were procured and are available in Canberra. Even the primary disseminated chalcocite ore is difficult to recognize as such, and the leached material contains no visible copper. Limonite casts of the type described by Blanchard are not visible to the unaided eye, though stains of limonite along bedding and cleavage planes may be seen in some places.

These remarks apply to the largest proportion of the Roan ore-bearing beds. However, malachite staining occurred in some places, a fact known to hunters and explorers prior to the geological investigation of the country. It was this fact which led to the careful examination and drilling of the deposit.

The accompanying plans and sections (Plate) illustrate the geology of the mine. Early investigators considered that the granite shown in the footwall was intrusive into the Roan formations which carry the ore, but Garlick and Brummer consider that the Roan beds rest unconformably on the granite. This point was discussed under general geology.

Nkana Mine (Rhokana Corporation)

The locality of this as well as the other principal mines of Rhodesia is shown on the accompanying geological map.

This mine produces 10,000 tons of ore per day containing approximately 3.0 per cent. Cu and 0.2 per cent Co. An extension of the orebody (Mindola) contains coarsely crystalline uraninite and will produce some uranium.

Mining is by caving methods and treatment is by standard flotation, smelting and subsequent refining. Rhokna Corporation is making preparations to produce cobalt which is widely disseminated in the ore in the form of carrollite and linnaeite,

but the usual method of cobalt extraction is by sulphuric acid leaching, and it is difficult to amalgamate this process with the present mill flow-sheet.

From the prospecting point of view Nkana was very interesting to me because the outcrop is very similar in size and type to that of Rum Jungle, Northern Territory, consisting as it does of graphitic schist lightly stained with copper carbonates. Thus, the only known copper-bearing outcrop is approximately 100 ft. in length and up to 20 ft. in width and occurs near a stream which has cut down th rough the old Miocene (?) peneplain level. Several kodachromes of this outcrop are available for inspection. No uranium minerals are seen in the outcrop and no uranium-bearing outcrop is found over the Mindola section of the deposit.

The Rhokana Corporation drills along the strike at 1,000 ft. intervals and carries out test pitting at 500 ft. intervals. The test pits are commonly 50 ft. apart and extend from 30 to 70 ft. in depth. It is sometimes necessary to extend the pits to 50-60 ft. in depth in order to find 0.10 per cent. Cu in the form of black oxides (which are inconspicuous) and this material may overlie ore containing from 2.5 to 5.5 per cent Cu.

Dr. Terrence Guernsey is the Chief Geologist of this mine and is a very charming and experienced man who worked for many years with Bancroft carrying out exploration for copper in Rhodesia. He was also associated with B.B.Brock in this work. Brock, in his capacity as Consulting Geologist to Anglo-American Corporation, is also Consultant to this mine.

Guernsey stated that weathering at Nkana usually extends to 200 ft. although at present water table is only 40-50 ft. and he suggested that this type of weathering was connected with the period during which the Kalahari Desert was formed. This Desert is now covered with a growth of trees and is in fact a fossil desert.

Guernsey showed me some oxidised copper minerals obtained from a depth of 2,000ft. which, he is quite definite, are pre-mine in age and were formed, he believes, by oxidizing waters circulating in channelways during the dry period. The oxidized minerals are commonly carbonates.

Baluba

This deposit was being prospected at the time of my visit and geo-chemical means were being used to test the suspected ore-bearing beds. It was found that material containing 0.05 per cent Co. and 0.1 per cent Cu respectively corresponded to primary ore containing 0.2 per cent Co and 3.5 per cent Cu. In the pits, it is common to find a black wad which contains Co. Mn and Cu. Some of the cobalt is present as the cobalt-nickel mineral siegenite. The black botryoidal mineral heterogenite (oxide of cobalt) is also found in some places.

Specimens of these minerals are available for inspection.

BELGIAN CONGO.

From Ndola I flew to Elizabethville, Belgian Congo, and arrived on 28/7/52. I had previously contacted Mr. H. Schuiling, Chief Geologist of the Union Miniere du Haute Katanga, the Company which controls the mining and mineral resources of the Congo, and he had arranged for my reception at Elizabethville and to be shown the Kipushi Mine which is about 30 miles from Elizabethville.

KIPUSHI.

As stated in the section on Rhodesia, the Kipushi ore deposit occurs in the Kakontwe Limestone which is a part of the Kundulungu "Series" in the upper part of the Katanga System. (The other important mines of the Congo occur in the lower Katanga System the Series des Mines).

The Kipushi ore deposit is a solid mass of sulphides occurring by replacement of the limestone near its faulted junction with shale. It is approximately 400 metres long and varies from 30 - 60 metres in width. The ore averages 10 per cent Cu, 15 per cent Zn, 1 to 1.5 per cent Pb, and 300 gms. Ag per ton. Production is 1,million tons of ore per year which yields 100,000 tons of copper and 120,000 tons of zinc. The ore is extremely interesting and rather unusual in that the copper is largely present as a bornite which contains about 6 per cent germanium. This germanium-bearing bornite is known as renierite. (Vaes, 1948).

Renierite which was named by Vaes used to be called orange bornite and is something like germanite in composition. It normally contains about:

41.5	Cu
13.8	Fe
6.8	Ge
3.5	Zn
0.95	As
31.85	S

Some specimens contain a trace of gallium and up to 0.61 per cent Sn. It was formerly thought that the silver which occurs in the ore was within the lattices of the bornite but spectrographic analyses indicated that this is not the case. A specimen of renierite is held in Canberra.

Mining at Kipushi is by top slicing and native labour is used almost exclusively. Owing to the autocombustion of the ore, there have been several fires in this mine and the large amount of timber which is used in the top slicing process makes them particularly dangerous. The Company has installed a very powerful electric pumping unit on the 550 metre level which is sealed off from the rest of the mine; when fires occur the mine is flooded and the pumps are able to de-water the mine again in a very short period of time.

The concentrate from Kipushi is smelted and refined at a plant situated about 10 miles from the mine between Kipushi and Elizabethville.

The Kipushi deposit is one of the richest in the world and must yield a very handsome profit. Belgian geologists have been searching for repetitions and their studies suggest that if repetitions do occur, they might be within Northern Rhodesia as the International Border line is very close to this mine. The Union Miniere's concession is confined to the Congo.

JADOTVILLE.

From Elizabethville, the capital of the Katanga region, I went by car to Jadotville which is purely a mining town and is the operating headquarters of the mining company. Many mining areas such as Kambove, Fungurume and Kolwezi were administered from this centre, but a new town is now being built at Kolwezi.

Copper-Cobalt Plant.

In Jadotville I made an inspection of the copper-cobalt treatment plant, known as Usines de Shituru, in which about 100,000 tons of copper and 4,000 tons of cobalt are being produced annually by combined leaching and electrolytic refining. This plant is designed to treat oxidised copper-cobalt ores and it is understood that it is unique in the world.

Copper-cobalt concentrates produced by washing plants situated at the mines are sent here via the electric railways. Sulphuric acid, manufactured at Jadotville from sulphide concentrates, is used to leach the ore in large lead-lined vats and to produce copper sulphate and cobalt sulphate.

This solution process is comparatively simple, but the separation of the cobalt from the copper within the sulphate solutions involves quite a long process which depends essentially on the relative position of copper and cobalt in the electro-motive series.

The copper is electrolytically refined and poured into shapes, wire bars and ingot bars. The cobalt is refined in an electric furnace and is sold in granules sealed in steel drums. Very high-grade products are produced from the refinery.

It is interesting that very few white men are seen on the job. N early all the operations are carried out by the African natives, and the control exercised by the Belgian engineers is unobtrusive. The engineers express themselves as being completely satisfied with the African labour.

The Jadotville sulphuric acid plant produces acid for the leaching of uranium ores at Shinkolobwe which is about 30 miles away.

Geological Laboratories.

At Jadotville, Mr. Schuiling, Chief Geologist of the company, has his headquarters, which are housed in a fine set of offices, laboratories, and museums. He has charge of the private museum of the company which contains probably the finest collection of African minerals in the world. The museum is a beautiful modern building which is equipped with fine show-cases, ultra-violet light etc., and contains only choice specimens.

There is also a large laboratory and museum in which Dr. J.S. Vaes works and where he has a very large collection of rough mineral specimens which he feels will be of great interest to universities and museums throughout the world after the present security blanket is lifted. Vaes is a first-class mineralogist and gave me the following spot tests:

1) Uranium: This is a micro-chemical test.
Dissolve mineral in HCl, dry, add drop of H_2O and pinch of sodium acetate which produces sodium uranium acetate which is a perfect tetrhedron and can be readily recognised under the microscope.

2) Cobalt: This test requires a concentrated solution.
Take a gramme of the mineral, dissolve in HCl, dry completely, add a drop of H_2O, add Hg(NH4) CnS. This produces beautiful blue crystals which can readily be recognised under the microscope. (To make this reagent take 30 grammes of mercuric chloride, 33 grammes ammonium sulpho-cyanide, 50 c.c. water. This will produce enough reagent for many tests.)

GEOLOGY OF KATANGA.

A good summary of the stratigraphy of Katanga, especially in its relation to ore occurrences, is given by Oosterbosh and Schuiling (1951), to whom the interested reader is referred. As already stated, there is a close relationship between the geology of the Congo and that of Rhodesia and the copper-cobalt belt which occurs in the two countries is virtually a geological unit. The classification of rock groups given on the geological map of the copper belt, Northern Rhodesia, (accompanying this report) is therefore relevant to the Congo.

Oosterbosh and Schuiling divided the cupriferous "Katanga System" as follows (from top to bottom):

Kundulungu series (or system) includes Kakontwe limestone	3,000 m
Large conglomerate of Kundulungu (tillite) down to	300 m
Dolomitic shale series (position of base unknown in the centre of the basin). Includes:	
An upper series of Mwashya series	100 to 500 m
A lower series or Mine Series.	

It is the "Series Des Mines" (S.D.M.) which contains the copper-cobalt mineralization and this is divided up as follows:

Dolomitic limestones, called "black ore limestones" (C.M.N.)	70 m
Dolomitic shales (S.D.)	120 m
Siliceous dolomites, partly organogenic (algae), massive, or coarse texture, called "cellular siliceous rocks" from the character of the weathered surface (R.S.C.)	20 m
Laminated siliceous dolomites, called "laminated siliceous rocks" (R.S.F.)	5 m
Stratified dolomites, microgranitic, called "stratified argillotalcose rocks" on account of the surface alteration (R.A.T.)	3.50 m
Dolomite chlorite arenaceous shale, called "gray argillotalcose rocks".	0.20 m

In practice, prospecting in the Congo is greatly assisted by the fact that the siliceous dolomite (R.S.C. - which contains collenia) is resistent to weathering and forms prominent hills. The formations immediately above and below this rock, which are known as the "schistes dolomitique" (dolomitic shales without much schisting) and the thinly stratified dolomites (R.S.F.) contain most of the ore. The "Series des mines" corresponds in age to the Lower Roan of Rhodesia but they are much more dolomitic in facies than is the Lower Roan.

The present structure of the SDM in the Congo is complicated because these rocks have commonly been thrust over the top of the younger Kundulungu and have travelled for many miles over these formations. The ore deposits commonly have no roots below the thrust plane. It is very common for the beds to be completely overturned and for very considerable faulting to occur. These facts complicate drilling and prospecting in general.

MINERALIZATION.

At the surface, some staining at least by copper carbonates is commonly present, probably owing to the neutralizing effect of the carbonate rocks.

In some places, large amounts of malachite may be found and deposits of this type were worked in ancient times by Africans who smelted the ore and produced copper pots and other cooking utensils. The first geologists to visit the Congo thus had quite promising

showings to inspect in contrast to those who worked in Rhodesia.

There is generally not much copper enrichment at the surface but there is a considerable amount of cobalt enrichment. The cobalt mostly occurs as the black oxide, heterogenite, but in some places the pink mineral spherocobaltite is found. Specimens of these two minerals are available for inspection. Quite extensive incrustations of these minerals may occur.

At Fungarume a considerable amount of cobalt ore containing 7 to 8 per cent Co was found at the surface. The primary ore normally contains about 0.3 per cent Co. The average grade of the secondary cobalt ore is estimated to be 1.3 per cent Co.

Commonly, of course, the cobalt minerals merely form thin black streaks within the orebody and these are very difficult to detect. The geochemical test noted is useful in this connection.

Although copper is commonly present in the outcrops of deposits, this is not universal and at Ruwe, to be mentioned below, virtually no copper occurred at the surface and the deposit was found owing to the geological deductions of Schuiling. In numerous other deposits also the full extent and significance of the mineralization would hardly be suspected from the surface showings.

Throughout a large proportion of the mines of the Congo, the primary copper mineral is chalcocite, which is known to extend to depths of 2,000 ft. and is not related in any way to the present surface. Cobalt commonly occurs in the mineral carrollite which contains 17 per cent Co and 37 per cent Cu. A notable feature is that very little pyrite is present; this is characteristic of Rhodesia also, and is a common feature of many ore deposits which have a syngenetic aspect (Bastin 1933) (B). Chalcopyrite and bournonite are found but are not as important as ore minerals as is chalcocite. The chalcocite-chalcopyrite-uraninite association with low pyrite is somewhat reminiscent of Rum Jungle.

Gangue minerals such as introduced quartz or introduced carbonates are not common, and the ore can be described as a cupriferous and cobaltiferous dolomitic shale. In this respect (apart from the dolomitic nature of the beds) it is similar to the ore of Rhodesia.

Origin of Mineralization

Oosterboch and Schuiling (1951), in the authoritative paper quoted, gave an interesting discussion on the origin of mineralization and concluded that the ore is probably of epi-genetic origin although they recognize the possible syngenetic origin. I am inclined to agree with Garlick that there is at least a syngenetic factor in the genesis of the ore, although there may have been some concentration by metamorphic processes; in the case of Schinkobwe, which, although in the SDM, is in veins, there must have been concentration of some type. Points which in my opinion suggestion a syngenetic factor are:

(1) Stratified nature of the deposits

(2) Uniformity in nature of mineralization, over long horizontal and vertical range

(3) Size of deposits. The deposits are more reminiscent of sedimentary iron ores than of epigenetic copper ores. It seems likely from the evidence I gathered that 1,000 million tons of ore have already been outlined by drilling and further ore may occur.

(4) General absence of gangue minerals. The ore is simply cupiferous and cobaltiferous shale.

(5) Mineralization is pre-thrusting in age and is not related to structure.

(6) Pyrite content is low which is characteristic of syngenetic conditions.

(7) Chalcocite is the main ore mineral and extends to depths of thousands of feet. Chalcocite cannot be related to the present surface any more than it can in Rhodesia, and it is not a product of oxidation and secondary deposition as is normal in epigenetic veins. Chalcocite is commonly a cold water mineral and is characteristic of syngenetic deposits, for example in the Red Bed sequence in Russia and in the south-west United States.

(8) The metal association - a point which is not normally discussed in this connection - is not characteristic of epigenetic conditions. The normal epigenetic copper deposit contains little cobalt which is not associated with granitic activity,

although copper is. Epigenetic cobalt is associated with basic igneous rocks e.g. in Queensland and in Ontario.

Uranium, which occurs sporadically throughout Rhodesia, and is also present in the SDM of the Congo, leads to suspicion regarding the epigenetic origin of the ores. For example, in Colorado, Utah, and New Mexico, copper deposition with which uranium is associated occurs in certain Permian and Mesozoic formations; vanadium is also present in many places. The weight of evidence suggests a syngenetic origin for this ore and this origin has generally been suggested for the somewhat similar deposits in the Permian of Russia. The presence of metal vanadium strongly supports this for although there is much vanadium in the earth's crust, magmatic processes do not lead to the concentration of vanadium because vanadium forms rock-forming minerals and has a low affinity for sulphur. For these reasons it is not commonly concentrated in ore deposits by magmatic processes and in spite of its wide-spread occurrence in the crust it is a very expensive metal. Similarly, ordinary epigenetic copper deposits do not normally contain much uranium.

We know, however, that in some deposits which have apparently been concentrated in association with granitization and granitic processes, uranium and copper occur. It is suspected that in these cases, for example Rum Jungle, there has been a prior concentration of copper and uranium by syngenetic processes and a later concentration by granitization processes. In these types of deposits there tends to be a marked stratigraphic control and an association with a certain type of sedimentation, that is, sedimentation close to a shore line and/or sedimentation of an epicontinental type. There is generally evidence that the deposition has taken place under comparatively arid conditions leading to the accumulation of redbeds and the deposition of evaporite deposits such as gypsum. Some of the uranium-bearing beds in the Triassic of Colorado have been traced laterally into gypsiferous deposits and gypsium is widely associated with the ore in that region.

There is commonly an association between the occurrence of greywacke and syngenetic copper deposits as in Rhodesia and southwest U.S. and the development of greywackes implies the existence of an arid climate which did not permit the deep weathering of

felspars but which permitted rapid deposition of erosion products by flooding.

If, as seems to be established, the Belgian Congo ore is pre-thrusting in age, then the ore deposits now found are simply random samples - remnants resulting from erosion of thrust flakes, and the main ore deposit of which these are the samples should occur underneath the thrust plane and under the Kundelungu. If this is true very large ore deposits may eventually be found in the Southern Congo and in Northern Rhodesia buried underneath the Kundelungu and a programme somewhat similar to that undertaken in South Africa would be well warranted. Judging from the size of the samples (1,000 million tons (?)), the main ore deposit could be substantial.

MINES OF KOLWEZI AREA.

Of the numerous deposits in this region, most of which have been geologically mapped and drilled, only two important deposits - those of Musonoi and Ruwe - are being actively mined and these were inspected at some length and numerous photographs of the ore occurrences and of the open cuts themselves were taken.

Musonoi.

At Musonoi oxidized (carbonate) copper ore occurring in the dolomitic shale and in the banded dolomite (R.S.F.) is being open cut. One million tons of rock are removed per month of which at present 10 per cent is ore. The ratio of ore to overburden will increase shortly.

The oxidized ore averages 7 per cent Cu and 0.3 per cent Co. As the cobalt ore is worth about fifteen times as much as copper, the ore may be considered as being equivalent in grade to about 12 per cent copper.

Mining is typical of the American open pit method and, in fact, the mining method was originally installed by American engineers. Six-cubic-yard electric shovels and 20-ton trucks (Euclid) are the basic equipment.

From the kodachromes it can be seen that the dolomitic shales carrying the ore are not very schisted and in most places have the appearance of being comparatively undisturbed by folding. However, the regional geological study shows that these beds have been

overturned and have probably been thrust for many miles.

All the mining is carried out by Africans but is, of course, under fairly close supervision by European engineers and foremen.

The ore is being produced 24 hours per day, partly because this is perhaps the most important cobalt mine in the world and cobalt is a metal of strategic importance. On each shift there are 60 natives and 2 white men.

Ruwe.

Ruwe is a most interesting deposit as there was no copper-bearing outcrop. I n cross-section the deposit is basin shaped with the S.D.M. resting on a thrust plane which is underlain by the younger Kundelungu rocks. During the thrusting the R.A.T. (base of S.D.M.), was highly brecciated near the thrust plane and surface waters carrying copper have percolated down into this brecciated rock, forming an extensive deposit of malachite.

Malachite is commonly found in lumps ranging from a few ounces to 20-30 pounds in weight. It is probable that the copper in this secondary deposit has been derived from the disseminated ore normally occurring the S.D.M. which has now been leached out. Schuiling suspected that this deposit might be present because copper-bearing springs were known to issue from the region near Ruwe which is topographically lower than the Ruwe deposit.

A small amount of gold occurred near the surface in the R.S.F. at Ruwe but, as stated above, copper showings were very sparce. Schuiling followed down the flat dip of the R.S.F. and found the secondary copper accumulation which has been proved by drilling to contain 18 million tons of ore.

T he accompanying photographs show that mining is carried out here using shovels and electric trains running along successive benches. The mining system is nearly identical with that originally worked out in the Bingham Canyon Mine in Utah, and is, in fact, reported to have been installed by an engineer from that mine. The system appears to run very smoothly and is now entirely supervised by Belgian engineers, the labour being African.

From the open pit at Ruwe the ore is hauled about half a mile to a washing plant. Here the loaded cars are hydraulically

tipped into the concrete-lined bin from which it is washed by means of hydrants through a very neat washing plant which handles the whole mine output of approximately 120,000 tons per month, although the total labour force employed is only 8.

The ore is beneficiated to a grade of 30 per cent Cu by means of jigging. One dozen jigs are employed and are all housed in a building 150 x 120 ft. Total washing cost is about 2/- per ton. The concentrate is then sent to Jadotville for leaching by the process already briefly described.

The grade of this ore is 3-4 per cent Cu and virtually no cobalt is present. The reason for this may be that the ore has been accumulated as a result of secondary processes and any cobalt which may originally have been present in the R.S.F. has no doubt been dispersed in the solutions. Cobalt is extremely mobile in surface waters.

This operation must be highly profitable as mining and drilling costs would probably not exceed 8/- per ton to the stage of producing the 30 per cent copper concentrate.

Mupini.

In the Mupini region, near Kolwezi, extensive beds of dolomitic schist of the S.D.M. have been carefully mapped and drilled but are not being worked at the present time. These deposits contain copper carbonates at the surface, some of which occurs as masses of malachite 1 to 2 lbs. in weight. In the pre-European era, the Africans sank pits along the outcrop to depths of 5-15 ft. and gouged out these small bodies of malachite.

Kodachromes showing the typical copper staining of the outcrop are available.

The deposits occur on a hill owing to the nature of the silicified dolomite which divides the two ore-bearing beds.

Fungarume.

This deposit was visited one Sunday afternoon with Mr. Schuiling. It has been geologically mapped and extensively drilled and, as a result, about 100 million tons of ore containing in the primary zone 5-6 per cent Cu and 0.3 per cent Co have been indicated.

Much secondary ore is available containing 1.3 per cent Co, and a considerable tonnage of cobalt ore containing 5 - 7 per cent Co has already been removed by scraping the surface. No mining is proceeding at present as it is the company's policy to develop the mineral resources of the Congo at a rate which is planned to synchronize with the general development of the Colony. Capital derived from mining is used to develop roads, railways, hydro-electric power schemes, towns, schools, hospitals, etc. In accordance with this policy, Fungarume is being left for the moment but this is a very important ore deposit and its total potential is not really known.

Copper outcrops were known at Fungarume from the beginning of the settlement of the Congo by white men, but until 1942, no one had reported cobalt, although inspection of the area by Schuiling and his staff soon discovered the 5 - 7 per cent ore mentioned above. This indicates how inconspicuous cobalt mineralization can be.

In 1942 Schuiling started investigation of the deposits and carried out extensive drilling. It was proved that chalcocite and carrollite extend throughout a large portion of the S.D.M. present in this region, and that these beds have been much broken up by folding and faulting. It is almost certain that, owing to the very complicated structure, the full possibilities of the area have not yet been proved as drilling has been entirely from the surface and some of the drilling intersections appears almost fortuitous.

VISIT TO MANGANESE DEPOSITS, KASAKELESA

KALAHARI DESERT

In company with R. OosterboschI inspected a manganese deposit at Kasekelesa, concerning the importance of which the Company had not quite made up its mind. The deposits are about 80 kms. from Kolwezi and in order the reach them it was necessary to cross part of the Kalahari "Desert". This section of the so called desert is a plateau about 1500 metres above sea-level. The plateau is underlain by 50 - 60 metres of sand of aeolian origin. There is a small ferruginous laterite capping on top of the sand. An interesting feature of this "desert", is that water table is now only 5 - 10 metres below the surface in most places and some parts of the area are almost swamp-like, the water table being so close to the surface that extensive tree growth is not possible. The desert is thought to

have been developed in Oligocene time when the climate must have been much drier than at present, as mentioned in the section on Rhodesia. This dry period may have been important for the deep leaching of copper and copper-cobalt deposits.

At Kasekelesa, small deposits of manganese ore are mined at intervals over a length of 2 kms . The ore occurs close to a fault which is bounded on one side by tillite of Kundelungu age and on the other by schists of the basement (Muva) complex. The main manganese deposits appear to me to be of a secondary nature only, and consist of a sheet up to 10 ft. thick and 40 ft. wide, which has been accumulated by a combination of stream action and cementation of a lateritic type. Some of the manganese is pisolitic, suggesting laterite, but in other cases this structure is absent. Where the surface sheet has been cleared off, what are apparently fissure veins of pyrolusite, up to 2 ft. wide, are exposed. The pyrolusite is probably not primary but it seems probable that some primary manganese mineralization exists. This is suggested by the observed veins and by the association of the deposit with the fault.

About 200,000 tons of manganese ore have been extracted from the deposit and production is currently at the rate of 1,000 tons per month. The deposit is not owned by Union Miniere and is being mined largely by pick-shovel-wheelbarrow techniques with African labour (see photographs).

The Congo contains other more important deposits of manganese but it was not possible to visit these and no precise information could be obtained on reserves. The policy of the mining company in general is not to talk very much about ore reserves.

DIAMONDS.

The Congo produces 75 - 80 per cent of the world's industrial diamonds, mostly from alluvial deposits. According to one of the geologists, no diamond pipes of any importance have yet been found. I was not able to visit the diamond deposits and doubt very much whether it would have been possible to obtain permission to do this.

Just prior to my visit the President of the United States had made some cutting remarks about people restricting the production of diamonds which were vitally needed in the tooling-up programme for armament production. The Belgians are sensitive to remarks of this

type and feel it is best not to give away too much information which might provide ammunition for further criticism.

DRILLING IN THE CONGO.

In the Congo as in South Africa and Northern Rhodesia, drilling is regarded as a most important adjunct to exploration and is very carefully planned. Much attention is paid to core recovery, and, to this end, large sized holes are favoured. A hole at the surface may be as large as 12 ins. in diameter and is gradually decreased to 5 ins. at about 500 ft. (depending on conditions in individual localities). Below this it is common practice to carry on holes with a diameter of approximately 2.75 ins.

Holes are carefully surveyed and deviations up to 3 degrees in 700 metres, even with these core sizes, are common; deviations up to 10 degrees have been noted.

BELGIUM-FRANCE-NORTH AFRICA.

From Elizabethville I flew to Brussels, Belgium, where I visited the Belgian Congo Museum of which the head is M. Robert. In this building is housed very extensive mineral collections from the Congo and also material of great ethnological and anthropological interest.

I also visited M.V. Van Straelen, Director of the Royal Institute of Natural Science at Brussels, under whose supervision much scientific work in Belgium and the Congo is co-ordinated and published. He is concerned with a great deal of the work in natural science carried out in the Universities of Belgium and some of the major investigations undertaken in these institutions are published by the Institute of Natural Science.

As a matter of interest, Van Straelen was associated during the first world war with Professor David of Australia in the military geology and engineering corps of the Allied armies. Like everyone else he spoke of David with profound respect.

One gained the impression that the level of scientific research and also of applied technology in Belgium was high. During the International Congress in North Africa M. Fourmarier of Belgium was awarded the Penrose Medal by the Society of Economic Geologists for work in this branch of geology.

In Paris, I saw M. Blondel, Director of Geological Studies for the Colonies and a big force in the economic geology of France and the French Empire. We discussed our respective ways of trying to increase the mineral production of the territories in which we were interested and I gained some useful information. I also had discussions with M. Roubault, Director of Raw Material, French Atomic Energy Commission. He is also in charge at Nancy, of the Ecole Superieur Geologique at which selected students are given a course of higher studies.

Important points to be learned from French and Belgian geologists appeared to me to be :-

(1) Stratigraphical studies are always carried on during economic investigations and generally turn out to be important. We in Australia have tended too much to ignore stratigraphy.

(2) The French never accepted the German and American petrological ideas, even when these were regarded as axiomatic by much of the rest of the world. They sustained the concept of the metamorphic origin of granite for more than a century. The modern return of the concept therefore does not represent such a revolution to them as it does to other schools of geology. One sees here that the acceptance or rejection of scientific ideas depends partly on factors of place and time which are quite independent of the validity of the idea. A concept which would be widely accepted in France, might receive very little support in America, for example.

However, this was not entirely true concerning my ideas on ore genesis. The French geologists from Nancy said that I had "pushed forward the barriers of science", but H.G. Ferguson, American President of the Society of Economic Geologists also said that a paper by me (Sullivan, 1948) had first started him thinking on the subject which would form the basis of his 1953 Presidential Address, and that his researches had confirmed ~~to~~ my suggestions regarding the relationship between types of geosynclines and metalliferous provinces.

A criticism of French mining often heard is lack of enterprise. Those with money keep it and do not indulge in speculative ventures. Canadian and American companies are pioneering much of the development of French North African mineral resources, for example

NINETEENTH INTERNATIONAL GEOLOGICAL CONGRESS, 1952.

As far as I was concerned, the Congress consisted of a voyage on the ship "Champollion" - 12,000 tons - from Marseilles to Tunis - - Oran - Algiers during the period August 24th to Sept. 6th, and the formal sessions of the Congress during the period Sept. 7th to Sept. 15th, and a visit to Cellidya, Morocco, after the Congress.

EXCURSION GROSSIERS.

About 300 Congressists, from 37 nations took part in the voyage of the Champollion. It represented a very good opportunity to become acquainted with geologists with very varied training and experience. This aspect was one of the most important parts of the Congress and I have arranged to exchange papers and ideas with a large number of people.

The Champollion arrived at Tunis on August 26th and, from then on, apart from official receptions by Governors etc., the time was occupied in making motor bus traverses through French North Africa. The ship steamed between ports each night, and long excursions were made nearly every day. These excursions took place from Tunis, Bizerta, Bone, Philippeville, Bougie and Oran. In some cases, 2 or more excursions were made from the one port. The excursions though too long and very tiring, were well designed to show the Congressists representative geological sections through the country and also gave a good insight into agricultural, ethnical, transportation and other aspects of the country.

A splendid guide book, with maps and sections, prepared by Rouboult, Hilley and Sadron (in French) was supplied to all members, and, as this is attached to this report, it is not proposed to describe each excursion here.

The rocks seen were mostly Tertiary and Mesozoic in age and contain numerous fossils. The stratigraphy seems to have been well worked out by French geologists and palaeontologists, and, in fact, is not complex compared with much of the Pre-Cambrian and Palaeozoic of Australia. One sees nice layered rocks, full of marker beds and type fossils, which contrast with the complex schist belts of this country. However, one is impressed by the thoroughness of the work of the Continentals in general, in spite of the fact that the

Tunisian, Algerian and Moroccan geological services in common with those in many parts of the world, are largely staffed by comparatively inexperienced recent graduates. This has resulted from the world-wide expansion of geological surveys since the war.

The excursions were mostly designed to exhibit the regional geology, and not much attention was paid to mineral deposits. This may have been a deliberate policy as virtually the whole world was represented at the Congress.

A considerable number of Kodachromes and other photographs were taken during the various excursions through North Africa and they are available at Canberra.

FORMAL SESSIONS.

A resume' of the communications given at the Congress has been published, and it was also proposed to publish all papers given. The papers given were grouped under the general headings :-

(1) The Pre-Cambrian - Subdivisions and Correlations of
(2) The Palaeozoic of North Africa and its correlation with the Palaeozoic of other Regions of the World.
(3) Mechanics of the Reformation of Rocks; Influence on Tectonic Concepts.
(4) Submarine Topography and Present Sedimentation.
(5) The Pre-Man animals and Fossil Men.
(6) The Genesis of Dyke Rocks.
(7) Present-Day and Ancient Deserts.
(8) Hydrogeology of Arid and Sub-Arid Regions.
(9) Contributions of Geophysics to Geology.
(10) Genesis of Iron Ore Deposits.
(11) Origin of Rock Phosphate Deposits.
(12) Diverse questions of Applied Geology.
(13) Diverse questions of General Geology.
(14) The Petroleum Fields of the Mediterranean and Near-East.
(15) Palaeovolcanology and its Relationship to Tectonics.

It was, of course, impossible to attend all sessions, as many proceeded simultaneously. It was often difficult to know when a particular paper would be presented, as no strict timetable was adhered to. Generally speaking, there were too many papers,

many of which would not be accepted for publication by leading journals; in consequence, good papers were swamped in a deluge of boring trivia. This was particularly so of the last two sections.

The language difficulty was, of course, severe, as no translation facilities were available at the technical sessions. These were provided for the official business sessions only.

However, many very good papers were given, of particular interest to Australia being the papers under sections 1 (Pre-Cambrian) and 2 (Hydrogeology of arid regions). Several papers in ore genesis given under section 11 were of interest to me and I was also most intrigued to read, for the first time, R.K. Miles' Summary of the G enesis of the Iron Ores of South Australia, which he attributes to granitization of iron-bearing formations. Without having been allowed to know anything about the South Australian Deposits, I had come to the same conclusion concerning the iron deposits, which I too visited in the Lake Superior Region - an idea which was quite new to the Americans but seems to have considerable supporting evidence. It is of very considerable prospecting importance.

When sessions could not be attended, much useful information was gained in private discussion with authors of interesting papers.

This might be the place to mention the very large amount of work (and money) required for the organization of an International Geological congress. The preparation of guide books, maps and other literature must have occupied a large staff of geologists for one or two years. The French, Tunisian and Algerian Governments, along with private companies, provided about 200 million francs,- £200,000 Sterling - to assist with the finances. People who have previously organized Congresses informed me that such large expenditure was not essential, but it was certain that if a Congress was to be held in Australia, considerable financial assistance from the Government would be required. Incidentally, many foreign geologists consider that it is Australia's turn to do this and considerable pressure was exerted on me, as Official Delegate to obtain an invitation for the next Congress to be held in Australia. American and Russian geologists were especially keen; those from Eur ope were inclined to think the journey too expensive.

The following is a copy of the speech which I made as official delegate of the Commonwealth, congratulating the French in their organization of the 19th Congress.

22nd September, 1952.

On behalf of the geologists of Australia I wish to express my admiration and profound respect for the manner in which the 19th International Geological Congress has been planned and carried out.

Apart from the excellent organization of the Congress itself, one has been impressed by the very efficient work of the French geologists in North Africa, and by the high level of development of the country carried out under the French administration.

One can only hope that French geology and French North Africa will continue to prosper, a feeling which is fully shared by all Australian geologists.

(C.J.SULLIVAN)
Official Delegate
Commonwealth of Australia.

VISIT TO CELLIDGA.

After the Congress, I made a private visit to Cellidga, Morocco, where lead-zinc ore is being mined by a company which is partly French but in which the St. Joseph Lead Co. and Newmont Mining Co. of America are interested.

Ore occurs in limestone of Liassic age, the deposits being similar in type to those of the Tri-State and S.E.Missouri areas of U.S.A. and to those of Tunisia. The French geologists consider that the localization of the field is controlled by large faults, though they occur only within certain formations.

Present known reserves are 25 million tons containing 3.0 per cent Pb and 3.0 per cent Zn.

Production is at the rate of 120,000 tons of ore per month. The mine is fully mechanized with American equipment, which is handled by the Moroccan workmen. Typical gear includes multiple jumbo drills, Joy loaders and rubber tyred "shuttle cars" to carry ore from working faces to trains or shutes. The lay-out is dependent on the flat dip of the orebodies and is based on the system used by

the St. Joseph Lead Co. at Bonne Terre, U.S.A.

ENGLAND.

The period 29th Sept. to 6th August was spent in London. Financial affairs were settled up to that time, visits were made to headquarters of a number of mining companies, to the Geological Survey and Museum, to the uranium section of the Survey and to the Research Laboratories at Teddington.

Among mining companies, a very hopeful attitude did not seem to prevail. They expected falling metal prices, not much money was available for investment and high taxation of successful properties made those who did have money reluctant to invest as they considered rewards were not commensurate with the risk involved. These attitudes appeared to be fairly general. A further cause for anxiety was the uncertainty regarding political developments in South Africa where a large amount of British money is invested. However, companies which control the copper belt in Rhodesia seemed happy enough, as did those who own Broken Hill, Australia. Many Australians are important in the London Mining world.

BRITISH GEOLOGICAL SURVEY.

T his institution is so well known that not too much time will be spent in describing it.

If the Bureau considered setting up a real museum, much could probably be learned from the design of the British Geological Museum.

The Survey is efficient, the men well trained and mapping is at a high level, being done mostly on 6 inches to a mile. No airphoto methods are required and only 1 geophysicist - called a geologist - is employed.

The Museum which is paré of the Survey, must be one of the best in the world and is beautifully equipped and designed.

The total strength of the Survey is 215 which comprises all types of personnel. The geological staff members 85, of whom all have a good honours degree and most have done a post-graduate course. However, the Director of the Survey Dr. Pugh, who was previously a Professor, agrees with me that a Survey can act as a training ground, provided time is available for reading and research.

The staff is roughly divided into field staff and special staff. The special staff comprises the petrology, chemistry, palaeontology, geophysics, water and the radioactive minerals groups.

Besides London, important branch offices are maintained at Manchester, Newcastle, Edinburgh and Belfast.

Every 2 years, the Geological Survey Board meets to review the general policy of the Survey. The Board consists of the Director, 3 Assistant Directors and 2 members from outside the organization who are expected to provide criticism and new ideas. These outside members are changed from time to time.

Two activities of the Survey appeared to me to be of particular interest :

(1) Entirely new coal fields are being sought and found under cover of Mesozoic rocks. The stratigraphic knowledge painstakingly built up over a century is paying handsome dividends in this way.

(2) The Geological Survey Water Department, set up in 1945 only, has now become very important. It is endowed by the Government with much authority and it is virtually responsible for underground water conservation in Great Britain.

The staff consists of 4 geologists and 7 Experimental officers. Its work comprises mainly :-

(a) Promoting conservation and proper use of underground water supplies. This is done by controlling drilling of new wells and the rates at which water can be taken from existing wells.

(b) Collecting and recording data upon which an intelligent water policy is based. The maps show :-

(i) Depth of Aquifer

(ii) Water table or pressure surface

(iii) Thickness of aquifer

(iv) Quality of water in terms of chlorine content, total hardness, temporary hardness, permanent hardness and total solids. The iron content is obtained in water from certain aquifers.

(v) Availability of water.

Australia appears to be behind in the scientific study of water resources.

CANADA

In Canada I visited the Geological Survey at Ottawa, saw little of the Alberta Oil Field, visited the uranium field at Beaverlodge Lake (Uranium City), and inspected the ore deposits of Sudbury, Noranda and Kerr Addison. I also spent some time at the University at Toronto and visited the Ontario Department of Mines in that city. In addition I had conversations with a number of mining geologists in Toronto and in Montreal.

CANADIAN GEOLOGICAL SURVEY.

In Ottawa I met the Director of the Survey but from then on I spent most of my time with A.H.Lang who directs the overall Government search for uranium in Canada and is the author of standard publications on uranium deposits.

Dr. Lang gave me much detailed information concerning the progress of the search for uranium in Canada. Notable features of this search are :-

(a) A great use is made of private prospectors who have discovered a large number of most important deposits. Uranium deposits are freely dealt with on the stock exchanges of Canada and although Lang stated that there had been considerable over-speculation, the over-all result appears to have been healthy.

(b) The use of airborne scintilometers was largely pioneered in Canada, but Lang is not over-enthusiastic about their usefulness. In areas where uranium is widespread in granitic and pegmetitic rocks, numerous anomalies are found which have little economic significance. This, of course, does not necessarily apply to the Rum Jungle Region of Australia where mineralization may occur in beds well removed from granites.

(c) The Canadian system of rapid map production is a good one and could be adopted with good results in Australia. When a geological survey party has mapped a region, a preliminary map of a low standard of draftsmanship, possibly based on the field sheets of the mapping party, is issued as soon as possible to prospectors and others interested in the region under consideration. This

applies especially to regions which may contain uranium. These maps are a great assistance to the prospectors and to mining companies, and the properly drafted maps are published at a considerably later date.

(d)The Canadian Geological Survey is not the most important agency prospecting for and producing uranium. This is the Crown Company, Eldorado Mining and Refining Limited, in which the stock is held by the Dominion Government, but the Company goes ahead more or less as a private concern. It has its own staff geologists, engineers metallurgists etc., owns the important Eldorado Mine at Pt. Radium, N.W.T., and also the most important known deposits at Uranium City, Beaverlodge Lake.

ALBERTA OIL FIELD.

I flew from Ottawa to Edmondton, Alberta. Edmondton is a centre of great activity. Wells are being drilled, refineries are being built, pipelines are being laid and much money is being made. It is reported that to date, American organizations have invested 1,000 million dollars in this venture.

Oil is being produced from the Cretaceous (from which it generally has to be pumped) and from the Devonian reef limestone (from which flow-oil is obtained).

I helped an American engineer from Sinclair check in a well which had been drilled to a depth of 3,600 feet in 5 days. The usual routine had been followed in bringing this well into production; this consisted of drilling, logging by Schlumberger and radioactive methods, perforating well at oil sand, sealing well, fixing pump and connecting to 4 inch pipeline which runs to an oil cleaner, thence to storage tank from which the pipeline company buys oil at regular intervals. Most of these operations are performed by separate companies which specialize in each particular type of work and whose services can be obtained at short notice by merely making a telephone call.

This particular well was interesting, because it had been drilled at an inclination of 60° in order to penetrate a sand situated beneath a lake.

The hole inspected was on the Armena Oil Field where the oil sand is about 16 feet thick has 20 per cent porosity, and contains about 25 per cent connate water; using a constant of 7758 barrels per acre foot, the area of 40 acres would contain approximately the following reserves :-

$$7758 \times 40 \times 16 \times \frac{75}{100} \times \frac{20}{100} \text{ barrels} = 750{,}000 \text{ bb.}$$

On a recovery of 35 per cent, this is equivalent to 260,000 barrels which at 2.5 dollars per barrel is worth approximately 500,000 dollars. The cost of drilling and equipping the well was approximately 50,000 dollars, which would give an operating profit of approximately 450,000 dollars.

This is typical of the production from the Cretaceous where scattered leases are commonly held by a large number of companies. In cases where a company owns only one or two leases on a particular field, supervision of production is commonly supplie d by a consulting organization and the owners do not maintain a staff. Production is limited by law to 50 barrels per day per well and a royalty of 12½ per cent is paid to the Provincial Government.

The particular well which we checked averaged 12 barrels per hour when the valves were first opened and the oil flowed freely without pumping. It was reported however, that normally, oil has to be pumped from the Cretaceous sand.

I spent only a weekend at Edmondton and hence saw only a very limited section of the total work which is being carried out. However the history of the field is an interesting one, in that its possibilities for production were considered by a number of major companies, but most of them did not think very highly of it. Finally the Imperial Oil Company of Canada struck oil in the Leduc Field, a circumstance which led to the renewal of geological and geophysical activity and the history of the area since that time has been one of continual expansion. The money invested and the production obtained has been a great fillip to the Canadian economy.

GOLD FIELDS REGION, BEAVERLODGE LAKE, NORTHERN SASKATCHEWAN.

A small town has been built in the area by Eldorado Mining and Refining Limited, and is now known as Uranium City. The

city is on the shores of Beaverlodge Lake and consists of a number of staff houses, office buildings, mess buildings and a recreation and shopping building all of which are tightly sealed against the weather and are centrally heated.

The Ace Mine, which is the best known in the district, has been explored by underground levels to a depth of 900 ft. and a 500-ton-a-day mill is in the course of erection. Several small companies are carrying out exploration of other deposits and the field is a centre of prospecting and speculative activity.

General Geology.

The geology of the district is well summarised by Lang (1952) whose paper gives a very useful description of all of the Canadian deposits of uranium and thorium. Other important papers are by Robinson (1952) and Mawdsley (1952). All these papers are important and those who are interested in uranium should read these. As listed by Lang after Christie the table of formations in the Beaverlodge area is as follows:-

Era	-	Formations and Lithology
Proterozoic		Diabase dykes
	Athabasca series	Basalt and andesite flows (a few believed to be sills) Arkose Conglomerate
		Unconformity
		Lamprophyre dykes Granite and granite-gneiss
		Intrusive contact
Archaean or Proterozoic	Tazin group....	Mafic rocks { amphibolite biotite schist or gneiss garnetiferous gneiss chlorite-bearing rocks epidote-bearing rocks chlorite-epidote rocks grading to more siliceous types Quartzite Conglomerate Dolomite and dolomitic quartzite.

The Tazin Group consists essentially of sedimentary rocks interbedded with basic igneous rocks all of which have been granitized and converted into gneisses. The sedimentary structures within the gneisses have been mapped. An important member of the Tazin Group is an argillite which shows a close spacial relationship to ore deposits and also contains disseminated uranium away from the actual ore concentrations.

The Athabasca Series overlies unconformably the Tazin and has also been granitized but to much lesser extent than the Tazin. There must have been two periods of granitization because the Athabasca contains boulders of granitized Tazin. Uranium deposits occur in both major rock groups.

Ore Deposits.

Ore deposits of the region can probably be divided into 3 main types, all of which are, in my opinion, related genetically.

(a) At the contacts of well-granitized rocks and comparatively ungranitized sections, uraninite occurs disseminated in biotite lenses in migmatite zones. This is characteristic of the Charlebois Lake area (Mawdsley, 1952). Similar to this is the Eagle where uranium is disseminated in cracks near the contact of gneiss and less granitized rock, but one major line of cracks contains most of the streaks and lenses of pitchblende.

Most of the types described above have not so far proved to be of great importance, but a somewhat similar deposit was being investigated during the time of my visit which may be very important. This deposit, which was being investigated by Gunnar Gold Ltd., occurs in a comparatively ungranitized bed which is both underlain and overlain by granitic gneiss. The ungranitized bed contains a considerable amount of amphibolite and bodies of calcite are also present. Much of the rock is felspathized and a considerable quantity of hematite also occurs. Uraninite is disseminated in the felspar-hematite-calcite rock and payable concentration have been found by drilling over widths of 8 to 60 feet. Mineralization is known to occur over a length of 3,500 feet, but has by no means shown to be continuously payable over this length.

Deposits which are generally similar to all the above have been

observed by the writer at Mt. Painter, South Australia where it is common to find uranium concentrations at discontinuities in the granitization. Hematite is also a feature of the South Australian deposits but calcite is generally absent.

(b) Related to, but generally slightly different from, the above is theoccurrence of uraninite in what are called pegmatite dykes, which appear to me to have been formed by felspathization along discontinuous cracks, or by replacement of beds, usually near the edges of masses of granitic gneiss as in the case of the deposits described under (a)/ These deposits are normally not as important economically as are the (a) group and they do not exhibit the hydrothermal features associated with the "a" type - i.e. calcite is not present to the same extent and the micas are also less in evidence.

(c) The most important deposits so far discovered in the region are those (such as the Ace) which occur along the St. Louis Fault, which, although they may be considered hydrothermal in type, are closely related to those described above.

Generally, where the argillite of the T azin Group impinges on the footwall of the fault, the beds have been replaced by red oligoclase felspar,forming lenses which may be 700 ft. long and up to 40 ft. wide. These lenses of felspar have been cracked open and stringers of pitchblende, up to ½ inch in width, cut through the felspar which forms an envelope around the payable shoots. Closely associated with the pitchblende are considerable quantities of calcite and hematite thus showing a relationship to the mineralization described under (a). Very few sulphides are present and the mineralization is essentially of the oxide type; this, in association with the felspathization, indicates to me a high temperature of deposition akin to pegmatization.

The St. Louis Fault is normal, and the younger Athabasca group occupies part of the hanging wall section. However,in this deposit, the payable ore is confined to the Tazin.

(d) The Martin Lake prospect, which has been explored by Eldorado, occurs in the Athabasca Group, which here consists of andesites alternating with grit and arkose. Stringers of pitchblende are found in cracks but the cracks are well defined only in the andesites and the shoots of ore occur in this rock. The mineralization

consists of calcite, dolomite, hematite and pitchblende; in marked contrast to the other deposits, there is no felspathization.

Genesis of Ores.

Lang ascribes the ore to non-outcropping granite of magmatic type, while the Eldorado geologists tend to ascribe it to basic igneous rocks. It seems clear to me however that the concentration of the uranium largely took place during the granitization of the sedimentary and volcanic rocks of the area, which has produced the granitic gneisses. This granitization has principally affected the Tazin and it is true that some ore occurs in the much younger Athabasca. Age determinations show however, that the pitchblende in this region varies in age between 1,850 million years and 1,000 million years. It is considered likely that the principal accumulations occurred in connection with the Tazin granitization. After the deposition of the Athabasca, there was a further period of marked folding and metamorphism which was accompanied by cracking of the Athabasca and the injection of a certain amount of pitchblende into these cracks. I believe that this can be considered as resulting from a slight mobilization of uranium during this period which may correspond to the ores which give an age of 1,000 million years. It is surprising how few people in North America are prepared to recognize any connection between the production of gneisses and the concentration of ores although this to me seems obvious. These remarks apply to the geologists who have worked in the Sudbury region and in the Lake Superior region. It was found that in many cases such an explanation simply had not occurred to these geologists. Similar misconceptions occurred in the Mt. Isa district of Queensland, Australia and in the Southern Cross district, Western Australia.

In some ways, the problem of the origin of these deposits are similar to the problem of the origin of the Broken Hill ores and of the Sullivan ores of British Columbia. The genesis of the ores may also be closely akin to that of many of the Swedish deposits occurring in a gneissic environment, especially at surfaces of discontinuity of granitic replacement. E. Grip, Chief Geologist, Boliden, with whom I discussed many of the Swedish deposits, informed me that, as a result of considerable geochemical work and of geological investigation, he is quite convinced that most of the Swedish lead-zinc ores have been

concentrated during the gneissification of rocks containing disseminations of lead and zinc. In the Athabasca area, the argillite of the Tazin appears to contain anomalous quantities of uranium, even where the argillite has not been greatly influenced by granitic activity.

The marked association of hematite with uranium is worthy of notice, and Canadian investigators have shown that pitchblende has the power to precipitate hematite from iron-bearing solutions. The marked red colour of many felspars associated with uranium is due to the presence of finely disseminated hematite.

Details concerning the actual and potential production of uranium from this district are contained in a separate report.

Before completing the description of the Athabasca region, it is worth recording that the general geological environment of these deposits is very similar to that at Mt. Painter, South Australia, where the red hematite-bearing felspathized zones also carry ore. Unfortunately the deposits so far found in South Australia appear to correspond to the comparatively unproductive types found near Lake Athabasca, and the fault-controlled felspathized zones of Lake Athabasca appear to be missing at Mount Painter. However, before visiting Athabasca I did not hold out much hope for finding payable uranium concentrations under general geological conditions such as those obtaining at Mt. Painter, and my experience at Lake Athabasca has substantially modified my opinions in this respect.

VISIT TO TORONTO

Ventures Ltd.

From Uranium City I flew to Toronto, via Edmondton. In Toronto I had some conversations with Mr. Duncan Derry, Chief Geologist, Ventures Ltd, which is one of the most active exploration companies in Canada. Derry is also one of the best known mining geologists in Canada.

Derry is very down-to-earth and questions of length, width, grade and structure dominate his thinking. He does not consider that geophysics is, as yet generally important in mining geology and he relies on drilling to a considerable extent.

The University.

At the University of Toronto I visited J.T. Wilson, Professor of

Geophysics, who is very active and full of ideas, but, in my view, his school of exploration geophysics is not very important, and his ideas on ore genesis are mediocre. At present he is studying air photographs of very large sections of Canada and from them is determining major tectonic patterns even where large sections of the rock are covered by snow and ice. This work, is, of course, very useful and interesting. Wilson's main interest is the investigation of his concept that continents grow from island arcs. Mathematics and geophysics are being used to probe the nature of the interior of the earth and Wilson has arrived at the unusual concept that andesite underlies the basaltic layer.

Dr. Langdon, Professor of Geology, is essentially a field and mining geologist and aims to turn out men of that type who are in great demand in Canada. At Toronto, 3 years are ordinarily spent to obtain a PHD., after the completion of the Bachelor's Degree. Langdon's mining course consists of analysis of structural patterns, application of strain ellipsoid to analysis of shearing patterns, repetition of patterns, 3 dimensional thinking, drilling problems, how to calculate position of holes on 3 dimensional diagrams etc. Langford attempts to develop independent thinking and makes his students write critiques of scientific papers.

A good deal of attention is being paid to geochemistry within the University where adequate spectrographic X-ray and other equipment is available. Geochemistry is, in fact,becoming much more important throughout North America. The geochemical work of the B.M.R. needs to be greatly strengthened. Important research into the genesis of ore deposits is being carried out by Dr. Smith within the Geology Department of the University.

Provincial Survey.

E.M. Hurst, who is Provincial Geologist in the Ontario Department of Mines, was born in Australia and was helpful to me while in Canada. He has a good staff of 12 geologists who are mostly carrying mapping. The maps produced are of two types :-

(a) Maps on a scale of 1 inch to 1 mile.

(b) Maps of mineralized regions, scale 1 inch to 1,000 ft.

All maps are supplied to the public at an early date.

The Ontario Department has not spent much money on geophysics, although it has carried out a considerable amount of airborne magnetometer work which has proved useful; it has led to the discovery near Marmora, S.E. Ontario, of a large deposit of iron ore in the Pre-Cambrian under 100 ft. of Palaeozoic limestone.

Hurst told me that he had covered 757 square miles for about 30,000 dollars, the flight lines being ½ mile apart, and the altitude 500 ft. Hurst considers that if the geology is complicated, the correspondence between geology and megnetometer results is not always good. Where the formations are broadly distributed the correspondence is good. However the records obtained by the magnetometer are fundamental facts of permanent value and are carefully preserved for future reference.

SUDBURY.

The International Nickel Company of Canada, which controls the main deposits at Sudbury (except Falconbridge) is carrying out exploration for nickel deposits throughout the world (but especially in Canada) and divides its geological staff into 3 main groups :-

(a) Operating geologists engaged on the problems of exploration and mine developments at Sudbury;

(b) Staff engaged in exploration for new deposits outside Sudbury.

(c) There is also an extensive research staff which carries out spectrographic, polished section and thin section studies, X-ray defraction studies and much chemical analysis. This staff supplies geochemical services which are considered to be of importance in the search for nickel and copper.

I spent most of my time with these geological departments but before going on to describe the work undertaken by these groups, a few comments on the mines will be given .

Ore Deposits - Outputs

The company controls the Creighton, Frood, Murray, Stobie, Levack and Garson mines in which total known reserves are approximately 250 million tons, containing approximately 1 per cent Cu and 1 per cent Ni and from which an annual production of 12.5 million tons of ore is obtained. The mines supply approximately 90 per cent of the

world production of nickel, and the Sudbury deposit, as a nickel deposit, is thus of unique importance in the world.

Geology.

The geology of the Sudbury area is well known and will not be recapitulated in detail here. It has been described by Knight (1917) and has been well summarized by Yates (1948). Briefly the ore deposits occur close to the junction of a norite or gabbro with granitic and gneissic rocks which have been divided into a number of granites and gneisses. Overlying the norite, which is folded into a basin, is a rock which was formerly called a micro-pegmatite and was regarded as a differentiate of the norite but is now thought by the Sudbury geologists to be probably a granitized tuff.

The ore consists essentially of pyrrhotite, chalcopyrite and pentlandite, the latter two being in approximately equal proportions and pyrrhotite much more abundant than either. Not much pyrite is present indicating a lack of sulphur. Magnetite and cubanite ($CuFeS_2$) occur in fairly small amounts. These sulphides may be disseminated in a quartz diorite, which occurs close to the contact in most cases, or it may be found in a breccia which contains fragments both of the granitic rock and of the norite, and is found close to the contact.

The ore deposits commonly occur at a bend (called an embayment) in the contact. The contact is usually folded into the form of a syncline at these favourable positions and the ore follows faithfully down the pitch.

A close examination was made by me at critical sections through the Creighton mine. Here it was observed that streaks and layers of basic rock variously called Gabbro or Norite remain in the footwall Creighton granite, to me clearly remnants of replacement, and most likely remnants of replacement of the Norite itself.

It is universally accepted on the field that the Creighton granite is younger than the Norite.

I also inspected in this mine so-called dykes of the rather mysterious quartz diorite which is found only in the vicinity of ore deposits, and commonly has a contact with the gabbroic remnants, which is extremely difficult to map. The quartz diorite commonly

contains abundant sulphides and in the Frood deposit constitutes the ore body.

The bodies of what are regarded as unreplaced sections of Norite are more abundant according to Sudbury Geologists in the vicinity of the ore deposits than elsewhere.

GENESIS OF ORE.

Yates in his paper adopted the view that the norite virtually had nothing to do with the ore except perhaps to act as a blanket in the same way as could a band of shale though he admitted that possibly the norite and the ore came from the same place.

This view was a reaction from the formerly widely held view that the nickel and copper sulphides had settled from the Norite by gravitational differentiation. Yates presented considerable body of evidence which was widely accepted to show that this view appeared to be untenable.

Since Yates's retirement the present geologists(Mitchener, Head of the Outside Exploration Department and Zorbrugge, Chief Mine Geologist) have returned to the former view of gravitational settling as they are quite well aware of the world-wide association between the basic igneous rocks and nickel copper deposits.

In my view the norite is probably the source rock, but the ore has been concentrated during the granitization of the norite. It has been found at Sudbury that the norite contains on the average approximately 0.015 per cent of nickel (South Range which contains most of the deposits - the North Range contains 0.0074 per cent Ni.) In the South Range 38.4 per cent of the nickel is present as sulphide and in the North Range the figure is 56.4 per cent. The remainder of the nickel may be present in the lattices of the magnesium-bearing minerals. In the South Range it would thus require a concentration of the nickel of approximately 100 times to produce the type of ore deposit now found. Now the granitic rock, which is admittedly younger than the norite and forms essentially the footwall of the ore-body, will not accept nickel into the consolidated rock and the nickel content of the norite which has been digested by the granite must be pushed outwards. It is considered likely that the dioritic rock is a hybrid type, formed near the contact and from the appearance of the orebody containing the sulphides as a type of emulsion, it is clear

that this rock has remained magmatic, as one would expect, after the consolidation of the main body of the granitic rock, because in many cases the granitic rock as well as the norite has been crushed and brecciated along the line of weakness formed by the contact prior to the injection of the quartz diorite. However, in many cases, the quartz diorite has solidified as a comparatively sulphide-free rock and the sulphides, or the components which compose them, have been expelled and been deposited in the brecciated zones. The brecciation has been particularly intense at points of irregularity in the contact such as those marked by the bends or embayments; these zones of brecciation extend up into the hangingwall norite and are complementary to the main zone of brecciation along the contact. These brecciated zones in the norite have in places been mineralized,

It was noted above that the ore occurrence shows certain relationship to the abundance of remnants of the norite within the granitic mass. This is commonly the case as was noted in the discussion on Beaverlodge Lake, because it is at the points where replacement is incomplete at the time that granitization is arrested that accumulations of sulphides and similar materials occur.

These views seem to be borne out to some extent by the extensive investigations for nickel which have been carried out by the International Nickel Company. In North-Eastern Canada there are very numerous occurrences of noritic sills, many of which have been folded into basin-shaped structures. These bodies commonly have associated with them a thin layer of sulphides especially near their base, but none of them have been found to have accumulations of nickel of economic size. Nevertheless, there is a world-wide association between basic rocks and nickel-copper deposits which continued to be ignored by Yates whose views were followed by Bateman, Graton, and others. The important difference between these deposits and Sudbury is in my opinion the granitization of the norite. In this connection it may be mentioned that the geologists at Sudbury have divided their granites and gneisses into many different groups, their concept being largely based on the idea that gneiss is a sheared magmatic granite and that, being sheared, it is older than the non-sheared rocks with which it is in contact.

Actually the Sudbury group of rocks appears to me to rest in a sea of granitised rocks most of which may be much the same age. Some of them are very gneissic, others are largely homogeneous. In fact I found that the mapping on the Creighton Mine would not stand up to critical examination. In some sections granites were given entirely different names from other sections and it was assumed that they were all different ages because of slight differences in appearance or minerality. The map was based on the assumption that granite is a homogeneous rock.

The point not commonly known is that there is a very considerable amount of quartz in many of the Sudbury ore deposits, and was quite abundant in the Creighton Mine which I saw. It could hardly be considered that the quartz has settled out by gravitational differentiation from the norite and it appears more likely that the quartz is something which has been added by the granitic process.

Geological Techniques.

As already suggested, the International Nickel Company is very interested in retaining its virtual monopoly of nickel production and received a rude shock when the geologists of Ventures jumped ahead of them and found the Falconbridge Ore Deposit at Sudbury. Falconbridge has also pegged the deeps of some of the international nickel mines thus the International Nickel Company is now very active in exploration and having plenty of money (1951 profits 62,000,000 dollars) is prepared to use all available methods. The air-borne magnetometer has been used extensively as would be expected, but, more interesting, the Company has been carrying out extensive experiments with air-borne electro-magnetic equipment and report valuable results. Although I had a look at the aircraft which was being used, I did not understand it fully and a certain amount of secrecy was being maintained. Dr. Stanley Davidson, who is well known to Mr. Haddon King of Zinc Corporation, has been closely connected with the development of the equipment.

The air-borne electro-magnetic equipment has been successful in finding pyrite and pyrrhotite bodies, but so far these have been low in copper and nickel. International Nickel considers that the equipment is good in deeply-weathered country and could be of considerable interest to Australia.

Geochemical methods have also been extensively used and their test for nickel in plants are maybe of interest.

Various sections of the test consist of :-

(1) ash
(2) take one gramme of ash
(3) take ash in solution with H.Cl (5ml.)
(4) add water and filter
(5) discard residue (free of Ni.)
(6) Add ammonium chloride (1 teasp.)
(7) add mixture Sodium Borate, citrate and tartrate with Sodium dimethyl glyoxime (for holding Fe up and buffering)
(8) add 5N NaOH solution until PH is 8 to 9. This gives a green solution.
(9) extract with Chloroform.
(10) shake with 5 ml. 1/10 HCl.
(11) oxidise with pot. persulphate. This gives colour which can be compared with standard colours.

The Company reported that although the extensive work had been carried out by spectro-chemical means to obtain the nickel content of rocks, results had not been entirely satisfactory and further experimentation was proceeding.

The Company of course is very active in diamond drilling and has 30 surface drills at work in the Sudbury area as well as 15 underground drills which are engaged in the search for nickel orebodies. A large amount of other drilling is carried out to outline deposits known to exist.

NORANDA, QUEBEC.

From Sudbury, I went to Noranda where Dr. Peter Price is Chief Geologist. This Company holds large interests in several other mines in the District such as Waite and Waite Amulet and is also interested in Kerr Addison. Dr. Price is an important figure in the investigation of all of these deposits.

Price is one of the most impressive geologists encountered by me during my travels, as besides having an intense practical knowledge of mining and mining geology he is somewhat unusual, in that he is fully alive to the latest developments in geology such as Turner's work on metamorphism and the new ideas of rock genesis. He himself has made important contributions to the study of rock alteration in the vicinity of ore deposits and has made use of this knowledge to find new ore deposits at East Waite.

Price has described the Horne Mine at Noranda in the Canadian Institute Volume and has again described it more fully in the Quebec

Mines Department publication, the Geology of Quebec Volumes 1, 2 and 3. These are firstclass publications and are recommended to all interested in ore deposits.

As is well known, the Horne deposit consists essentially of massive sulphides and may contain an average of 50 per cent pyrite as well as pyrrhotite, chalcopyrite and gold. The ratio of gold to copper is high and from a production of 55 million tons to a depth of 3,000 ft., an average of 3.6 dwt. of gold per ton and 2.2 per cent copper has been obtained. Between 1927 and 1951 the mine produced 33,766,000 tons of ore containing 1,423 million pounds of copper and 5,176,000 oz. of gold. The annual output has at times attained 2 million tons but now fluctuates between 1.25 and 1.4 million tons. The orebody averaged 18,000 tons per foot to the 3,000ft. level. Below the 3,000 ft. level pyrite replaced pyrrhotite and copper decreased to a marked extent. The Mine is being developed to a depth of 5,000 ft. in the search for ore and 4 drills have been working continuously for 10 years to the same end.

The Mine occurs in region of volcanic activity (mostly basic - includes many gabbroic masses) and is associated with the Horne Creek Fault of which is considered by some to be an off-shoot of the very long Cadillac - Malarctic "Break" along which Kirkland Lake and Kerr Addison are also believed to occur. Evidence for the existence of this "Break" seem to me to be somewhat dubious.

As the geology of Noranda has been published and these publications are readily available I will discuss only those features which appear to me to have particular interest :-

Price is carrying out a lot of interesting work on rock alteration about which he would not give detailed information but which is to be presented to the 1953 Toronto Meeting of the Geological Society of America. Price's work is based to some extent on that of Lovering, (1949) but he does not by any means accept all of Lovering's conclusions. He considers that chlorite is a good guide to copper, but only certain types of chlorite which he did not specify. He studies ore deposits for rock alteration by taking samples at 5 ft. intervals across the strike at over 3 00 ft./ intervals along the strike. Samples are taken where possible at 100 ft. vertical intervals.

Price finds, as I would expect, that ore deposits of differing genesis have different criteria of rock alteration. Different types of ore have different types of rock alteration associated with them. At East Waite a flat ore body which comes no closer than 400 ft. to the surface and occurs between layers of flat-lying volcanic rocks was found by Price by following up rock alteration clues obtained in scout drilling.

Price, like many other geologists, is inclined to ascribe the Noranda ore to unknown deeply buried granitic intrusives. In my opinion this may not be sound. The ore is chalcophile in type and is closely associated in space with basic rocks; in fact within the orebody it is common to find dolerites which, because they are frayed and inter-penetrated by the ore have always been considered to be pre-ore in age and to have had no sign of mineralization. These dolerites, however, seem to me to be closely associated with the gabbroic masses which are a very common occurrence in the district and to be possible feeders along which the ore solutions came in. Very similar conditions appear to occur at the Mt. Elliott Mine, Selwyn, Queensland (Sullivan 1952). Ore is closely associated with basic igneous rocks and basic igneous material occurs within the sulphide orebody. The high gold copper ratio is in my opinion characteristic of the basic rock association and is not commonly found in ore deposits which have been concentrated by granitic processes. The structure of the Mine (Price 1948) is also very reminiscent of the structure of the Mt. Elliott Mine, as in both cases the orebody as a whole is dominated structurally by a major fault, but non-outcropping masses of ore occur in structures which are essentially complementary to the major fault.

Before leaving their description of the Noranda area two remarks of Price may be worth recording. We were discussing Newhouse's compilation on the structural control of ore deposits and Price (1942) considered this book had probably done a lot of harm by making geologists believe that if they understood a few geometrical principles the problem of ore search for them had ended. I fully agreed with this objection and have published a number of uncomplimentary remarks

of the same tenor (Sullivan 1950). Price considered that far from explanations being simple we geologists "were like a bunch of monkeys trying to read the New York Times."

KERR ADDISON MINE

LARDER LAKE DISTRICT ONTARIO

From Noranda I went to Kerr Addison, which is now the largest and most important gold mine in Canada. The combined length of the shoots is approximately 2,400 ft. the width is up to 140 ft. but averages 40 ft. The average grade is 0.22 oz. per ton. The orebody varies in size from level to level as the following table shows :-

Depth	Tons per vertical foot
0. - 700 ft.	7,000
700 - 1600 "	13,000
1600 - "	14,000
1600 - 1900 "	10,000
1900 - 2500 "	10,000

The deposit averages about 11,000 tons per foot.

The present output is approximately 4500 tons of ore per day averaging 0.22 oz. 1900 men are employed.

Geology.

The geology of the area has been very well described by Thomson (1943) who carried out very extensive regional and detail mapping in the area.

The rocks of the district are shown in the following table :-

QUATERNARY
Pleistocene: Clay, sand, gravel.
Great unconformity

PRE-CAMBRIAN
Keweenawan or Matachewan: Diabase.
Intrusive contact

Huronian (Cobalt Series): Conglomerate, arkose, greywacke, quartzite, and slate.

Great unconformity

Algoman: Carbonate rock or "dolomite"[1]
Granite, quartz,syenite, syenite, syenite porphyry, quartz porphyry, felsite, mica syenite and lamprophyre,[2] quartz diorite, diorite.

Intrusive contact

Timiskaming: Basic Volcanics: Basic lava, spherulitic lava fragmental lava; agglomerate and tuff, dacite talc-chlorite schist.
Acid Volcanics: Trachyte, porphyritic trachyt trachytic breccia and agglomerate, tuff.
Fine-grained sediments: Greywacke, arkose, quartzite, slate, iron formation.
Conglomerate with some interbedded greywacke.

	Erosional unconformity
Post-Keewatin [3]	Diorite and gabbro.
	Intrusive contact
Keewatin	Iron formation. Basic Volcanics (greenstone): Andesite, basalt, and pillow lava, dioritic lava; spherulitic and amygdaloidal lava, fragmental lava, agglomerate and tuff, chlorite and talc-chlorite schists. Acid Volcanics: Rhyolite and trachyte, acid fragmental lava.

1. In certain areas the pre-existing rock has been almost completely replaced by carbonates of iron, magnesium, and calcium. This carbonate rock is locally known as "dolomite". There are all gradations from "dolomite" to partially carbonatized and unaltered rock.
2. The mica syenite, lamprophyre, and diorite dikes are often heavily carbonatized and intersected by quartz stringers
3. Possibly post-Timiskaming.

For further details on these rocks the readers are referred to Thomson (1943.)

The Kerr Addison Mine is situated on a long fault-zone which is marked by the presence of sheared talc-chlorite-carbonate schists tx over widths up to 500 ft. which has been called the Larder Lake "Break" and is considered by Thomson to extend intermittently at least for a length of 100 miles in Ontario and Quebec. He considers that either along this fault or in faults associated with it a large number of most important mines of these two provinces are situated. These mines include from West to East Kirkland Lake (situated on a subsidiary fault) Anoki, Omega, Kerr Addison, and Noranda; the well known Malartic - Cadillac "Break" is considered by him to be a continuation of the Larder Lake "Break". (Thomson, 1943, p. 32)

Within the Kerr Addison Mine itself, large bodies of ore are associated with a highly carbonated rock, often containing green mica as well as talc and chlorite. These bodies tend to be parallel to the strike of enclosing sedimentary and volcanic rocks. This is partly because shearing has been localized along the contact between greywacke and volcanic rocks. Ore also occurs in basic lavas, where it follows the bedding, and in syenite dykes; in addition smaller amounts occur in tuffs and in talc-chlorite schists which have not been highly carbonated.

Into these rocks a large amount of quartz of at least 3 generations has been injected. The quartz veins in the carbonate rocks contain scanty disseminated pyrite and native gold. Within the

lavas and tuffs there is considerable pyrite mineralization as well as traces of chalcopyrite, galena, and sphalerite. Scheelite is to be found in some of the tuffs.

The localization of the ore is thought to be related to the presence of the Larder shearing zone and in detail it is found that the ore occurs in the more brittle beds which have been selectively fractured. In particular, ore appears to be localized in these beds where they form a gentle synclinal fold within the shearing zone.

Genesis.

In discussing the genesis of these deposits, many Canadian geologists do not go any further than the Larder Lake "Break" and the inference is drawn by such men as J.T. Wilson that the ore is of abyssal origin and has no relationship to the rocks which one now observes at the surface. However in studying the maps of the gold province of Ontario and also in visiting the region, one cannot help but be vastly impressed by the similarity which exists between this province and the Western Australia gold province, and this similarity has been widely commented on by geologists who had seen both. If the gold ore was of abyssal origin this similarity in the geology of the two regions would have little significance, and in my opinion explanation may lie in the fact that in both provinces there has been a vast amount of volcanic activity including the outpouring of large quantities of the basaltic and andesitic rocks and the accumulations of big thicknesses of tuffs. In both areas synclines of these volcanic rocks lie as remnants in large areas of later granite generally of Algoman Age.

It was noted in the Ontario province that the Larder Lake "Break" marks approximately the northern boundary of the large area of Algoman granite and gneiss. In many places the later Cobalt Series (Huronion) which is younger than the granite, occurs to the South of the Larder Lake "Break" but where this is eroded the granite may be seen. It thus seems likely, as one would expect, that this "Break", besides being a structural discontinuity, is also so to speak a plane of geochemical discontinuity or a plane up to which replacement has tended to proceed and then stopped. Although the Fault cuts the Huronian, and has been active after the deposition of the Huronian, it

was most probably of importance also in pre-Huronian, for example Algoman, times.

T he well-known association between gold and andesitic lavas needs no emphasis, and the importance of granitic rocks, especially porphyries, in the Ontario province has been noted by many geologists and is shown on numerous maps. The ores of the province are essentially quartz veins which shows their granitic affinity. The granitization of the region is thus considered to have been the means whereby the gold was concentrated. However, the abundance of carbonates which are associated with gold both in Western Australia and Canada is not understood by me although it is a fact. It has been noted however, that carbonate are characteristic of volcanic areas as against gold-bearing areas which are essentially sedimentary in type. Carbonation is associated with volcanic activity as at Waihi, New Zealand, even where there has been no granitic effect. Granitic activity by itself does not commonly produce carbonation. Granitization acting on volcanic sequences does apparently produce widespread carbonation of rocks.

The gold mining industry in Canada at the time of my visit was languishing on account of the fixed price of gold and the rising costs of production. The appreciation of the Canadian Dollar in terms of the American Dollar (100 cents Canadian = 104 cents American) was also an adverse factor although the Canadians were very proud of this phenomenon. Many of the most important mines of the past, such as Kirkland Lake, Teck-Hughes, and Hollinger were reported to be feeling the strain, although all hoped for a rise in the price of gold.

UNITED STATES OF AMERICA

From Montreal I returned to New York on October 30, and from there visited Washington D.C., the Marquette Range of Michigan, the Copper Deposits of the Keeweenaw Peninsula, the lead zinc deposits of South Eastern Missouri (Bonneterre), the Uranium deposits of the Front Range, Colorado, the Plateau uranium deposits of Colorado, Ar izona and New Mexico and the somewhat different uranium deposits near Grants, New Mexico. I then inspected under the auspices of the Kennecott Mining Company a number of the most important copper deposits in New Mexico

Arizona, and Utah, and from Salt Lake City, Utah I flew to Butte, Montana, where I saw something of the copper ore deposits and also visited some uranium occurrences in the district. From Butte I returned to San Francisco, from where I left for Australia on December 11th.

WASHINGTON. D.C.

In Washington I called on Mr. Jesse Johnstone, Director of raw materials U.S. Atomic Energy Commission (at his request) and discussed with him our progress at Rum Jungle and also obtained considerable assistance towards seeing everything important in connection with the Commission's programme in the United States. The results of these talks were communicated to Dr. Fisher in a letter of the 16th November 1952.

As I was in Washington for only 2 working days, November 3rd and 4th, I concentrated on discussions with the metalliferous group and especially saw a good deal of V.E. McElvey who is in charge of the U.S.G.S.'s search for uranium and whom I had previously met in North Africa. McElvey is a very keen type, interested in uranium in all its aspects and has seen many of the uranium deposits from the world. Should he come to Australia, it would be of value to us for him to visit the Rum Jungle Area.

With McElvey, Art Butler and others I held a conference on the occurrence and genesis of uranium ores and on prospecting for these ores.

From their experience on the Colorado Plateau and from information gained especially in Rhodesia and the Congo, this group considered the Red Bed sequence of continental clastics was very important for the occurrence of uranium. The most important are clastic dumps, resulting from epeirogenic uplifts - uranium is not found in marine sandstones. These problems will be further discussed in the description of the Colorado Plateau.

From the practical point of view McElvey in seeking for uranium has utilized

(1) search of museum specimens
(2) stimulation of public interest by publication of literature.
(3) search of literature.
(4) interesting of mining companies in search.
(5) geochemical research on rocks, mill products and ores of all types.

I visited a very large laboratory which is under the control of a Dr. Rabbitt which is carrying out thousands of analysis along these lines. The laboratory employs a technical staff of 110, which is essentially engaged on the study of uranium geochemistry. The main techniques are chemical study, spectrographic study, X-ray study and petrological and mineralogical examination. The laboratory has 11 spectrographs engaged in this work. The analysis of 250,000 samples has been carried out, 85,000 of which have been on phosphates. It has been found that the phosphates contained about 0.01 per cent uranium which is partly tied up in the apatite. Much investigation has been carried out of the uranium content of carbonaceous shales and some formations such as the Chatanooka shale, have been found to average about 0.007 per cent U.

Spectrochemical methods are used for many of these investigations, but a fluorescent method for the determination of uranium has been found to be most sensitive, and by this means quantities of the order of 10^{-8} gm. can be detected.

The laboratory appeared to be rather grandiose in conception and contained every possible type of equipment some of which is very expensive. So many results have been obtained, that in many cases the geologists did not appear to me to have time to sort out the data and to make sense of them. I would not advocate the setting up of a laboratory of anything like this magnitude in Australia, but I am sure that if proper representations were made, studies of Australian materials especially from the Rum Jungle Area would be carried out for us.

I was very kindly received by all of the staff of the U.S.G.S. whom I met, and the Director, Dr. W.E.Wrather arranged a luncheon for me. In Washington I was the guest of H.C. Ferguson, President of the Society of Economic Geologists, who with other colleagues, in the U .S.G.S. had been investigating my ideas on the origin of the metalliferous provinces of the West U.S. Ferguson was preparing his presidential address to the Society of Economic Geologists and he stated that the "basic argument" was derived from my paper Ore and Granitization. (Sullivan, 1948).

MARQUETTE RANGE - MICHIGAN

On the Marquette Range, Michigan, I was looked after by the Jones and Laughtlin Steel Corporation which has several underground mines in this area and is also carrying out an active exploration programme.

General Geology.

The stratigraphy of the Lake Superior Iron Ranges has been described in many memoirs and in text books. At the base is the Keewatin. The Keewatin mostly consists of basic extrusives which are generally considered to have been followed by the Laurentian granitic gneiss. Above this is the Huronian, which contains the sedimentary iron formations. In Australia the Keewatin would correspond to the Kalgoorlie and Warrawoona greenstones and the Huronian probably to the Mosquito Creek, Mt. Isa and similar groups. Killarney granite is believed to have come in at the end of the Huronian, and then there is very marked unconformity above which the comparatively flatlying Keeweenawan which corresponds to our Nullagine was laid down. The top of this late Pre-Cambrian group appears to grade in to the Cambrian. The Keewanawan Lavas contain the important copper deposits on the Keewanawan Peninsula, which are described below.

There appears to me to have been some confusion in the differentiation of the Laurentian and Killarney granites and geologists have stated that there are masses of Killarney granite intruding the Laurentian granite. As elsewhere in the world, there has been a tendency to call a granite Archaen (Laurentian) if it was gneissic. The geologists of the steel company now consider that they have proved that the granite to the south of the Marquette Range, which was previously considered as Laurentian, is actually intrusive into the Huronian iron formations; this point has a very important bearing on the genesis of the ores and will be referred to again below. The iron-bearing formation at Marquette is essentially a chert which may contain up to 30 per cent iron which is almost universally believed to be of syngenetic origin. The iron may be in the form of iron carbonates which are believed to have been the original form in which they were deposited, but in many cases the carbonate has been converted to silicate. In some cases, especially near the granite, specularite and magnetite have been produced, apparently by metamorphism.

The high grade iron ore mainly consists of soft red hematite although some specularite ("hard ore") is mined.

In the Marquette Range the iron formation (Negaumee) is approximately 2,000 ft. thick and is underlain by a bed of shale as shown in the accompanying sketch section. These formations are folded into a sharp syncline which has been faulted. The orebodies are largely localized near the base of the iron formations in sharp synclinal folds the formation of which has generally been accompanied by faulting. The ore is thus localized in structural traps and its occurrence shows no relationship to the present surface or to the Pre-Cambrian surface.

Genesis.

The role of the iron formation as a source rock for iron has been obvious to all investigators, but the method by which the iron carbonates and silicates have been converted into hematite and concentrated into workable deposits has been the subject of considerable speculation. It has generally been assumed that this resulted from the action of meteoric waters and no one as far as I know has described any importance to the granite. The mapping of the region shows however that there is a remarkably close relationship between the distribution of the granite (much of it mapped as Laurentian - pre-iron formation in age) and the distribution of the payable ore deposits. However Tyler (1949) has indicated the hydrothermal nature of some of the processes in the formation of Lake Superior soft iron ore from the iron formation, and that Marquette uraninite apparently of hydrothermal origin has also been found. It seems likely to me that the accumulation of iron oxides into payable ore deposits has largely been effected by solutions emanating from the granite and that in fact, the Lake Superior ore is very similar in genesis to the ores of many other fields in which metal is disseminated in source rock concentrated into structural traps during periods of metamorphism and granitic activity. If this is so, it probably means that much more ore remains to be found in the Lake Superior region because the search for ore becomes largely a search for structural traps which will show no relationship to the present surface.

Ore Search Techniques

Geologists searching for ore in this region base their work on geological mapping, and it may seem surprising how much new information is continually being gathered in a region which has been the subject of geological investigations for such a long period of time. Airborne magnetic surveys have proved useful in delineating the iron formation as a whole, which may contain magnetite. The highly magnetic ores are considered unfavourable for ore as the soft oxidised hematite shows up as a magnetic low. Gravimetric surveys are widely used but do not easily detect a body of hematite surrounded by rock, which contains 30 per cent Fe.

Once an iron formation is located the geologists search for signs of "oxidation". The oxidation generally has nothing to do with modern topography or climate and may as indicated above be due to the action of hydrothermal solutions. Nevertheless it is something which can be detected at the surface or in drill cores and is regarded as a very important guide to ore. Extensive drilling is carried out and much care is devoted to the design of core barrels and to slow drilling, so that high core recoveries are obtained.

The typical underground mine worked in the Marquette Range may yield 1 million tons of ore per 100 ft. vertically and outputs may range from 500,000 to 1 million tons per year. The price paid for ore is 9 dollars per ton at Lake Erie ports, which in this case are 800 miles from the mine.

KEEWENAW COPPER DEPOSITS

From Ishpeming, centre of Marquette Range mining, I made a one-day visit to the Calumnet and Hecla mine on the Keewenaw Peninsula, Michigan, where Dr. Tom Broderick has been Chief Geologist for very many years. Dr. Broderick has written widely on these deposit s and the interested reader is referred to Broderick, (1946.)

The copper mostly occurs in the native state in the brecciated tops of flows of Keewanawan (Nullagine ?) age and in the Calumnet conglomerate which occurs between flows. Spectacular masses of copper over 1 million pounds in weight have been found in cracks in the brecciated flow-tops and in the conglomerate.

Calcite, which occurs in masses up to 5 pounds in weight, is the

commonest gangue mineral in the flow-tops but in addition prehnite and adularia are found. Mining has been carried 9,000 ft. down the dip and it has been found that the total volume of copper present at any given horizon is fairly constant. However on account of the increase of costs with depth, the company finds it difficult to compete with lower cost producers in South Western U.S. and Rhodesia and current production is at the rate of 40 million pounds per year which is about 1/5th of the maximum rate of production achieved in the past. The grade of the ore ranges from 1 to 1.5 per cent Cu.

Literature seen by me in the past has given no clue as to why these deposits should be unique, and as the possibility exists that payable deposits of copper occur in the somewhat equivalent basic flows of the Australian Nullagine, some consideration of this aspect seems warranted. The area is currently being studied by the U.S.G.S. and the conclusions arrived at which seemed to me to be sound are :-

(a) The Keewanaw basalts are about 18,000 ft. thick, which is unusual.

(b) Basalts are folded into the form of a large basin and towards the deeper portions of this basin the Basaltic rocks must have been depressed into a region of comparatively high temperature which would lead to metamorphic effects.

(c) It is believed that under these conditions copper has been mobilised and has been concentrated in the permeable parts of the section. The ordinary flows contain 0.01 to 0.02 per cent Cu, which is not uncommon for this type of rock, but could supply a large quantity of copper. Practical guides to copper deposits of this type are :-

(a) abundance of calcite prehnite and adularia in flow tops.

(b) widespread red staining due to the presence of iron. The red iron oxide is considered important for the precipitation of copper and is widespread even in the conglomerate.

(c) Presence of numerous masses and pieces of metallic copper which were very prominent in the Keewenaw area and are also associated to a lesser extent with other less important deposits of this type.

(d) As implied above it is probably important to have a great thickness of flows and also that they should have been tiltered at angles of 40° or more.

(e) It has been found that copper deposits of this type do not occur in flows which have been sufficiently metamorphosed to reach the green schist facies, the implication being that copper formerly contained in this area has moved to higher levels.

BONNE TERRE LEAD DEPOSITS, SOUTH EASTERN MISSOURI.

In Africa I had met Dr. John S. Brown, Chief Geologist of the St. Joseph Lead Company which controls Bonn Terre, and he had invited me to see these deposits. I also had letters of introduction to the General Manager in New York and from these beginnings the visit was arranged. I spent 2 days, November 10th and 11th, inspecting these deposits.

Geology.

The lead deposits of this region occur in the BonneTerre dolomite which is approximately 400 ft. thick and is Cambrian to Ordovician in age. This formation is underlain by the Lamotte sand, which is normally 50 to 100 ft. thick, but in places may be up to 500 ft. thick, and the dolomite is overlain by the Davis Shale, a relatively impermeable formation. The Cambro - Ordovician rocks rest unconformably on an irregular surface of Pre-Cambrian granite and generally have very flat dips. However, over hills of the granite basement slight domal structures occur and ore is associated with the structures. Generally speaking, however, there has been virtually no folding and very little faulting since the deposition of these beds, and there has been no regional metamorphism and no magmatic activity.

Certain stratigraphical positions in the Bonne Terre Limestone are specially favourable for ore and these are shown on the accompanying section. In some cases, however, payable mineralization (3 per cent Pb.) may occur over a thickness of 200 ft., although in other sections of the mines stopes are 10 to 20 ft. high.

As the top of the Bonn Terre limestone is normally close fo the surface, a large amount of exploration is carried out by relatively closely spaced vertical diamond drill holes and about 2 million ft. per year is currently being drilled. However, the Geological

Department of about 20 men is engaged in guiding exploration (including underground development) and considerable structural and lithological studies are undertaken. Within possible pay zones key-horizons within the dolomite are contoured and it is found that the ore distribution shows a close relationship to the occurrence of anticlinal axes. Small anticlinal warps can often be seen in the backs of the huge open stopes and it is apparent from inspection that the stoping has followed the trend of these warps. This relationship is shown on the accompanying map. It is in these anticlinal positions also that the big thicknesses of ore occur and away from the axes it is confined to the especially favourable beds.

In the favourable ground there has been considerable recrystalization of the limestone and this is considered a favourable sign in the search for ore.

There is a general suggestion that the dolomites are more porous and coarser grained over the tops of the buried ridges, a circumstance noted in connection with the development of oil traps (Trask, 19).

Interbedded with the dolomite 1 inch to 3 inch bands of dark shale are commonly found and these may contain much marcasite. Marcasite is commonly found in sedimentary deposits under acid conditions as distinct from deposits formed under alkoline conditions (Edwards and Baker, 1951.)

Genesis.

There has been for many years discussion concerning the origin of these deposits, the theories alternating between syngenetic and epigenetic. It is now established quite definitely that there has been concentration of the Bonne Terre ores and that they occur in structural traps akin to oil traps. It is also clear, however, that there has been little orogenic and no magmatic activity in the areas since the deposition of the limestone. It has been established however that there is a series of tension faults which form grabenlike structures in the western portion of the area and although the relationship between the ore deposits and the occurrence of these faults is by no means obvious, some geologists believe that there is such a relationship. There appears to be a relationship between graben structures and the occurrence of lead deposits in the Boubekir ore of Morocco. It is thus uncertain whether the lead and zinc were deposited in the beds at the time of their formation, or was introduced through

the faults,
but it does seem very likely that concentration of the lead around buried granite hills has been effected under comparatively cool conditions and is very reminiscent of the accumulation of oil into pools during the compaction of sediments.

Mining Notes.

A production of approximately 20,000 tons of ore per day containing about 3.5 per cent Pb is obtained from the B.T. Mines. Total production exceeds 8 million tons of lead worth more than 1,000 million dollars.

Mining is carried out very cheaply by using mechanical equipment including multiple drill jumbos by the use of which 2 men may supervise simultaneous drilling of several holes and no laborious work is involved on the part of the operator. By means of Joy-Sullivan loaders, similar to those seen in coal mines, ore is fed rapidly on two rubber tyred electric shuttle cars which transport rapidly about 10 tons of ore to loading points on the underground railway system. Haulage costs are low on account of the shallow depths of the deposits.

Geochemistry and Geophysics.

The exploration Department has tried out most known means of exploration including gravity surveys for the detection of buried granitic ridges but state that they have not had a great deal of success as the problem is a very difficult one. The dithizone method of lead detection is being used extensively to test soils over suspected lead deposits and is apparently considered useful as the company is still proceeding with this work. A point of interest is that they have developed a mechanical shaker, which will shake simultaneously 5 samples.

Important references for Bonne Terre are (Garrells & Dryer 1952, Bastin 1939 and Tarr 1936).

CLIMAX COLORADO

From St. Louis I flew to Denver, Colorado, where I was looked after by the A.E.C. One of the staff had formerly held a high position at Climax, and I visited this mine in his company.

At his highest point the Climax orebody is approximately 12,000 ft. above sea level and in order to reach the mine from Denver, one passes over Loveland Pass where the altitude is 12,000 ft.

Considerable difficulties are involved in working a mine at this altitude, and it is necessary to have plentiful mechanical equipment as men are not capable of great exertion.

Current production is approximately 15,000 tons per day of ore containing 0.5 per cent MoS_2 and 0.025 per cent WO_3. A small amount of cassiterite is also obtained. It is proposed to increase production to 25,000 tons per day and the money to do this has been advanced by the American Government as Climax molybdenum in production has important defence significance. The money advanced by the Government is being used to prepare a new level which is being done on contract, and will develop approximately 100 million tons of ore. Total reserves established by diamond drilling are approximately 300 million tons.

The mining method is block caving, the method which is universally used in North America for largescale underground mining. Approximately 850 men are at present employed in the production of 15,000 tons per day. Sampling of the orebody is carried out by diamond drilling mostly from underground workings and 230,000 ft. of drilling was required to indicate 300 million tons of ore. This means that a sample was taken of one part in 150,000 and the result obtained is found to be within 5 per cent of the true grade. On the whole, Climax orebody is considered to have a very regular grade. It is found that for the purpose of planning the production on this deposit, it is necessary to have approximately 100,000 million tons of ore in reserve.

Climax is probably the most important molybdenum deposit as such in the world but it is surpassed in production of molybdenum by the porphyry deposits which with their huge production of ore obtain important quantities of molybdenum as a by-product.

Geology.

Standard descriptions of Climax have usually represented it as an intrusive stock containing disseminated mineralization similar in type to the porphyry coppers. However to me Climax appeared to be essentially similar to the molybdenum-and-tungsten-bearing pipes of Eastern Australia which have been described by Andrews and further discussed by Blanchard. These pipes represent loci of intensive hydrothermal alteration, essentially silicification; there is also a considerable development of sericite and clay minerals. Kaolinite is the most important clay mineral, but dickite and pinite

occur in lesser amounts. A certain amount of lepidolite also occurs. Montmorillonite is found on the fringes of the highly siliceous ore and the kaolinite is found further from the orebody. The alteration has occurred in a series of pulses - as is commonly the case - and preceded the introduction of the molybdenite.

The molybdenite is mostly fine in grain and is all in fracture fillings - it is not disseminated in the rock as one might expect. This occurrence of ore in fracture fillings is characteristic of virtually all large granitic deposits seen by me, including the porphyry coppers, and unfractured rock does not contain payable ore.

As shown in the accompanied diagram, the known orebodies occur in the form of 2 large arches which are each underlain and overlain by unpayable granitic material. It could easily have been assumed that the orebody was exhausted when the first arch had been mined out. In fact it took considerably geological acumen to realize that the top arch as a whole possibly represented ore apart from high-grade fracture fillings of a semi-continuous type which were mined in the first place. It is worth noticing that nearly all ore deposits of this type have associated with them high-grade fissure-fillings and it is these which first attract attention and form the main object of early mining. This was the case in most of the porphyry copper deposits. It is believed possible that low-grade disseminated molybdenum deposits occur in Australia, as it took many years of work and study to prove that the Climax deposit was really as large as it is. These deposits are by no means obvious.

URANIUM DEPOSITS OF FRONT RANGE, COLORADO

The Denver Office of the A.E.C. is carrying out a considerable search for uranium in the Front Range to the west of Denver and I visited two of the most important prospects.

Copper King Mine.

This deposit was visited with Mr. E. Thurlow, Chief of the Denver Office. The deposit occupies a weak shear in granite; some ore follows joint planes where they are close to the shear. The shaft has been sunk to a depth of 50 ft. and about 100 ft. of driving has been carried out. The A.E.C. has also carried out 3,000 ft. of drilling which was based on the results of a geological and scintillometer survey. Within the workings, ore containing 0.15 to 0.3 per

cent U_3O_8 could be seen over a width of 3 ft. and a length of 7 ft. but in other places only 1 inch seams of ore were visible. 44 tons of ore containing 0.48 per cent U_3O_8 had been produced and special parcel of 5 tons containing 0.71 per cent had also been obtained.

At the 50 ft. level irregular patches and seams of pyrite and chalcopyrite could be seen, and associated with these is a sooty uraninite which is found in many such deposits elsewhere in the Western United States and is probably similar to the material obtained in Portugal. It was reported that X-ray studies had shown that this actually was uraninite although it could hardly be deduced to be such by ordinary inspection. It is usually a moist muddy black material (where the ground is wet) or under dryer conditions it is a soft pulverulent material. One gets the impression that in some cases original uranium minerals have been dissolved and redeposited more or less in situ to produce this type of ore although it has been seen by me at depths of 150 ft. below the surface.

It is not likely that more than a few tons of uranium could be produced from the Copper King Deposit.

Caribou Mine.

I visited the Caribou mine with Mr. Les Smith, a young graduate of the University of Colorado, now employed by the A.E.C.

This is an old silver mine which was known from the literature to contain a small amount of uranium and was carefully mapped and prospected by the A.E.C. They have financed a certain amount of drilling and development and the silver mining company was to produce any uranium which might be found.

The ore occurs in a Tertiary quartz monzonite stock intruding Idaho Springs (Pre-Cambrian) granitized metasediments, now largely gneisses and schists. The deposit is of the vein type, filling fissures, and consists of quartz, dolomite, pyrite, galena, sphalerite, proustite, (sulphide of Ag, As, Sb,) and pitchblende.

The silver-bearing shoots may be 2.5 ft. in width and 200 ft. in length, while pitchblende has been found to occur over a width of 0.8 ft. and a length of 30 ft. The Uranium-bearing shoots have been found to persist for 150 ft. down the pitch and the individual silver-bearing shoots are known to persist for 500 ft. The deposit as a whole has been worked to the 1,000 ft. level. Secondary ore

extended to a depth of 500 ft. Much silver was obtained in the secondary zone and in the primary zone the ore averages about 30 oz. Ag. per ton and approximately 2 per cent lead. The small uranium-bearing shoots contain about 0.3 per cent U_3O_8.

As in the Copper King Mine the uranium occurs mostly as a sooty pitchblende- at least it is seen as such in drives which have been opened for any length of time. The geologists told me that in fresh ore the pitchblende is more solid-looking and that the development of the mud-like material appears to result from solution and redeposition in situ. In one or two places in this mine pieces of wood were being replaced by yellow uranium minerals, possibly zippeite, the uranium was derived from the acid mine waters.

The best uranium-bearing ore has been found between the 800 ft. and 1020 ft. levels and in these sections the silver content of the ore is generally lower than it was in the upper levels. A type of zoning is thus suggested.

The A.E.C. has carried out 1500 ft. of drilling, mostly from underground, and has also financed some development. However the small size of the shoots found to date indicate that chances of substantial production are remote, and in fact at the time of my visit the company appeared to be in imminent danger of becoming bankrupt.

The work and money which have been devoted by the A.E.C. to the exploration of these deposits is typical of the approach of that organization which tries to ensure that no possible chance of finding uranium is overlooked.

Central City District.

This old mining town is about 40 miles from the Caribou and about the same distance west of Denver. In the last century it was a booming gold-mining town and some of the old Saloons with all their equipment of 1890 Vintage are still preserved for the edification of Eastern visitors wanting to see something of the Old West.

A group of gold-pyrite and quartz veins occurring in the Idaho Springs formation were worked intensively in the past for gold, but most of these mines are now collapsed and are inaccessible. However, it is known that over a period of 50 years possibly 1,000 tons of

pitchblende concentrates containing up to 40 per cent U_3O_8 were obtained, although it is not known exactly where this all occurred, and the uranium production certainly resulted from the mining of a very large tonnage of ore - possibly 50 million tons.

The A.E.C. has financed about 500 ft. of drifting in one of the mines at a cost of about 60,000 dollars, but results obtained have been quite unencouraging. The problem facing them is to decide whether to reopen this dangerous rabbit warren of old workings in the hope that uranium will be found or to abandon the project. It would be quite easy to spend 10 to 20 million dollars on this project and generally speaking the prospect of favourable results is not very bright. However, the area has produced 100 million dollars in gold in the past, and presumably some further gold production could be obtained in addition to the by-product uranium.

COLORADO PLATEAU URANIUM PROVINCE.

The Colorado Plateau Uranium Province occupies part of South Eastern Colorado, North-western New Mexico, North-eastern Arizona, and South-eastern Utah. Representative deposits in all of these states were visited, but not all mines in the region were inspected as they are very numerous. Visits to the area were carried out under the auspices of the A.E.C., the work being based on their offices at Grand Junction, Colorado, Grants, New Mexico, and Salt Lake City, Utah. The A.E.C. was most useful in every way and went to considerable trouble and expense to ensure that I saw everything possible in the limited time available.

General Geology.

A type section in the Plateau is as follows :-

Age	Formation Name	Description	Thickness
Cretaceous	Mancos	Black marine shale	3,000 ft
Cretaceous	Dakota	Conglomerate and grey sandstone	200 ft.
Jurassic	Morrison	Upper shale (brushy basin)	240 ft.
		Saltwash, interbedded sandstone and shale may be red but mostly bleached	250 ft.
Jurassic	Sommerville	Bright red marine shale	10 to 100 ft.

Jurassic	Entrada	Cross-bedded red windblown sandstone	40 to 150 ft.
Jurassic	Carmel	Red shale	0. to 70 ft.
Jurassic	Navajo	Cross-bedded windblown sandstone, dun coloured	0 to 1000ft.
Jurassic	Kayenta	Red lensy sandstone	200 ft.
Jurassic	Windgate	Massive red cliff-formed sandstone	400 ft.
Triassic	Chinle	Red shale	200 to 1000 ft.
Triassic	Shinarup	Conglomerate and grey sandstone. Very lenticular mostly in channels in underlying formation	40 to 270ft.
Triassic	Monkopi	Siltstone and sandstone, not present in Eastern Plateau	Up to 400ft. (2,00 ft. in Nevada)
Permian	De Chelly	Massive cliff-formed red to brown sandstone	10 to 500ft.

Below this is a big thickness of Palaeozoic sediments, some of which contain oil, but they are not of great interest in the present context as they do not contain any uranium as far as is known. The most important uranium-bearing formations are the saltwash member of the Morrison (Jurassic) - which carries by far the greater part of the known uranium deposits- and the Shinarup Formation of the Triassic. These remarks apply especially to Colorado and Arizona; in New Mexico, limestone which occurs just below the Morrison has been found to be an important formation for the occurrence of uranium.

The saltwash and Shinarup Formations are deltaic floodplain deposits. Although the Mancos shale of the Cretaceous is marine most of the other deposits are terrestrial or windblown.

The Plateau region has not been subject to the type of folding which is associated with the deformation of geosynclines, the structures present being characteristic of those produced by mountain uplift movements; monoclinal folds, slight domings and broad basins occur, but these are in marked contrast to the severe folding of rocks of the same age in the Sierra Nevada to the West of the Plateau and in the Rockies to the East.

Mines Visited.

There are about one dozen mines in the Plateau which account for most of the production and in addition there are about 200 known showings of uranium-bearing minerals most of which are not thought at present to be of great economic importance. It was arranged that I should see important representatives of the various types of deposits, in so far as time and accessibility permitted; and these are described below.

(1) Outlaw Mine.

This mine occurs on Outlaw Mesa, Colorado, and is owned by the Climax Uranium Company, an off-shoot of Climax Molybdenum.

The deposit occurs in the Salt-wash and has a known reserve of 120,000 tons, production to date is 40,000 tons, averaging 0.25 to 0.30 per cent U_3O_8. Current output is at the rate of 100 to 120 tons per day. Ore may occur over thicknesses up to 20 ft. but the average is 6 ft.; in places, widths as low as 2 ft. are mined. The total strike length of the deposit goes up to 1,600 ft. but the average is 1000 ft.

The ore occurs in a sand lens which appears to fill a channel of stream origin.

Much bleaching and kaolinization is evident in the vicinity of the ore. Red limonite is common and is probably derived from pyritic ore with which black vanadium oxide is associated. Uranium in the form of carnotite is closely associated with the Vanadium. Tree trunks and fragments replaced by rich uranium and vanadium ores occur in the mine.

The ore mostly parallels the bedding but in places it crosses bedding obliquely and these features are called "rolls".

Mining costs on this deposit are very low because the ore widths are sufficient to enable the use of equipment, and this is also facilitated by the almost horizontal dip of the deposit. 3 men per shift, employing 2 machines, one rubber-tyred shuttle buggy, one mechanical loader and a hoist and skip are easily able to maintain the required output of 120 tons per day, an average of 10 tons per man-shift.

The ore is carted about 50 miles to a custom treatment plant.

(2) Happy Jack Mine.

This mine is situated in the White Canyon area of Colorado. The ore occurs in the Shinarup Formation. The length of the deposit is about 2,000 ft.; it extends for 400 to 500 ft. down the dip and averages about 15 inches in thickness. The average grade is 0.25 pe r cent U_3O_8 and 1 per cent Cu. 175,000 tons of ore have been blocked out and total reserves may be 300,000 tons. Current production is at the rate of 30 tons per day; this is limited at present by the capacity of the mill of the Vanadium Corporation of America, situated at Hite; the material still presents difficulties in treatment.

This mine was regarded as of no importance less than 10 years ago, as the surface showings were comparatively unpromising, and a small adit into the side of the mesa had not been thought to have revealed important material. The owners sold it to 3 men who had very little experience of minerals for about 1,000 dollars. At present these 3 men gross 300,000 dollars per year out of which they pay the wages of one additional man and the cost of mining, carting, and treatment, which are not very high.

As in the case of the Outlaw, described above, the deposit occurs in a channel. The main gangue mineral is calcite which is specially abundant in the carbonaceous rock; gypsum is also abundant in occurrence. The ore contains the sulphides pyrite and chalcopyrite which occur well down the dip, at the outcrop these have been converted to limonite and copper carbonates. Uranium is found as a sooty uraninite but is also present in much of the lode as carnotite. Vanadium is present, but in much smaller quantities than in most mines, which contain lesser quantities of copper. There is an inverse relationship between these two metals.

The sediments, which are well exposed within the mine and which enclose the ore, are current bedded deltaic deposits, which contain a considerable amount of carbonaceous material and fragments of wood.

It has been found that besides copper and uranium the deposit contains low percentages of cobalt and nickel which are each thought to be present to the extent of approximately 0.01 per cent.

This mine could obviou sly produce more ore than it does at present and production is limited by the capacity of the Hite Mill and by the fact that the owners do not wish to pay too heavy an income tax.

(3) Monument No. 2 Mine, Monument Valley, Arizona.

This mine is owned by the Vanadium Corporation of America and is on the Navajo Indian Reservation. About 150 Indians are employed as labourers, a condition which was insisted upon by the Indian High Council which has considerable power in granting mineral rights within the reservation.

Current production is at the rate of 120 tons per day of ore containing 0.3 per cent U_3O_8. Grade in the past has been up to 0.8 per cent U_3O_8. About 150,000 tons of ore have been mined and it is estimated that about 300,000 tons remain in the deposit.

Carnotite is the most important uranium mineral but vanadium is also present as the oxides, hewetite and vanoxide, which are red and black respectively.

The ore occurs in a definite channel which can be observed on the sides of mesas. The channel has been traced over a length of 5,500 ft. but a length of 2,600 ft. has been eroded away. The channel is known to be up to 1500 ft. wide in some places but the maximum productive width is 700 ft. The maximum ore-bearing thickness is 40 ft. but this includes 3 lenses of ore which are separated by comparatively barren rock.

The channel was formed by river action which eroded part of the underlying Monkopi and in which were deposited the coarse illsorted crossbedded lenticular sediments of the Shinarup. Ore occurs in the portion of the channel immediately upstream from where the main channel splits into a number of subsidiary channels such as are seen on modern lake surfaces. It is in these portions of streams that alluvial tin etc. deposits are found, and the foremen on the mine consider that the deposit is of alluvial origin.

There is a widespread association between these undoubted stream channels and the occurrence of uranium in the Colorado Plateau and it seems possible that the rivers which flowed in these channels contained uranium and vanadium in solution and that these metals were deposited where the current slowed down and where reducing conditions, which are now evidenced by the abundance of carbonaceous material and of preserved wood obtained. The high permeability of the sediments is also thought to have been a contributing factor.

(4) Lukachukai Mountains, Arizona.

I visited the A.E.C. camp at the Lukachukai Mountains primarily for the purpose of seeing the combined geological, radiometric, and drilling project for ore search of the A.E.C. which will be described in a separate section of this report. However, some geological notes on ore occurrence obtained here are given now.

The ore is confined to alternating shale and sandstone, associated with the depositional edge of the Saltwash member of the Morrison Formation. There is a definite association of the ore with this facies change.

The direction of dip of the cross bedding is used as a guide to the direction of stream flow, which helps in mapping this facies change. In the favourable area carbon may be present to the extent of 100 to 1000 times the normal content of the saltwash.

It is thought by the local geologists that uranium and vanadium moving in solution in ground water are arrested near the impermeable shale and that deposition takes place in the permeable strata where they are rich in carbon. Continuity of sandy beds which allow continuous flow of solutions is believed to be important for the occurrences of ore. The factor of transmissability, which is a function of thickness and permeability, is being calculated for most prospect areas.

To date about 300,000 tons of ore have been indicated by 175 ft. of drilling. The geologists of the area consider that they may be able to discover 1 million tons.

The ore consists of carnotite plus black oxide of vanadium as well as a black uranium mineral which looks like carbon, but is thought to be one of the amorphous forms of uraninite. Some 30 to 40 per cent of the uranium is present in this form. This black soft amorphous material is not easily recognised as a definite mineral, even by experts, and probably some further work remains to be done before its true nature is elucidated; some consider that it is a form of thucolite.

Colour changes in the Saltwash are important and show a close relationship to ore distribution. Where the normal reddish-brown colour of the formation is converted to light bleached-looking material, ore tends to occur. Accordingly contour maps are made

of the distribution of bleaching and these are correlated with similar maps showing facies type and direction of cross-bedding. These factors all tend to show a relationship to the distribution of radioactivity as found by examining the rims of the mesas and by drilling.

The investigation of the Lukachukai Mountains is part of the current programme of the A.E.C. and large scale mining of the ore found has not yet been undertaken.

(5) Mines near Gallup, New Mexico.

In New Mexico I was handed over by the Grand Junction office of the A.E.C. to Mr. Paul Melancon of the A.E.C. office at Grants, New Mexico. Mr. Melancon met me at the airport at Gallup from where we visited two or three small but interesting deposits.

This is a comparatively new area for uranium and exploration has shown that uranium occurs in a number of formations which were not previously thought to contain it. These include the Mesa Verde Formation of the Cretaceous which is about 2,000 ft. thick and occurs immediately above the Mancos shale shown in the table. The Mesa Verde contains sub-bituminous coal in seams 1.5 to 4 ft. thick. The Dakota sandstone, the Summerville shale and the Todilto limestone (which is believed to correspond in age to the Entrada sandstone of the Jurassic) have also been found to contain ore.

The Hogback No. 4 deposit situated 3 miles north-east of Gallup consists of a band of lowgrade coal or coaly shale containing 20 to 30 per cent volatiles and 70 per cent ash. It has a length of 800 ft. and an average thickness of 2 ft., and has been open-cut to a depth of 10 ft. It contains about 0.2 per cent U_3O_8, but no uranium minerals can be seen with the naked eye and the uranium-bearing material has not yet been identified. It is thought that the uranium may be present as a hydrocarbon.

The coal is part of the Dakota sandstone which overlies the Morrison, the most important uranium-bearing formation in Colorado and Arizona.

Production has not been seriously attempted as yet from this deposit but experiments have shown that a considerable beneficiation of the ore can be obtained by burning the coal and that a reasonable extraction can be obtained by leaching.

The Benecite deposit situated 5 miles East of Gallup is in the Dakota sandstone and is associated with 2 seams of black shale. Uranium stains can be seen in the shale, but they do not appear to account for the grade of 0.25 per cent U_3O_8, which the deposit is reported to contain. A shipment of 250 tons of ore obtained from a pit 75 ft. in length is reported to have returned 0.25 per cent U_3O_8 and 0.12 per cent V_2O_5.

(6) Gay Eagle Claim, Grants, New Mexico.

Ore occurs here in Todilto limestone which lies on top of Entrada sandstone. Carnotite can be seen in the limestone over widths of 2 to 5 ft. especially where the limestone is puckered into small anticlinal folds. Although the yellow colour of the carnotite can easily be seen, it does not appear to account for the total radioactivity of the ore, and it is probable that pitchblende is present, although it is very disseminated and is somewhat difficult to identify positively in the field. Associated with the uranium are calcite and pyrite and probably also hematite. Some fluorite and baryte are also present.

The deposit is thought to contain only 200 to 500 tons of ore.

(7) F.O. Manoal Claims section 30, Near Grants.

This is another deposit in the Todilto from which 2,400 tons of ore containing 0.24 per cent U_3O_8 and about 0.25 per cent V_2O_5 have been obtained by stripping. Here the Todilto limestone, which is 4 ft. thick, lies close to the surface immediately on top of the Entrada sandstone.

Green and yellow secondary uranium minerals (locally called carnotite) occur in cracks in the limestone. Limonite boxworks observed by me appeared to have been derived from sulphides and it also seems likely that some pitchblende is present in this deposit.

The ore is associated with a small anticlinal fold as in the case of the Gay Eagle described above.

(8) Santa Fe Claims

Claims held by the Santa Fe Railway Company and on nearby blocks were briefly inspected.

The Company has spent a good deal of money in test-pitting the flat-lying Todilto limestone where it is near the surface and have probably indicated about 300,000 tons of ore which is thought to

contain about 0.2 per cent U_3O_8. The ore contains finely disseminated pitchblende which on oxidation gives green and yellow uranium staining. Ore has been proved over an area about 1,000 ft. long and 150 to 200ft. wide. It is possible that repetitions of this deposit could be found by following down its long axes and it appears to me that this area is worth considerably more prospecting. There is obviously no relationship between the present surface and the occurrence of the ore and where the Todilto limestone dips beneath the overlying Summerville further non-outcropping deposits may occur.

Santa Fe has erected a treatment plant about 20 miles from Grants and as their deposits are alongside their own railway lines and the ore can be mined by open-cutting, they are in a position to achieve a considerable production.

(9) Blue Peak Mine, Grants.

Here uranium occurs in the Morrison, especially in its more porous sections. However, the ore does not occur throughout the Morrison and is largely confined to the rock on the down-dip side of joint-planes at right angles to the bedding, which is here inclined at approximately 10° from the horizontal. The Morrison outcrops on the side of a mesa and here the typical staining of carnotite may be seen. Dark limonite is also present, however, and this is probably derived from sulphides which are found where the ore-bearing bed has been followed down by the adits. Black uranium-bearing wad has been found, which is similar to the material which is called urananite or pitchblende elsewhere in the Plateau. There is a considerable amount of gypsum in the ore which is found in veinlets following the bedding or jointing.

4,500 tons of ore produced to date have contained 0.15 per cent U_3O_8.

(10) Poison Canyon.

This deposit is similar to the Blue Peak in many ways. The ore is a dark carbonaceous grit which in many places contains clay galls which are often stained with bright green schröckingerite. For the most part, however, the ore is black and the uranium is probably present as a uranium wad or as uraninite.

Logs are present in some places (see photo) and these are replaced by black uranium and vanadium minerals.

The deposit is confined to a very cross-bedded section of the Morrison formation.

Genesis of Colorado Plateau Ores.

Since these deposits were first visited by geologists there has been considerable discussion concerning their origin, with most authors considering that a syngenetic origin was most likely. This was the original view of Hess (1933) and has been strongly maintained by Fischer (1937) and by Fischer and Hilpert (1952). Fischer is in charge of the U.S.G.S. work at Grand Junction, Colorado, from where the main uranium work of this organization is carried out. However, E.V. Reinhardt (1952) believes that the distribution of the uranium deposits is related to the Tertiary volcanic and intrusive masses which are found mainly in the mountain ranges of the Plateau, while L.C. Graton has also suggested that the ore is of epigenetic origin.

In my opinion there is a marked syngenetic character about these ores, the evidence being as follows :-

(a) The ore occurs in certain sedimentary formations and is largely confined to them.

(b) These formations were deposited under epi-continental conditions containing many arkoses and are of the red-bed type. It is found that uranium, copper, and vanadium accumulate elsewhere under such conditions of sedimentation, for example in Eastern Russia and in the Permian of Europe (Bastin 1933).

(c) The Mesozoic sediments of the Colorado Plateau have not been subjected to intensive folding or faulting such as is requisite for the formation of granite and no granites are known to intrude these formations. It is granitic activity which is most important in the formation of epigenetic copper uranium deposits.

(d) The metal association found in the Colorado Plateau deposits is not characteristic of epigenetic deposits but is characteristic of deposits formed by deposition from comparatively cold water; thus under epigenetic conditions, vanadium is not concentrated into ore deposits because of its tendency to form rock-forming minerals, a tendency which is associated with its poor affinity for sulphur. This characteristic of vanadium explains why, although vanadium is comparatively common in the earth's crust, it is not found extensively in ore deposits. Uranium and vanadium are commonly deposited under

reducing conditions in black shales. Copper is widespread in the Colorado Plateau, but it is also widespread under similar conditions of sedimentation in Russia, in Germany and in the Permian red beds of North Central Texas and of Oklahoma, and others suspect that the Rhodesian copper was also deposited under these conditions. Uranium is not characteristically associated with copper under ordinary epigenetic conditions and granitic activity, for example, tends to separate copper, uranium, and vanadium; the vanadium goes into the micas of the granite, the oxides of uranium are concentrated in the pegmatites and in high temperature oxide-type deposits, while the copper with its high affinity for sulphur tends to be concentrated in lower temperature deposits in the higher levels of the crust.

There are some factors however, which favour the idea of an epigenetic origin for these ores. These are :-

(a) Although the ore deposition is essentially controlled by stratigraphic factors, in places the ore does cross bedding and may be localised along join planes as in the Blue Peak Mines of New Mexico, described above. Also, ore is not found throughout the favourable formations, but as pointed out by Reinhardt(1952) tends to be situated on the flanks of domal structures, the cores of which are the present mountain ranges which are largely occupied by Tertiary volcanic and intrusive rocks. Additionally age determinations tend to place the ore in the Tertiary and not in the Jurassic which is the age of the most important ore-bearing formations. I believe that the evidence indicates that if the metals were originally deposited with the sediments, there has certainly been a reconcentration of these metals during the Tertiary and that the doming of the sediments and the volcanic activity which took place at this time facilitated the concentration of the ores. The relationship is somewhat similar to that found in the Missouri Lead Field (Bonne Terre, described above) where lead also occurs on domal structures and is certainly not a sedimentation feature as now found. However these phenomena do not prove that the ore is of epigenetic origin any more than the occurrence of oil in domal structures proves that oil is of magmatic origin. In this connection it is interesting that some of the important uranium occurrences in domal structures in the Mesazoic are underlain by actual salt domes in the Palaezoic and oil is associated with some of

these structures. It is difficult to envisage the occurrence of oil under geological conditions suitable for the accumulation of epigenetic ore deposits.

(b) In the past the argument for a syngenetic origin was partly based on the fact that only secondary minerals such as carnotite had notxbeen found and that no sulphides or pitchblende were known to occur. However, deeper mining and intensive drilling have now shown that copper and iron sulphides are of widespread occurrence and much pitchblende has also been found. Some sulphides of vanadium are also reported to occur. However the temperature ranges over which these minerals may form are not well known although it is of course well known that pyrite may be formed under conditions of sedimentation.

OTHER URANIUM DEPOSITS U.S.A.

Marysvale, Utah.

The A.E.C. maintains a special office at Marysvale, which at the time of my visit was under the control of Mr. Eugene Nelson. Two mines, the Prospector and the Freedom, are being exploited by the Vanadium Corporation of America. ~~Black~~ Production is planned as 120 tons of ore per day, but at present this is not being maintained.

The ore deposits in this region are fissure fillings occurring in a granitic stock. The stock intrudes the Mesozoic formations which carry the ore of the Colorado Plateau, but is unconformably overlain by a group of Tertiary volcanic rocks (see accompanying section). The ore occurs along the shears and forms by replacement of the granitic rock. The replaced rock contains a large amount of clay and is soft; a good deal of timbering is required to prevent it from collapsing during stoping operations. In addition to the clay, a good deal of black fluorite is present as well as black and blue molybdenum minerals (Ilsemannite, possibly hydratic oxide of Mo, and jordisite, $Mo S_2$). Gypsum veinlets are common.

On the 100 ft. and 200 ft. levels of the Prospector vein, a radioactive black material may be seen in the backs of the drives. This black material is partly fluorite and molybdenite but it contains uranium as it can be seen to be producing yellow uranium ochres (Zippeite ?). Some of the geologists consider that this black radioactive material is a secondary mineral but it is closely associated with pyrite as well as with the sulphides mentioned above, although

the uraananite which may formerly have been present may have been partly oxidised and redeposited in situ, there does not appear to me to have been a great deal of secondary enrichment. Nevertheless the uranium mineralogy of this type of deposit, which is essentially similar to the deposits described from the Front Range of Colorado and to the occurrences in Montana, to be described below, is not at all easy to sort out at first glance. From reading, these deposits appear to me to be rather similar to those which occur in Portugal.

In the Prospector Mine the ore may average 12 inches in width but is up to 4ft. in some places. The vein has been traced over a length of 900 ft.

The Freedom Mine at Marysvale adjoins the Prospector and is essentially similar in type, although it outcrops at an altitude about 300 ft. lower than does the Prospector. It has been tested by extensive editing and driving and has been producing about 50 tons a day for two or three years.

On both of these deposits a good deal of work is required to obtain a few tons of ore, but it seems likely that they will be capable of producing about 100 tons of uranium a year.

Deposits of Jefferson Country, Montana.

These deposits were visited with Mr. Jarrard of the A.E.C. office at Butte.

The deposits occur in the northern third of the Boulder Batholith which is called quartz monzonite and is also referred to as the Butte granite.

They occupy steeply-dipping shears or faults which contain chert and fine-grained quartz as well as limonite near the surface; the amount of limonite present is small indicating a lack of sulphide content. Molybdenite has been found in one of the deposits (W.Wilson).

The two most important deposits were inspected.

(a) President Woodrow Wilson.

Shoots of ore in this deposit have a length of 60 ft. and a width of 3 ft., and have been proved over a vertical distance of 80 ft. The silicified shear in which the ore occurs has been traced over a length of 1,500 ft.

Within the workings it was seen that in addition to the ore occurring in the steeply dipping shear, autunite, torbernite, limonite,

and gummite, with a small quantity of pitchblende, occur in flatly-dipping joint planes near the steep control fracture.

The workings are still essentially in the oxidised zone and I expect that the primary mineralization will consist of pyrite molybdenite and uraninite.

(b) President George Washington.

This deposit is similar to the Woodrow Wilson but is not so oxidised.

On this lens a silicified fissure has been traced over a length of more than 1500 ft. but uranium-bearing ore has been proved only over a length of 50 ft., a width of 2.5 ft., and a vertical distance of 70 ft. Ore carrying uraninite is exposed in an adit but no sulphides were seen. Near the surface a considerable quantity of autunite and torbernite was obtained.

These two deposits are more promising than those of the Front Range of Colorado on which more time and effort are being expended, although they are similar in type, both to the Front Range deposits and to the Marysvale deposits.

In the Woodrow Wilson, bodies of gummite up to 50 lbs. in weight were obtained near the surface and it seems probable that some correspondingly large masses of uraninite occur in the primary zone.

The deposits fill very well defined structures which are brecciated zones only partly filled with low temperature quartz; in many cases although the structure continues as a narrow crack, no quartz replacement is present. It is also notable that very much less kaolinization has occurred than at Marysvale.

Only sporadic work - mostly financed by the A.E.C. - was in progress at the time of my visit, but it seems probable that these deposits could produce about 20 tons of ore per day, containing perhaps 0.2 per cent U_3O_8. At present various promoters buy ore from the mine which contains less than 0.1 per cent U_3O_8 and cart it to other holes in the ground which they call uranium mines, and in which sufferers from arthritis and other similar diseases are "treated"; the ore is also sold in 1 lb. bags, which may be taken home and placed under the pillows of sufferers from these diseases. Considerable sums of money

are being made in this way.

PORPHYRY COPPER DEPOSITS OF THE SOUTH WESTERN U.S.

Over a period of about 10 days I visited representative deposits of the above type, these visits were made possible largely by the assistance of the Kennecott Copper Corporation which provided a car and a geologist-guide.

This visit was of the greatest interest as these are the most productive deposits in the world and have an annual output of about 700,000 tons of metallic copper. Their sheer size and importance are thus impressive, and along with these go the specialized large-scale mining techniques, the development of which has made possible the exploitation of these lowgrade deposits.

From the geological point of view, as one who had read some of the literature, but had not seen the deposits, I think I was most impressed by the following factors some of which I had not really expected to see.

(1) nearly all the deposits are associated with very extensive fracturing of the porphyries.

(2) The porphyries have commonly undergone a great deal of alteration which has commonly resulted in the development of abundant clay minerals. Some of this is of hydrothermal origin but some of it also is associated with supergene processes and appears to be produced by the large amount of sulphuric acid developed during the oxidisation of the sulphides. Silicification is widespread, especially where payable ore occurs, and this is of course of hydrothermal origin. The subject of alteration, which has been intensively studied in these deposits, will be discussed further below.

(3) In many cases high-grade fissure-filling deposits or contact deposits have occurred within or near the disseminated porphyry ores and these have drawn attention to the occurrence of the deposit. Most of the porphyry localities have been known as copper producers for generations and the exploitation of the larger bodies of disseminated ore has resulted from acts of creative imagination of engineers and geologists who realized that large deposits might be present and that it might be possible to achieve the means of working them economically.

(4) Dip oxidisation is characteristic of the deposits and one

always sees the red cap-rock which is sufficient to attract attention to a prospective porphyry copper. The details of oxidation products have been widely described, especially by Blanchard and his school, and his techniques are still followed in the copper belt. However, as we have found in Australia, geochemical means can be used very extensively to supplement knowledge deduced by leached-outcrop studies, and these are finding great application in the U.S.A. Very possibly they will partly replace leached-outcrop studies.

(5) Contrary to what has generally been stated, some of the porphyry deposits probably contain payable primary ore, the grade being 0.75 to 1.0 per cent Cu. Deposits in this class may include Bingham Canyon, Utah, San Manuel, Arizona, and Ajo, Arizona. Some other deposits have only a small amount of secondary enrichment; but in other deposits, such as Santa Rita, New Mexico, enrichment has resulted in a secondary ore, containing about 1 per cent Cu. from a primary ore containing about 0.2 per cent Cu.

(6) In many of the deposits in the South Western U.S. (and also, it was reported to me by Anaconda geologists, in Mexico and Chile) there is a very close association between the payable porphyry copper deposits and the occurrence of diabase which is older than the porphyry and contains a good deal of copper. This association is quite remarkable and has apparently been noted by other geologists, and as I have suggested (Sullivan 1948) it is possible that these widespread copper-bearing basic intrusives may have been the source rocks from which the copper was concentrated by later granitic activity and may explain to some extent the occurrence of this metalliferous province as a whole.

Below are discussed briefly the deposits visited by me.

Santa Rita, New Mexico.

This mine has a production of 22,500 tons of ore per day, containing 0.8 per cent Cu. The cut-off grade is 0.5 per cent Cu. and the ratio of mullock to ore is 1.5 or 2 :1.

Ore is won by open-cutting (see Kodachromes), the pit being roughly circular and about 850 ft. in diameter. Exploration has shown that it will be possible to extend the pit for a further 200 ft. on one side. Secondary enrichment extends to a depth of 1,000 ft.

where the grade falls to approximately 0.2 per cent; it is not envisaged that this material will be mined.

Geology.

In this region the geological column extends from the Pre-Cambrian to the Tertiary. The Pre-Cambrian rocks are schists and gneisses which are overlain by Cambrian and Ordovician limestones, Devonian shales, Mississippian limestone, Pennsylvanian limestone and shale, and Permium red beds. These are unconformably overlain by Mesozoic slates and quartzites, and porphyry sills of Cretaceous age. Porphyry intrusives of late Cretaceous age carry the copper deposits and are followed by Tertiary rhyolites and andesites; these are unconformably underlain by Quaternary gravels and sands, some of which contain syngenetic copper, derived from the erosion of the porphyry.

The area is one of intensive folding, faulting, and igneous activity.

The Santa Rita stock is a granodiorite porphyry which extends for 1 mile in the North-south direction and is ½ mile wide. The porphyry is not homogeneous and in places contains remnants of sediments.

Within the ore zone the brecciation of the porphyry is very marked and there has evidently been much tectonic activity, the latest of which coincides in time with the Laramide revolution. The mine occurs in the Basement Range structural province which is characterized by a great deal of strike faulting and by volcanic activity. The Santa Rita area itself was apparently especially active volcanically.

The rock alteration may be divided into the following stages :-

(a) Biotite only partly chloritized, felspar hard and shiny.

(b) Biotite completely chloritized; felspar soft kaolinized. Rock texture still present. Some ore is associated with this phase.

(c) Biotite converted to hydro-mica; felspar completely kaolinize Much payable ore occurs associated with this stage.

(d) Original rock texture obliterated. Much silica present as quartz. This is called the siliceous stage and is not as favourable for ore as (c) above.

Although there is little or no lead-zinc associated with the Santa Rita stock, important deposits of these metals occur near the

Hanover stock only one or two miles away. These deposits occur along the contact of granodiorite and quartz monzonite dykes mostly where they intersect crinoidal limestone of Mississippian age. Other limestones also produce some ore near the contact with these dykes.

An interesting feature of Santa Rita is, that rock containing small quantities of copper, which would not pay for milling, is stacked in huge dumps which are subjected to leaching. About 3,500 gallons of water charged with sulphuric acid are circulated each minute and 20 to 50 pounds of copper are recovered from each 1,000 gallons of water. The nature of the material is such that the solutions are generated themselves and it is only necessary to add about 500 gallons of fresh water per minute to the liquid in circulation. Leaching of this type is widely practised in the South-western U.S.. either on waste dumps or on ground which has been caved, but still contains copper. At Globe, Arizona, all copper is extracted by leaching, but in this case the ore is crushed. Here also the copper sulphate solution is not run over old tin cans for copper precipitation; as is normally the case, but is taken to a electrolytic plant where copper is obtained by electrolysis. The Santa Rita Mine is owned by the Kennecott Copper Corporation.

Morenci, Arizona.

This is a typical open-cut porphyry-copper mine from which a production of 50 thousand tons of ore per day is obtained; in addition about twice this quantity of waste rock is mined and has to be disposed of; this is often a problem for a geologist who has to be certain that he is not dumping waste rock on possible non-outcropping ore shoots. The Company employs 2700 men of whom 1,000 are directly engaged in mining.

This mine is owned by the Phelps-Dodge Corporation and the central geological office of the Corporation is situated here. The Chief Geologist is Louis Reber and the geology at Morenci itself is looked after by Lewis Smith.

The copper mineralization is associated with a stock of monzonite and the mineralized ground is bounded on the South-east by the important San Francisco Fault which has a large vertical displacement. It is thought that this fault has had something to do with the emplacement of the ore. Numerous diabase intrusives occur

in the vicinity of the mine.

The ore contains approximately 1 per cent Cu. as well as, possibly, 0.05 per cent Mo. Small quantities of vanadium are reported to be present.

Smith has taken a great interest in leached-outcrop studies and followed fairly closely the published techniques of Blanchard. He is interested to know whether there is concentration of limonite whetherthe limonite is indigenous or transported and whether the gangue is reactive or non-reactive. Most felspars as well as kaolin and sericite are non-reactive whereas orthoclase reacts with acid solutions. At Morenci it is found that hematite occurs over a reactive gangue, if abundant pyrite is present.

Smith, following other investigators, considers that montmorillonite is of supergene origin while beidellite, halloysite and allophane are of hypogene origin. These distinctions have been used to determine favourable sites for drilling, but enquiries in other quarters in American indicated that much alteration which has been thought in the past to be of hypogene origin is probably of supergene origin.

The ratio of pyrite to chalcocite is, as pointed out by Blanchard, of fundamental importance in leached-outcrop interpretation, and where the ratio Fe:Cu is of the order of 3 or 5:1 the iron sulphate bergstromite may be seen prominently developed near the base of the oxidised zone. This passes upward into limonite. The type and quantity of the limonite present depends on the nature of the gangue, quantity of sulphides present, and ratio of Cu:Fe.

Immediately below the oxidised zone, there is generally not much chalcocite present, only pyrite. The chalcocite commences about 300 ft. below this and may extend for a further 600 ft,.

San Manuel, Arizona.

The San Manuel is an interesting deposit, because for many years its possibilities were neglected and it was not until the U.S. Bureau of Mines carried out some drilling, that companies were sufficiently encouraged to consider exploring the deposit further.

The orebody occurs in a monzonite which has also been called granite and is of Tertiary age. This ore-bearing rock is largely concealed beneath the Gila conglomerate which is of Quaternary age. In the vicinity of the mine the junction of these two rock-groups occurs along the San Manuel Fault.

At the surface chrysolla occurs over an area about 400 ft. square and this outcrop contains about 0.8 per cent Cu which is about the same as the grade of the primary ore. An important feature of this deposit is that although oxidisation extends in places to a depth of 1,000 ft., there has not been very much secondary enrichment of the ore and the main production will come from primary material.

At the present time about 140 men are engaged in developing this deposit and it is proposed to mine 30,000 tons per day of ore containing 0.8 per cent Cu and 0.03 per cent Mo.. as a large proportion of the deposit is covered by the Gila it will not be possible to use open-cutting methods and caving will be the most important method of mining.

The geology and structure of the deposits have been well summarized by Steel (1952). In cross section the orebody is an overturned syncline and Haddon King who has seen it suggests that this structure may have been inherited from sediments which have been converted into granitic rocks. Although such thinking is anathema to many American geologists, it is being increasingly found that some of these granitic and porphyritic rocks show evidence of having been formed largely by replacement.

As is the case with many of the porphyry copper deposits, evidence of basic igneous activity is abundant and diabase is found interfingered with the monsonite porphyry. The diabase contains chalcopyrite and pyrite.

The San Manuel deposit is controlled by Newmont Mining Corporation, but much of the capital for the initial development

has been advanced by the U.S. Government. The proposed mining operation is one of the most daring which has yet been undertaken in American copper mining, in that it is proposed to mine, by underground means, ore of a grade which is slightly below that commonly mined by open-cutting.

Ray - Arizona.

This mine produces 15,000 tons of ore per day containing 1.2 to 1.3. per cent Cu. It is mostly chalcocite ore of secondary origin and the protore normally contains about 0.3 per cent Cu.. However, large bodies of diabase occurring in the mine contain from 0.5. to 1 per cent as chalcopyrite and much of this is mined and treated.

The basal rock of the district is the Pinal (Pre-Cambrian) Schist which has been intruded by older Pre-Cambrian granite and diorite. It is overlain successively by rocks of the younger Pre-Cambrian Apache group, by middle Cambrian Troy Quartzite and by limestones of Devonian Mississippian and Pennsylvanian ages. These rocks were intruded during Cretaceous to early Tertiary (Laramide) time by diabase, quartz diorite, quartz monzonite and quartz diorite prophyry. The ore is associated with this Laramide activity and the rocks of this period are unconformably overlain by Tertiary Whitetail conglomerate, Tertiary dacite and tuff, and Tertiary-Quarternary Gila conglomerate.

The pit from which production is obtained is mostly in the Pinal Schist in which large sills of diabase of Mesazoic age occur. Prophyry intrudes both of these rocks and ore occurs in all three.

The mineralized Pinal Schist and porphyry are both brecciated and have also been subjected to considerable hydrothermal alteration. However the diabase does not give the impression of having been shattered, although it is the one rock which is known so far to contain payable primary ore. One almost gets the impression that the ore in this rock is essentially syngenetic with the rock itself. Otis M. Clarke (1952) believes that the mineralization largely came up along the Ray Fault which bounds the orebody on its north-eastern side; this fault is also apparently the main locus for the introduction of diabase. The diabase contains approximatley 10 per cent Fe. and is high in pyrite; in spite of this, no secondary enrichment occurs in the diabase.

The Pind Schist is highly, altered largely to sericite, but this alteration extends outside of the ore zone. The ore is accompanied by bleaching and pyritization.

Clarke, who is Chief Geologist for the Ray Division of the Kennecott Copper Corporation, uses leached outcrop studies in the search for ore, but has also found that geochemical methods for detecting the presence of copper in soils and plants, as well as in leached capping, give valuable guides to drilling. Studies of this type in conjunction with a knowledge of the structural control of the deposits have enabled him to add about 500 million tons to probable reserves.

To date, about 75 million tons of ore, containing 1.5 per cent Cu have been mined by underground methods, and since 1947, when the open pit was commenced, 5 million tons of ore and 40 million tons of overburden have beenremoved.

The Ray deposit was not particularly attractive at the surface, although widespread copper staining was present, especially near diabase dykes; some silver was also found. Early mining was from low-grade disseminated orebodies, containing mainly chalcocite. No high-grade veins of any substantial size occurred in the area.

The supergene sulphide enrichment has been controlled by thrust faults by the original position of primary ore and by rock-types. No chalcocite is found in diabase, and it is worth noting also that the ore in this rock is richer in gold and silver than is the ore or other types. Diorite occuring about a mile from this deposit contains 0.1 to 0.2. per cent Cu. whereas the nearby granite porphyry contains no copper to any marked extent.

Miami-Inspiration, Globe, Arizona.

The Globe area of Arizona has been one of the most important copper districts in the world and from an area 10 miles long and 3 miles wide, about 3 million tons of metallic copper have been obtained. The most productive mines have been the Castle Dome and Inspiration-Miami, but only the latter mine was inspected. The area is now controlled by the Anaconda Company and from these two properties, about 30,000 tons of ore per day are obtained, the grade being slightly in excess of 1 per cent.

The geology of the Globe - Miami district has been well summarized by Peterson (1952). The geological column extends from the Pre-Cambrian to the Gila conglomerate of Quaternary age, but the mineralization is associated with the Laramide revolution, during which largescale north-easterly trending faulting occurred and large bodies of diabase were intruded along these faults. Subsequently granitic activity took place with the production of the Schultze granite and accompanying granite porphyries. The ore is mostly associated with the granite porphyry and with the diabase, which shows an intimate association with the ore, e.g. the Castle Dome orebody is symmetrically arranged with regard to a sill of diabase and the copper content of the sill is usually at least double the copper content of the surrounding rocks; additionally the quartz monzonite, adjacent to the sill is substantially richer in copper than is the average ore.

Secondary enrichment of the orebody mostly took place before the deposition of the Gila, but some is thought to have occurred later. Oxidation has resulted in the production of chrysocolla as the main oxidized copper mineral and very few carbonates are present. However chrysocolla does not occur at the surface over the whole orebody and much of it is represented by maroon limonite which is typically derived from leaching of chalcocite.

Copper is recovered at Inspiration - Miami entirely by leaching. About 12 per cent of the production is obtained by circulating acid waters through caved ground and the remainder is won by leaching the present production in vats. The ore is crushed to ½inch and is fed into 13 tanks, each containing 10,000 tons. Each tank is leached for

8 days, after which the copper-charged solution is sent to the electrolytic tank house, where the copper is precipitated and is later electrolytically refined.

The basic reactions of the leaching process depend on the presence of ferric sulphate as well as of sulphuric acid, as the leaching of chalcocite requires the presence of ferric iron. The first reaction which takes place may be written thus :-

The ferric sulphate is thus reduced to ferrous sulphate. During the precipitation of the copper however, the ferrous sulphate is converted back into ferric sulphate and these active solutions are again utilized.

The extraction obtained by these methods is approximately 85 per cent. The acid required is made on the mine from native sulphur which is imported from Texas. It appears as though the acid leaching of copper ores may continue to expand and may in the future enable the working of lower grade ores than has been possible in the past.

Bingham Canyon, Utah.

The Bingham Canyon mine is the most important copper producer in the world with an output of 90,000 tons of ore per 24 hours, the ore containing 0.93 per cent Cu. 0.05 MoS_2 and about 35 cents in gold. Mine production is equivalent to an annual output of approximately 300,000 tons of copper, 15,000 tons of molybdenum concentrates and 500,000 oz. of gold. It is generally necessary to remove about 130,000 tons of waste rock for every 100,000 tons of ore mined.

Contrary to the views which have normally been expressed in the past, the present geologist, Russel Anderson, believes that large quantities of primary ore extend in depth and that this ore is not very much below the grade of 0.9 per cent which has been mined in the past.

A second important point concerning the geology of this deposit is that Bronson Stringham, Professor of Mineralogy at University of Utah, believes that the so called Bingham stock has been formed essentially by replacement i.e. that it is due to some form of granitization, and this is an important point in considering the genesis of the ore deposits (Stringham, 1952). As far as I was able

to ascertain, no diabasic rocks occur in or around this deposit and it is therefore difficult to relate it genetically to the deposits already described in Arizona and New Mexico.

High-grade streaks and veins of copper ore have been known and exploited in the Bingham Canyon district for many years, but the mining of the disseminated ores in the porphyry was commenced by B.C.Jacklin, Kennecott engineer, who was the first to consider that this was possible economically. His successful exploitation of the Bingham deposit followed by that at Ray, Arizona, initiated the large-scale exploitation of the porphyry copper deposits which has revolutionized copper production in the U.S. and has for many years dominated the world copper market.

At present, geological work carried out at Bingham does not seem very exciting or original and consists in laying out a sufficient number of bores to ensure that mining remains within the prescribed limits of grade.

However, the geological knowledge of the deposit is maintained at a high level and north-south sections as well as east-west sections are taken through the deposit at 100 ft. intervals;in order to keep these sections up to date continuous mapping is required.

The ore deposit is approximately 2,600 ft. by 2,800 ft. and has been open-cut to a depth of 2,000 ft. from 29 levels. The mining operation requires 2,400 men, which however, is a small number for the production obtained. Mining is by benching, the ore being loaded on to electric trains by means of 40 shovels.

As in the case of all porphyry copper deposits, the degree of fracturing is high, and it has been estimated that 50 per cent of the ore is obtained from fractures and 50 per cent from minerals disseminated in the rock.

Alteration has also been extensive and has been well described by Stringham and Taylor, (1950). In connection with this work, Stringham (1952) has also given a most useful summary of the temperature conditions and the conditions of acidity under which various hydrothermal alteration minerals form. Bureau geologists are referred to this paper.

Butte Montana.

Bute, Montana, has been referred to as the richest hill on earth,

and, in fact, over a length of about 2 miles an enormous production of copper and zinc have been obtained. For many years the cut-off grade was 8 per cent copper and, even now, they do not bother very much about mining ore of less than 3 per cent grade if its occurs in bodies less than 20 ft. wide. It was not uncommon in the past to mine large bodies of ore containing 20 to 30 per cent copper as a primary mineralization. In inspecting extensive mine workings at Bute, one sees copper (chalcopyrite and bornite) scattered throughout large areas of granitic rock and there is no doubt that the hill as a whole represents an enormous geochemical anomaly.

The geology of Bute has been discussed by many authors and below are given only a few features noted by myself :-

The Bute deposits occur at the southern end of the Boulder granitic bathylith of Tertiary age which is about 60 miles long and 40 miles wide. Only small quanitities of ore are associated with most of this bathylith and no one has yet been able to give an adequate reason as to why the copper concentration occurs where it does. There has certainly been a large amount of fracturing where the ore deposits occur and it seems likely that this part of the granitic body remained active when most of the rest of the granitic material had become solidified. There is a good deal of rhyolitic activity around Bute which is not common in the rest of the region and although this rhyolite is post-ore in age, Anaconda geologists have assumed that the rhyolite is in some way connected with the granite. Thistends to bear out the suggestion given above.

At present Anaconda is commencing mining of disseminated ores of a grade of approximately 1.6 per cent Cu which occurred in the walls of the high-grades lodes which have been mined in the past. To this end the Kelly shaft has been sunk and large-scale development has been carried out with a view to caving. Planned production from the Kelly Shaft is 15,000 tons per day but, at present, only about 5,000 tons per day are being obtained, because great difficulty is being experienced in holding the ground from which large lodes have formerly been mined.

After nearly a century of mining probable reserves at Butte are still very large and drilling has indicated the presence of about 160 million tons of ore which is available for block caving between the surface and the 3,400 ft. level. However, other possibilities indicate that there may be 450 million tons to a depth of 3,400 ft. To this level ore could be caved over a width of about 150 ft.

Interesting sidelights on Butte mining are that it is difficult to obtain American miners for many of the caving operations and Mexicans are largely employed for this purpose. In fact, a good deal of the copper mining industry of the West U.S. now depends on Mexican labour. The second interesting point is that in the workings from the Kelly Shaft there is a central radio station and radio transceivers are attached to all ore trains, supply trains, etc. By means of this equipment it is possible to maintain a very good traffic control which is very necessary in these complex workings, and it is also possible to save a large amount of time, because foremen and others are able to order supplies and forward information in very quick time from distant and inaccessible workings.

As is well known, the Anaconda Company at Buttehas generally maintained a geological staff of high quality and Anaconda geologists generally consider that they are the best in the world. Although some that I met did not seem very bright, the record of the Company is impressive in that, at Bute itself, mining and exploration have been kept at a high level of efficiency and a vast amount of mineral has been found, while in addition, the geological staff has played a large part in making Anaconda the most important copper producing company in the world. It is in this position partly owing to its large holdings in South America where it controls the vast Chuqimata deposit (2.5 miles long by 0.75 miles wide) as well as Chile Exploration, Andes Copper and Porta Reales; Kennecott produces more copper within the U.S.A. where it is responsible for 46 per cent of total production. The Butte area has been mapped several times at a scale of 1 inch to 40 ft. and all of this mapping has been compiled on the 1 inch to 50 ft. mine working plans.

CONCLUSIONS AND RECOMMENDATIONS

ORE POSSIBILITIES FOR AUSTRALIA

Diamonds in Australia.

The knowledge and experience of the South African experts on the geology of diamonds, suggests that diamonds could occur in areas such as the Kimberley Division of Western Australia.

Rhodesia - Congo and Rum Jungle.

The many similarities which exist between the general geology, the type of mineralization, the metal association and the oxidation histories of the Rhodesia - Congo copper belt and the Rum Jungle district of the Northern Territory, suggest that important deposits of copper, uranium and possibly cobalt, which would not necessarily look impressive at the surface, might occur in the A ustralian district.

Gneiss and Uranium.

A study of Lake Athabaska geology shows that important uranium deposits may occur in gneissic provinces and that the Australian red felspar-uraninite type of occurrence may bear further examination.

Criteria for Porphyry Copper Deposits.

The descriptions of the various porphyry copper deposits of the South-Western U.S. given above provide means whereby potential deposits of this type could be recognized in Australia. Besides granitic and porphyritic activity, it may be necessary to have preceding basic igneous activity for the development of a copper province of this type.

Big M ines for the Future.

The day of small-scale vein mining is passing and it appears as though important production will come in the future from very large deposits disseminated in igneous rocks or in beds. Australian geologists should be paying attention to the search for masses of rock which contain unusual quantities of various metals which perhaps may not be mined immediately but would be important resources for the future. Geochemical knowledge is needed in this search.

Geology, Geophysics and Watersupply.

In the light of overseas practice, Australia and the Bureau do not appear to be paying sufficient attention to the development and conservation of water-supplies, which all admit, are of maximum importance to this country. By contrast, South Africa, England and the U.S.A., for example, pay a great deal of attention to these matters which are largely geological and geophysical in nature.

Criteria for Copper in Basalts.

Australia has important basaltic provinces, but the search of these for copper deposits without geological aids is a very big task. For the occurrence of deposits of economic importance, it appears necessary to have large thicknesses of basalt, which have been folded down into regions of metamorphism, where mobilization of the copper content of the rocks has occurred enabling the concentration of native copper in porous flow-tops. In productive districts signs of this mobilization in the form of abundant calcite, prehnite and native copper deposition, are found.

TECHNIQUES OF ORE SEARCH

Importance of Drilling

In all countries where success is being obtained in the search for new deposits, the science of drilling is of the utmost importance and geologists, recognizing humbly their lack of real knowledge of sub-surface conditions, use drilling to obtain geological information as well as to test for the presence of payable quantities of metals.

Integration of Geology and Geophysics.

In South Africa the successful search for ore based on geological and geophysical principles has depended, to a very large extent, on a very close liaison between these two subjects. The geologists know a good deal about geophysics, and geophysicists are well acquainted with geology. This is made possible by initial training in both these subjects within the universities and by a close working collaboration between the various specialists.

Geochemistry, Coming Science.

The study of theoretical geochemistry and the collecting of geochemical data are increasing rapidly in all countries visited by me and it seems probable to me that geochemistry will be just as important in searching for new ore deposits as is geophysics at the present time. Chemistry is widely used in Rhodesia and in the Congo for the search for ore and its applications to the study of oxidized capping, which was partly pioneered within the Bureau, is finding increasing application and will supplement or replace some geological and geophysical techniques.

Rock Alteration.

Precise rock alteration studies are becoming routine on many deposits especially in North America and are important guides to ore, especially perhaps in large deposits in granitic rocks.

Comprehensive Approach.

Without attempting to imply that geologists should study everything, irrespective of its proved relationship to ore occurrence, it is necessary to emphasize that there are fashions in geology, as in everything else, and that the almost total concentration of interest on structural geology during the past 10 years has not been very sound. Such concentration on particular aspects leads to extensive under-estimation of the complexity of the problems associated with the search for new ore deposits and has, in fact, cost Australia and other countries quite a lot of money. It also leads to a lack of humility on the part of geologists, which tends to prevent them from persuing other possible fruitful lines of investigations.

SUGGESTIONS FOR BUREAU.

Introduction.

The following suggestions are offered with the feeling that the Bureau is performing a very important task in Australia, that the author is not fully conversant with many of the activities of the Bureau which, however, he knows to be important; and that in some aspects, the Bureau is possibly in advance of most other organizations in the world. The air-photo mapping techniques employed in Australia - largely pioneered by the North Australian survey and by the Bureau - are thought to be superior for our purposes to most of those seen abroad. Very few organizations also have our extensive geophysical knowledge and experience while the enthusiasm and energy of the

personnel are also quite striking when compared with those of some other organizations. In the light of my experience abroad however, it is suggested that the following matters, which affect the efficiency of the Bureau, could receive attention.

Geology and Geophysics Not Integrated.

All experience abroad indicates that there is too sharp a division between the geological and geophysical activities of the Bureau. Neither geologists nor geophysicists have received sufficient training in both sciences, and this position is not remedied by the fact that they rarely see each other.

Level of Australian Training, Low.

The degree of training given to geologists in most Australian Universities is fairly low compared with that obtained within most European and American Universities. This is a position which cannot be easily remedied, because in many cases, Australians students have not sufficient money and the universities are not sufficiently well endowed to extend the courses to the levels obtaining elsewhere. If this position is recognised, it is logical that training and wide reading should continu e within the Bureau, for without this, we tend to be simply mining the treasure of knowledge gained by our staffs within the universities and the treasure is not being replenished. It is suggested that geologists should spend less time gathering field data, as at present they are compelled to spend virtually their whole time gathering this data and compiling it on maps, often at two or three scales. Frequently this leaves them no time to digest and sort out the information gathered, and to read and discuss adequately the big volume of published material relevant to their investigations. Under these circumstances, although they are gaining practical experience in the recognition of rock s and in the compilation of data, their thought tends to atrophy and they are in danger of remaining at the level at which they left university or even of forgetting a good deal of their original knowledge.

Combined with these disadvantages are the fact that publication within the Bureau tends to lag and the younger geologists generally speaking do not have time for the preparation and publication of papers in outside journals. The lack of opportunity for reading and lack of the chance to publish may lead to a position in which some people leave the staff and others tend to degenerate into 9 to 5 hacks, such as are to be found in some other organizations in Australia. If the quality of the future work of the Bureau depends primarily on the quality of the men who will constitute its staff, and it is definitely a function of the Bureau to develop the available talent, rather than to exploit it.

These remarks do not apply to me, as I have had considerable opportunities, but I feel that they apply to our permanent field geologists.

Chemistry Needed.

During its birth-pangs, the Bureau has not been able to provide sufficiently for adequate chemical, geochemical and petrologica investigations. This position is now being remedied, but is recommended that a first-class chemist, at least equivalent to Senior Geologi» or possibly Superintending Geologist in status, should be appointed t/ initiate and lay down sound lines for the chemical work of the Bureau Good laboratories are of course a feature of most overseas organizations of comparable size, and the use of modern equipment requires the mos extensive knowledge and experience. A couple of young graduates would not have much hope of carrying out what is required.

Water-supply Neglected.

It is thought that in some ways the Bureau is the natural organization to formulate and carry out a national water policy which could contribute greatly to the development of this country.

Availability of Plans and Reports.

Canada has shown that it is possible to make available quickly the salient results from field investigations carried out by the geological surveys. It is believed that we should avoid any tendency to bury our plans and numerous reports in archives and that even incomplete studies should be made available to those who can use them. Our unpublished report series contains already a great deal of useful information but, probably, much of this is not used by the public, possibly for the reason that the public does not even know of its existence. Possibly some sort of a review to publish some of these reports, or at least list them in print, would be of considerable advantage.

ACKNOWLEDGMENT.

I am extremely grateful to the Bureau of Mineral Resources, Geology and Geophysics, to the Department of National Development and to the Australian Government, for having given me an opportunity to examine mines and mineral deposits and to meet geologists in wide areas of the world.

The tour has cost the Australian people a considerable sum of money and it is hoped that the information contained in this report may in turn be of value in the discovery of further wealth in Australia. I would be only too happy to discuss further, with those interested, the deposits which I saw abroad, to show them the maps and specimens obtained, and the numerous coloured photographs taken. I sincerely hope that partly as a result of this visit, the Bureau may be able to discover new big ore deposits in the future.

REFERENCES
(In order cited)

Frost, A., McIntyre, R.C., Papenfus, E.B., and Weiss, O., 1946: The Discovery and Prospecting of a Potential Gold Field near Odensaalsrust in the Orange Free State, Union of South Africa. Trans. Geol. Soc. S. Africa, 49, pp. 1-24.

Brock, B.B., 1950: The Vredefort Ring. Trans. Geol. Soc. S. Africa, 53, pp. 131-144.

Kay, Marshall, 1951: North American Geosynclines. Geol. Soc. Amer., Mem. 48.

Wade, Arthur, and Prider, R.T., 1940: Leucite - Bearing Rocks of West Kimberley, Q.J.G.S., 156, p. 39.

Davidson, D.M., 1931: The Geology of Chambishi, Northern Rhodesia, Econ. Geol., 26, pp. 131-152.

Gray, Anton, 1930: The Correlation of the Ore-Bearing Sediments, of the Katanga and Rhodesian Copperbelt. Econ. Geol., 25, p. 788.

Garlick, W.G., and Brummer, J.J., 1951: The Age of the Granites of the Northern Rhodesian Copperbelt. Econ Geol. 46, pp. 478 - 497.

Vaes, J.F., 1948: La Benierite. Ann. Soc. Geol. de Belg., Tome 72, pp. 19 - 32.

Oosterbosch, R., and Schuiling, H., 1951: Copper Mineralization in the Fungarume Region, Katanga. Econ. Geol., 46 (2), pp. 121-148.

Bastin, E.S. 1933: The Chalcocite and Native Copper Types of Ore Deposits. Econ. Geol. 28 (5), pp. 407-443.

Lang, A.H., 1952: Canadian Deposits of Uranium and Thorium. Geol. Surv. Can., Econom. Geol. Series No. 16.

Robinson, S.G., 1952: The Occurrence of Uranium in the Lake Athabaska Region. Can. Min. & Met. Bull., 45 (480), pp. 204-207.

Mawdsley, J.B., 1952: Uraninite - Bearing Deposits, Charlebois Lake Area, Northern Saskatchewan. Can. Min. & Met. Bull., 45 (482), pp. 366-375.

Knight, C.W., 1917: Geology of Sudbury Area. Rpt. of Ontario Nickel Commission. pp. 105-211.

Yates, A.B., 1948: Properties of International Nickel Company of Canada. Structural Geology of Canadian Ore Deposits. Can. Inst. Min. & Met. p. 602.

Price, Peter, 1948: Horne Mine. Structural Geology of Canadian Ore Deposits. Can. Inst. Min. & Met. pp. 763-772.

Lovering, T.S., 1949: Rock Alteration as a Guide to Ore, East Tintic District, Utah, Econ. Geol. Mon. No. 1

Sullivan, C.J., 1952: The Mt. Elliott Mine, Selwyn, Queensland, Comm. Bur. Min. Res. Geol. & Geophys. Rpt. No. 1952/32 (unpub.)

Newhouse, W.H., 1942: Ore Deposits as Related to Structural Features. Princetonp

Sullivan, C.J., 1950: Mineral Exploration in Australia. Fourth Empire Mining & Metallurgical Congress. London. pp. 269 - 291.

Thomson, J.E., 1943: Geology of McGarry and McVittie, Townships, Larder Lake Area. Ont. Dept. Mines, Vol 50(7).

Sullivan, C.J., 1948: Ore and Granitization. Econ. Geol. 43, pp. 471 - 498.

Tyler, S.A., 1949: Development of Lake Superior Soft Iron Ore from metamorphosed Iron-Formations, Bull. Geol. Soc. Amer. 60, pp. 1101-1124.

Broderick, J.M., Hohl, C.P., and Eidemiller, H.N., 1946: Recent Contributions to the Geology of the Michigan Copper District. Econ. Geol. 41, pp. 712 - 713.

Trusk, P.D. (Editor), Applied Sedimentation. p. 18.

Edwards, A.B., and Baker, J.S., 1951: Some Occurrences of Supergene Iron Sulphides in Relation to their Environment of Deposition. Sed. Petrol. 21 (1) pp. 34-46.

Garrells, R.M., and Dryer, R.M., 1952: Mechanism of Limestone Replacement at Low Temperatures and Pressures. Bull. Geol. Soc. Amer. 63, pp. 325-379.

Tarr, W.A., 1936: Origin of South-Eastern Missouri Lead Deposits Econ. Geol.

Bastin, E.S., 1939: Geol. Soc. Amer. Spec. Pap. No. 24.

Hess, F.L., 1933: Ore Deposits of the Western States, p. 473. Am. Inst. Min. & Met. Eng.

Fischer, R.P., 1937: Sedimentary Deposits of Copper, Vanadium, Uranium and Silver in South Western United States, Econ. Geol. 32, p. 906.

Fischer, R.P., and Hilpert, L.S., 1952: Geology of the Uravan Mineral Belt. U.S.G.S. Bull. 988-A.

Reinhardt, E.V., 1952: The Distribution of Uranium - Vanadium Deposits in the Colorado Plateau Relative to Tertiary Intrusive Masses. U.S.A.E.C. Grand Junction.

Clarke, Otis M., 1952: Structural Control of Ore Deposition at Ray, Arizona. Arizona Geol. Soc. Guide Book p. 91.

Steel, H.T., 1952: San Manuel Copper Deposit. Arizona Geol Soc. Guide Book p. 91.

Peterson, N.P., 1952: Structural History of Globe Miami District, Arizona Geol. Soc. Guide Book p. 123.

Stringham, Bronson, 1952: Geology and Hydrothermal Alteration of the Bingham Copper Mine. Geol. Soc. Amer. Field Trip Guide.

Stringham, Bronson, and Taylor, Allen, 1952: Natronite at Bingham, Utah, Amer. Miner 35: 1060 - 1066.

Stringham, Bronson, 1952: Fields of Formation of Some Common Hydrothermal Alteration Minerals. Econ. Geol. 47, pp. 661 - 664.