NOTES ON THE GEOLOGY AND MINERAL DEPOSITS OF CANADA AND AUSTRALIA -

A COMPARISON BASED ON AN EXCHANGE VISIT WITH THE GEOLOGICAL SURVEY OF CANADA FEBRUARY 1966 TO MARCH 1967

by

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INTRODUCTION

From February 1966 to March 1967, the writer worked with the Geological Survey of Canada under an exchange agreement between the Geological Survey of Canada and the Bureau of Mineral Resources. For part of this time, he worked with Dr. S.M. Roscoe, who is engaged in metallogenic studies in the Central Part of the Canadian Shield, and he visited parties carrying out studies of particular groups of mineral deposits, Archaean volcanic rocks, Pleistocene deposits, and geochemistry in northern Ontario and western Quebec, and regional mapping parties in the North-west Territories. He also visited regional offices of the Geological Survey of Canada at Calgary and Vancouver, and the Resident Geologist's Office at Yellowknife, and he had opportunities to meet officers of the Provincial Geological Surveys in Ontario, Quebec, Saskatchewan and British Columbia, as well as geologists of many mining companies throughout the country. Eighteen major operating mines were visited, as well as numerous prospects, small producers and properties under investigation or development; the major mines included properties at Sudbury (Cu-Ni), Elliot Lake (U), Yellowknife (Au), Pine Point (Pb-Zn), Esterhazy (K), Noranda and Timmins (Cu-Zn), Cobalt (Co and Ag), Oka (Cb), Michipicoten and Steep Rock Lake (Fe), Sullivan (Pb-Zn), Bethlehem and Craigmont (Cu), and Boss Mountain (Mo).

This report is divided into three main sections. In the first, some general comments on the geology of Canada are given; the second contains descriptions of a number of current G.S.C. projects with which the writer had particularly close contact; while the third contains an accounts of major mines and mineral deposits visited by the writer, together with some notes on comparable Australia occurrences and some current theories of ore genesis.

GENERAL GEOLOGY

It is obviously impossible to give a full account of the geology of Canada within the limits of this report, and it is only intended to discuss a few features to which the writer's attention happened to be particularly attracted.

Broadly speaking, Canada consists of a Precambrian Shield with a total extent of almost 2,000,000 square miles, flanked by the St. Lawrence Lowlands and the Appalachian region to the east, and by the Interior Plains and the Cordillera to the west.

Rocks of the Precambrian Shield

Archaean:

Undoubted Archaean rocks predominate in the Superior Province, comprising the greater part of northern Ontario and northern and western Quebec, and the Slave Province, comprising the western portion of the North-West Territories. In the intervening Churchill Province, the rocks have been affected by the post-Lower Proterozoic Hudsonian orogeny, and their absolute ages have not been conclusively established, but it seems likely that considerable portions of this Province are also of Archaean age.

In areas of undoubted Archaean age, the dominant types are generally granitic, gneissic and migmatitic rocks, within which occur numerous elongated belts of sedimentary and volcanic rocks, up to several hundred miles in length and some tens of miles in width. These belts commonly also include sporadic occurrences of basic and ultra-basic rocks and locally important intrusions of granite, granodiorite and syenite. In these respects, the major areas of Canadian Archaean rocks are therefore closely comparable to the Yilgarn and Pilbara blocks of Western Australia.

For reasons which will become apparent in subsequent sections of this report, interest in areas of Canadian Archaean rocks has been very much concentrated in recent years on the dominantly volcanic sequences within the sedimentary - volcanic belts, and the available information on these sequences appears to be much more complete than that on comparable areas of Australia. However, the associated sedimentary sequences and the surrounding granite - gneiss complexes have not been studied in comparable detail, and in particular it is not at present possible to determine whether a consistent division can be established between an older series of gneisses of dominantly migmatitic origin and a younger series of granites with generally sharp intrusive contacts, such as has been postulated in parts of Western Australia, (e.g. Prider, 1965).

The large-scale relationship of these granite - gneiss complexes to the sedimentary - volcanic belts is also a question of considerable general interest. As in Australia, the granite -gneiss complexes at most Canadian localities are reported to intrude the sedimentary - volcanic sequences and to have sharp contacts showing features characteristic of magmatic activity, although wide zones of granitisation occur in a few areas, e.g. at Lake Opasatika, 15 miles south-west of Noranda. The only locality seen by the writer where these relationships are thought to be reversed is at Steep Rock, where a supposedly Archaean sedimentary - volcanic succession, including an iron ore member, appears to rest unconformably on a granitic basement.

In the areas where the granite - gneiss complexes show sharp intrusive contacts against the volcanic - sedimentary sequences, the width and intensity of contact metamorphism are generally slight in relation to the size of the granite - gneiss masses and in relation to the extensive migmatisation and granitisation which is evidenced by the relict structures commonly found in the gneisses. There seems to be at least a possibility, therefore, that the greater portion of these granite - gneiss complexes actually pre-dates the deposition of the sedimentary - volcanic sequences, and that local remobilisation of portions of the complexes accounts for the now observed intrusive contacts, (Gross & Ferguson, 1965). Any checks on these relationships by petrological or geochemical studies, either in Canada or Australia, would therefore be of considerable interest.

Proterozoic:

Apart from the high-grade metamorphic rocks of the Grenville Province, known Proterozoic sequences are best developed in parts of central Ontario, in the Labrador Trough and in scattered areas of the North-West Territories.

In Ontario, the most wide-spread and economically most significant Proterozoic succession is the Huronian, comprising a thick sequence of conglomerates, greywackes, quartzites, argillites and minor limestones, dated at about 2,100 to 2,200 million years (Aphebian), and extending intermittently from the northern shore of Lake Huron to the Quebec border in the vicinity of Noranda. This succession is of economic importance because it contains the uraniferous conglomerates of the Elliot Lake - Blind River area, and the greater portion of the silver - cobalt veins of the Cobalt and Gowganda areas.

Other Proterozoic sequences in central Ontario include the Animikie and younger rocks of the Port Arthur - Thunder Bay area and the Keweenawan of the Batchawana area north of Sault Ste. Marie. Of these, only the Gunflint Iron Formation (Animikie) was seen in the field by the writer.

The writer has no personal acquaintance with the rocks of the Labrador Trough, but from available reports they appear to be predominantly a shelf-facies sequence, no unlike that of the Hamersley Province of Western Australia. To the east of the Trough, equivalent rocks have been involved in an orogeny of Hudsonian age and the entire sequence is therefore referred to the Aphebian (Lower Proterozoic).

In the North-West Territories, there are a number of Proterozic sequences, some of which will be described more fully in the section on Regional Mapping. Briefly, the ages of some of the major successions are though to be:

Echo Bay, Great Slave and Hurwitz Groups:

Aphebian (Lower Proterozoic).

Dubawnt and Et-Then Groups:

Palaeohelikian (Middle Proterozoic).

Coppermine lavas and sediments:

Neohelikian to Hadrynian (Upper Proterozoic).

Diabase Dykes and Sills:

Diabase dykes and sills (dolerites in Australian usage) are very wide-spread in the Canadian Precambrian Shield and apart from their association with particular groups of mineral deposits, such as the Ag - Co veins of the Cobalt and Gowganda areas and the Au-and Co-bearing veins of the Sault Ste. Marie - Sudbury area, the main interest of this group of rocks appears to lie in the evidence which they provide for repeated widespread igneous activity in otherwise stable portions of the Shield. A systematic investigation of these rock types in the Australian Shield could therefore also be expected to provide results of considerable general interest.

The Grenville Province:

This region occupies a north-easterly trending zone of approximately 1,000 by 200 miles, extending along the south-east margin of the Canadian Shield, and is characterised by high-grade gneisses, granulites and amphibolites, and in part by prominent quartzites and marbles. It now appears to be generally agreed that the Grenville Province includes rocks of both Archaean and Proterozoic age, which underwent intensive deformation and igneous intrusion in the Grenville Orogeny, about 945 million years ago.

The north-western boundary of this Province is the Grenville Front, representing a relatively narrow zone, from a few hundred yards to a few miles in width, in which metamorphic grade and igneous activity show a rapid increase, and which generally truncates the structural trends of the adjoining Superior Province and the Labrador Trough.

Although faulting appears to play only a minor part in the location of the Grenville Front at the surface, the abrupt and on the whole rather linear character of the Front suggests that it may be indirectly controlled by a major deep-seated break or thrust, possibly representing a long-continuing structural trend, since it is also parallel to the axis of the Appalachian Geosyncline. The presence of such a major deep-seated feature is also supported by the occurrence of a major gravity low coincident with part of the Front in the Wabush Lake area of Quebec - Labrador.

In the southern part of Western Australia, notably to the south-east of Kalgoorlie, areas of high-grade metamorphic rocks of probably mixed Archaean and Proterozoic derivation show many features in common with the Grenville Province, and geophysical investigations of the boundaries of these areas against the less altered blocks, especially by gravity and deep seismic surveys, may again produce results of interest towards the elucidation of the history of the Shield as a whole.

The Arunta Complex of Central Australia also shows some striking resemblances to the Grenville Province in the dominant assemblage of rock types and mineral deposits and in its probable tectonic history.

Appalachian Region

The writer did not have an opportunity of seeing this region, but a strong similarity to parts of the Tasman Geosyncline is apparent from published reports, with a preponderance of Palaeozoic rocks, including some volcanic and pyroclastic sequences, and extensive occurrences of intrusive rocks, ranging from acid to ultrabasic.

Cordilleran Region

This is a very large and complex region, including the major mountain chains of Canada, and shows a strong zonal arrangement of both rocks and mineral deposits, which generally decrease in age from east to west. The most easterly part of this region is composed dominantly of Proterozoic and Palaeozoic rocks, including some major turbidite sequences, and the Sullivan lead-zinc mine has been the outstanding mineral producer of this area. In the central and western (coastal) parts of the region, Mesozoic and Tertiary rocks predominate, including very extensive occurrences of both volcanic and intrusive igneous rocks, and the main mineral deposits are disseminated copper and molybdenum occurrences and magnetite-rich copper and gold replacement deposits.

Pleistocene Deposits

Large portions of all the major Canadian regions, - Shield, Appalachians, Cordillera, Plains and Lowlands, - are covered by deposits of Pleistocene age, which include glacial deposits, (till, eskers and moraine deposits), as well as lacustrine and fluvial deposits, (mainly sands, gravels and clays), and which commonly attain thicknesses of some tens of feet and occasionally up to several hundred feet. These deposits have been extensively investigated, partly because of the information which they provide on the Pleistocene history of the area, and partly because of their intrinic importance as sources of sand and gravel, as shallow aquifers and as parent material of the soils in many of the better agricultural areas.

CURRENT G.S.C. PROJECTS

Regional Mapping

About 75% of Canada is now covered by geological maps at scales of 8 miles : 1 inch or larger, and all the G.S.C. regional parties visited by the writer in 1966 were working in areas which had already been covered by reconnaissance surveys and were concentrating on particular aspects of the local geology. Details of some of these projects are listed here mainly to give an indication of the type of investigation currently being undertaken by the G.S.C.

South Shore of Great Slave Lake (W. Reinhardt): This is an area composed largely of Archaean granites and granite gneisses, and the current mapping is intended to differentialte some of the major units within this assemblage and to establish their age relations. A major feature of this area is a group of east-north-east trending zones of deformation, up to five miles wide, associated with the MacDonald Fault system. These are sometimes referred to as "mylonitised zones", but the deformation has not been sufficient to obliterate original small-scale banding in the gneisses.

East Arm of Great Slave Lake (P. Hoffman): This is an area of Proterozoic sediments and minor volcanics, comprising the Great Slave Group, composed mainly of conglomerates, red shales, limestones and dolomites, and the Et Then Group, mainly of conglomerates and limestones. Both groups are cut by a number of very large diabase sills and occasional dykes. The total thickness of the sedimentary succession is of the order of 20,000 feet and the structure is an assymetric syncline with a gently dipping north limb and a steep and locally faulted south limb. Many of the carbonate beds consist almost entirely of beautifully preserved stromatolites, from a few inches to several feet in diameter, and including many compound and branching forms. The main purpose of the present study is to establish a detailed stratigraphic succession, which it is hoped to use for correlation with other Proterozoic sequences in the North-West Territories.

Coppermine River Area (R. Baragar): This area consists dominantly of flat-lying to gently dipping Proterozoic basaltic lavas with an estimated total thickness of about 10,000 feet, overlain by a comparable thickness of sandstone, shale and dolomite. Both the volcanics and the overlying sediments are intruded by a number of very large well-exposed diabase sills.

Mapping is currently concentrated on the volcanic rocks, which are thought to be related to the Muscox Intrusion. Chained and levelled traverses are being run across the succession and samples for chemical analysis are collected at 200-foot stratigraphic intervals. Samples are also collected from both lavas and sills for age determination and palaeomagnetic work.

Individual flows have been found to range up to about 150 feet thick, and most flows have vesicular or amygdaloidal tops. Native copper is sparsely disseminated through some of the flows, and there are also sporadic small quartz-carbonate-bornite-chalcopyrite lodes, several of which have been tested by shallow diamond drilling. Altogether, the assemblage is very reminiscent of parts of the Australian Antrim Plateau and Kurundi sequences.

Thelon River - Beverley Lake Area (A. Donaldson): This area is largely underlain by sedimentary and volcanic rocks of the Dubawnt Group (Middle Proterozoic), which has been sub-divided into six formations, comprising conglomerates, red-beds, volcanics, white sandstones and dolomites. These rocks are flat-lying or gently dipping and cover a total area of about 30,000 square miles. To the west, they are faulted against Archaean gneisses, but to the east they rest with a strong angular unconformity onArchaean greenstones and gneisses and on folded quartzites and conglomerates of the Lower Proterozoic Hurwitz Group. They are cut by a number of east-north-east trending faults which line up with the MacDonald Fault in the East Arm area of Great Slave Lake, and by a few north-north-west trending diabase dykes.

No significant mineralisation has been noted in these rocks up date, but conglomerates in the basal portion of both the Dubawnt and Hurwitz Groups are reported to show some similarity in general lithological and depositional characteristics to the uraniferous conglomerates of the Elliot Lake - Blind River area.

Rankin Inlet Area (W. Heywood): This is an area of Archaean greenstones, gneisses, granites and meta-sediments, which has previously been mapped on 8 miles : 1 inch scale by helicopter reconnaissance, and is now being re-mapped on 4 mile : 1 inch scale by ground traverses. Aeromagnetic maps and air photos at 1: 60,000 scale are available, but new photo coverage at 1 : 30,000 scale is to be obtained, and some colour photography is also to be undertaken.

Special Investigations

Studies of Particular Mineral Deposits or Groups of Deposits:

A number of investigations of particular mineral deposits or groups of deposits are currently being undertaken by G.S.C. officers, usually with an emphasis on laboratory studies, such as mineragraphy, trace element studies, age determination, lead and sulphur isotope determinations, etc. These include on the one hand Canada-wide investigations of deposits of a particular commodity, such as iron ore, nickel or lead-zinc deposits, and on the other hand case-history studies of individual deposits by groups of specialists, such as those recently undertaken at the Coronation Mine, Sasketchewan, and the Whalesback Deposit, Newfoundland. The results of most of these investigations have not yet been published.

Metallogenic Study of central portion of Canadian Shield:

A metallogenic study of an area of about 600 by 200 miles, between Lake Superior and Chibougamau, is being undertaken by Dr. S.M. Roscoe, and some 20 separate classes of mineral deposits have been recognised, based largely on age, mineral composition and association with particular rock types.

The most important of these classes are as follows:

1. Iron Formations associated with Archaean volcanic - sedimentary successions, such as Lowphos, Sherman Mine, Adams Mine, and the deposits of the Steep Rock and Michipicoten areas.

2. Massive sulphide deposits associated with Archaean volcanic - sedimentary successions, such as the Texas Gulf Sulphur Corporation ore body at Timmins and the Cu - Zn deposits of the Noranda and Mattagami areas.

3. Deposits associated with basic and ultra-basic complexes, such as the copper deposits of the Opemiska and Chibougamau areas, as well as minor Cu - Ni and asbestos deposits elsewhere in the area.

4. Deposits associated with late Archaean acid and intermediate intrusive rocks, especially the gold deposits of the Timmins and Kirkland Lake areas, and the gold and molybdenite deposits of the Val D'Or area.

5. Uraniferous conglomerates at the base of the Huronian succession, best developed in the Elliot Lake area.

6. Deposits associated with Proterozoic diabase dykes and sills, especially the Ag - Co veins at Cobalt and the Au - Cu veins of the Sault Ste. Marie - Sudbury area.

7. Ni - Cu deposits associated with the Sudbury irruptive.

Examples of most of these groups will be described more fully in subsequent sections of this report.

Investigation of mineralised Archaean volcanic - sedimentary successions:

This is part of a long-range study by Dr. A.M. Goodwin; the belt which is currently under investigation extends for a distance of about 400 miles from Porcupine, Ontario, via Kirkland Lake and Noranda, to Chibougamau, Quebec. In 1966, a number of traverses were laid out by Dr. Goodwin's party across this belt in the Kirkland Lake - Noranda area, where the average stratigraphic thickness of the volcanic succession is estimated at 20,000 to 30,000 feet. Along each traverse line, rock types and attitudes were recorded, using air photos and existing maps where possible, and samples for chemical analysis, trace element studies and thin section examination were taken at stratigraphic intervals of 500 to 1,000 feet, depending on quality of exposures, variability of rock types, etc.

Two major sub-divisions have been recognised within this belt; these consist of a dominantly basaltic sequence, overlain by a sequence of alternating rhyolites and andesites. The rhyolites are frequently fragmental and probably largely pyroclastic, while the andesites are commonly amygdaloidal, occasionally show flow breccias and frequently contain pillow structures. This sub-division is a matter of considerable economic importance, as gold deposits are commonly associated with the basic volcanics, while other mineral occurrences, and especially massive Cu- Zn sulphide bodies, show strong preference for the upper portions of some of the acid sequences and especially for the contacts of major rhyolite or phyroclastic units with overlying andesites (Goodwin, 1965). Moreover, a comparison of the Porcupine - Noranda - Chibougamau volcanic belt with two smaller, roughly parallel belts to the north, extending respectively from the vicinity of Red Lake to Lake St. Joseph, and from the vicinity of Kenora to Lake Nippigon, has shown that the proportion of acid volcanic rocks varies from belt to belt, and the number of Cu - Zn sulphide deposits within each belt depends not only on the area of the belt, but also on the proportion of acid volcanic rocks within it, which in this case increases from north to south (Goodwin, 1966A).

Diabase Dykes and Sills:

A study of diabase dykes and sills in the Precambrian Shield is being undertaken by Dr. W.F. Fahrig with the aim of grouping all known occurrences into swarms according to age, chemical and petrological characteristics, attitude and possibly association with particular groups of mineral deposits. From preliminary data, it appears that it will be possible to distinguish at least ten or twelve major swarms, ranging in age from about 2,500 to not more than 700 million years, and that some of these swarms contain several hundred individual dykes and extend over areas up to 1,000 miles long and up to 200 miles wide (Fahrig & Wanless, 1963).

In several areas, swarms of different ages overlap or intersect, and one of the conclusions from this study is that the Shield as a whole has been subjected to far more frequent igneous activity than had previously been realised, especially when the evidence of the diabase dyke swarms is combined with that of the carbonatite - alkaline igneous complexes in areas like the Chapleau - Kapuskasing - Moosonee zone, and certain circular structures such as the Manicouagan and Clearwater Lake "craters" in Quebec, which are regarded as relatively young (certainly post-Precambrian) volcanic vents. Ultimately, it may be possible to relate these various diabase dyke swarms to other features of tectonic significance, such as orogenies and major periods of granitic intrusion, but this does not appear possible at the present time.

In several areas, diabase dykes and sills appear to be associated with particular groups of mineral deposits, such as the Ag - Co veins of the Cobalt and Gowganda areas, the Au-and Cu-bearing quartz veins of the Sault Ste. Marie - Sudbury area, and the Ag, Pb-Zn and Cu-Ni deposits of the Thunder Bay and Port Arthur areas. However, there is at present insufficient information to determine whether the groups of diabase sills or dykes which appear to be most closely associated with particular groups of mineral deposits, show any distinctive characteristics, especially in trace element contents, which might be of value in clarifying the origin of these mineral deposits and in delineating additional areas of possible favourable economic potential.

Pleistocene Glacial Deposits:

The tracing of rock and mineral fragments in Pleistocene glacial deposits is being undertaken by Dr. H.A. Lee in order to perfect a method of using material in these superficial deposits as a guide to the underlying or near-by bedrock, and where appropriate, to mineral deposits in the bedrock.

The use of boulder trains as a guide to mineral deposits has of course been empirically employed for many years, but the present investigation is an attempt to develop this method on a statistical basis to the stage where optimum sample size and sample interval can be determined for any given set of connditions (Lee, 1965). The area selected for investigation in 1966 was part of an esker in Munro Township, north of Kirkland Lake. This esker, which has a width of about two miles and rises 150 to 200 feet above the level of the surrounding country, is part of a structure which has been traced, with only minor interruptions, for a distance of about 200 miles, roughly in a north - south direction. Similar structures, with roughly parallel trends, occur at intervals of approximately eight miles for the best part of a hundred miles to the east and west of the area under investigation. Most of these eskers are compound structures, composed of numerous superimposed sand and gravel ridges with a maximum total thickness of glacial material of about 500 feet. They are thought to be the product of deposition from sub-glacial streams during the final phases of retreat of the ice sheet, but the details of the process are not clear.

In Munro Township, ten pits, each twelve feet deep and 40 feet long, were dug in the crest of the esker at 2,000-foot intervals, using a back-hoe, and each pit was sampled over 4-foot vertical intervals and 8-foot horizontal intervals. The samples were then examined for the proportion of a distinctive rock type (dunite) in the 8mm to 16 mm fraction (count 200 pebbles) and the 3 mm to 8 mm fraction (count 400 pebbles), and determinations of the amount of magnetite, pyrope garnet and free gold in one cubic foot of material are also to be carried out. As a result of these investigations, it appears that peak concentrations of dunite pebbles, amounting to about 3% of the pebbles counted, occur about eight miles down-ice from the outcrop from which they are thought to be derived, and that this distance is independant of the size of the pebbles. Down-ice from this peak, the concentration decreases assymptotically, but up-ice it falls to zero some distance before the source is reached. Results for the magnetite, garnet and gold distributions are expected to show generally similar features.

In the case of till deposits, the same general features have been noted, but the distance of transport is of the order of a few thousand feet instead of several miles.

Geochemistry

Over the past few years, the G.S.C. has carried out pilot studies in a number of widely separated areas, representing most of the major geological environments encountered in Canada. These include investigations in the Cordillera (Ag-Pb-Zn veins at Keno Hills, Yukon), in the Appalachians (Cu-Pb-Zn lodes at Bathurst, New Brunswick), and in the Precambrian Shield (Au lodes in Archaean greenstones at Yellowknife, N.W.T. and Ag-Co veins in Proterozoic sedimentary rocks and diabase sills at Cobalt, Ont.). In each area, a variety of methods was tried, including stream sediment, water, residual soil, glacial material and bed-rock sampling. Generally, sampling of stream waters and stream sediments appears to have given the most encouraging results under Cordilleran and Appalachian conditions, while soil and/or bed-rock samples are required in the Shield. In addition, a number of biogeochemical investigations have been undertaken, involving the determination of trace elements in soils and in the leaves, twigs, bark, etc. of various plant species growing both above and remote from known mineral deposits.

During 1966, the main programme of the Section was an investigation in the Cobalt area, carried out by a party under Dr. R.W. Boyle. A total of about 3,000 samples were processed during the season, comprising rock samples, soils, glacial till, and spring and well waters. Elements determined included Hg by vapour absorption, Co, Mn, Bi, Ag and Ni by emission spectrograph, and Cu, Pb, Zn, As, Sb, Mo and W by fusion and colorimetric methods. The spectrograph was mounted in a trailer which was brought from Ottawa for the season, but the sample preparation and chemical laboratories were set up in the local School of Mines at Haileybury; eight students were engaged in sample preparation and routine chemical determinations.

In rock samples, - mainly diamond drill cores, - concentrations of all the metals were found to be anomalously high within about 100 feet of all known silver- and cobalt-bearing veins; the effect was most marked in the case of As, which attained concentrations of more than 50 ppm from a background of about 5 ppm, and Ag which attained values of 2 to 5 ppm from a background of about 0.3 ppm (Boyle, 1966). In surface samples, no recognisable anomalies could be recorded from areas where the veins were overlain by glacial clay, but anomalies were clearly recognisable in areas where the veins were overlain by soil or by up to 60 feet of till. In soil-covered areas, anomalies in the A horizon were consistently stronger than those in the B or C horizons, presumably due to the concentration of metal values by organic agencies (plant roots, etc.).

Geophysical Surveys

The G.S.C. is currently engaged in a series of joint Federal - Provincial regional aeromagnetic contract surveys, which have now been in progress for about five years and currently result in the publication of about 400 to 500 maps each year, mostly on a scale of 1 mile to 1 inch. These surveys have been of considerable value, not only in locating anomalies thought to be associated directly with ore bodies, but also in tracing geological contacts and other structural features in areas of poor outcrops or superficial cover.

Regional gravity surveys have also been carried out in several areas, and some major structural features have been delineated, e.g. the Chapleau - Kapuskasing - Moosonee gravity high in the central portion of the Shield; this is also a zone of late Proterozoic or younger carbonatite and alkaline igneous complexes, and probably represents a major zone of weakness or instability within the Shield.

The Survey is also carrying our experimental work on air-borne E.M. methods, especially the INPUT system, which is a refinement of the I.P. system and which has been shown to be capable of delineating shallow aquifers, as well as locating anomalies associated with both massive and disseminated sulphide ore bodies.

Among other successes, the method is credited with finding the anomaly which led to the discovery of the Texas Gulf Sulphur Corporation ore body north of Timmins. Radiometric surveys have also been used in areas where uranium mineralisation is known or suspected.

Conventional seismic surveys have been undertaken in connection with some special geological investigations, e.g. to elucidate the structure of the Cordilleran Foothills zone, and hammer seismic surveys have been used in connection with Pleistocene and Engineering Geology investigations. In 1966, a seismic survey was undertaken by the G.S.C. in the Elliot Lake area, and preliminary results suggest that it succeeded in providing some useful structural data within the Huronian succession, although the unconformity at the base of this succession could not be traced in detail by this method.

The G.S.C. has also carried out some colour air photo evaluation, and the preliminary conclusion was that about 50% more outcrop could be recognised in colour photos compared to black and white, but there was little improvement in the recognition of rock types. Some infra-red photography has also been carried out and the results appear to be of considerable interest to hydrologists, as it enables water from different sources to be distinguished, e.g. springs discharging into lakes.

Sub-divisions of the Precambrian and Tectonic Maps

Until a few years ago, Precambrian formations in Canada, as in Australia, were largely correlated on the basis of petrological and lithological features and similarities in degree and type of deformation and metamorphism. Thus the predominantly basic volcanic sequences of the Canadian Shield were referred to as Keewatin, the sedimentary sequences marked by a predominance of greywackes and related rocks were referred to as Timiskaming, and the granites and gneisses which intruded these formations were referred to as Algoman, and all these terms were regarded as having an absolute age significance. However, with the increasing availability of radioactive age determinations, and more detailed stratigraphic information, it has become clear that not all the rocks formerly grouped in any one of these classifications are strictly contemporaneous, and the terms are now used in a descriptive sense only.

Moreover, there has been a tendency until recently to group "undifferentiated Precambrian Rocks", especially those of high metamorphic grade, with areas of proven Archaean basement. As additional age determinations and more detailed stratigraphic work has been undertaken, many such areas have now been assigned a definite Proterozoic age, e.g. parts of the Grenville Province and parts of the area east of the Labrador Trough. By analogy with these changed interpretations, the possibility should be considered that some of the Australian rocks previously regarded as Archaean, e.g. the Willyama Series and the rocks of the Arunta Block, may also be considerably younger.

In an attempt to develop a standard nomenclature throughout the country, the G.S.C. have recently put forward a scheme for the sub-division of the Precambrian which, like the Bureau's proposals, involves a two-fold sub-division into Archaean and Proterozic, and a further sub-division of the Proterozoic into three main units, and which is largely based on radioactive age determinations by the K - Ar method.

However, the Canadian proposals differ considerably from the Australian scheme, both in the way in which the sub-divisions were selected, and in the absolute age of their boundaries. Essentially, the Canadian system is based on the dating of major periods of igneous activity and metamorphism, the ends of which are then taken as the upper boundaries of the various eras (Stockwell, 1964). In practice, the age selected for each of these boundaries is the mean of the available age determinations on rocks thought to have been involved in that cycle of activity, minus the standard deviation of that group of determinations.

For its general application to the major sedimentary and volcanic sequences of the Shield, this scheme implies the assumption that major breaks in deposition coincide with orogenies, and hence with peak periods of igneous activity and metamorphism, and this assumption cannot yet be regarded as proven, since only age determinations on igneous and metamorphic rocks are at present available in sufficient numbers to be used for regional correlation.

The major sub-divisions according to the G.S.C. proposals are as follows, with the Australian sub-divisions shown for comparison:

Canada				Australia	
Era.		Orogeny			
Hadrinian			600 m.y.		
			880 m.y.		
		Grenville			
Helikian	Neohelikian			Adelaidean	
			1280 m.y.		
		Elsonian			1400 m.y.
	Palaeohelikian				
			1640 m.y.	Carpentarian	
		Hudsonian			
Aphebian					1800 m.y.
			2390 m.y.		
		Kenoran		Lower Proterozoic	
Archaean					
					2400 - 2600 m.y.

The differences in the approach to the sub-division of the Precambrian in Canada and in Australia are reflected in the character of the Tectonic Maps of the two areas. The Tectonic Map of the Canadian Shield (G.S.C. Map 4-1965) groups rocks primarily according to the period of deformation and igneous activity in which they assumed their dominant present characteristics, so that for instance the "Grenville Province" comprises rocks of probable Archaean, Aphebian and Helikian age, which received their main deformation and metamorphism in the Grenville Orogeny. By contrast, the 1960 Tectonic Map of Australia is essentially a generalised geological map, on which as much structural information as possible has been superimposed, [illegible] and the rocks, as far as possible, are grouped according to their original date of deposition, extrusion or intrusion, as the case may be.

Compared to the Australian method, based on the selection of type sequences for at least two of the sub-divisions of the Proterozoic, the Canadian approach has considerable advantages when dealing with areas of igneous and metamorphic rocks, and it is amenable to the statistical evaluation of age determination data, but, as mentioned previously, its relevance to major unmetamorphosed sedimentary and volcanic sequences still has to be demonstrated. The Australian approach has the advantage of providing a physical standard of reference and comparison, but it is faced with the difficulties of choosing type sequences to represent a record of continuous deposition over the very long periods involved (several hundred million years), and of selecting time boundaries which should, as far as possible, also be relevant to major depositional sequences elsewhere on the continent.

A new Tectonic Map of Australia is currently in preparation (May 1968) and is expected to be much closer to the Canadian Map (G.S.C. 4-1965) than the 1960 edition. However, the principles to be used in the selection and presentation of units to be shown on this map have not yet been sufficiently clarified to allow a detailed comparison.

MINERAL DEPOSITS

Central Shield Area

Archaean Iron Formations

These range from magnetite-rich jaspilites, as at Lowphos and the Sherman and Adams Mines, to siderite and siderite-pyrite lenses, as at Michipicoten, and to goethite-hematite zones, as at Steep Rock Lake. They are all regarded by local geologists as examples of Algoma type iron formations, characterised by limited lateral extent and association with varying amounts of chert and tuffaceous rocks, and typically occurring as intercalations in major volcanic belts of dominantly andesitic composition (Gross, 1965).

Moose Mountain Mine (Lowphos): (Markland, 1966). This mine, situated 20 miles north of Sudbury, is operated by Lowphos Ore Ltd., a subsidiary of the Hanna Mining Co. A total of eleven lenses of magnetite-bearing iron formation, ranging up to 5,000 feet in length and 400 feet in width, are known in an area of about 5 by 3 miles. The deposits, together with associated cherts, tuffs and pyroclastic rocks, occur within a major succession of basic to intermediate volcanics, which generally trend northerly to north-westerly, and are intruded by granite and pegmatite to the south-west. The banding and contacts of the iron formation lenses generally conform to this trend, but some large-scale drag-folding occurs and the over-all structure may be a syncline with an overturned east limb.

One of the smaller lenses of iron formation (No. 6) occurs within about 200 feet of the granite contact and is of interest in showing fine inter-layering of magnetite-rich bands with layers of quartz and pegmatite, giving a migmatitic effect, but it is not known whether the quartz and pegmatite represent material introduced from the near-by granite or are derived by recrystallisation from originally siliceous interbeds within the iron formation itself. Approximately 1,500,000 tons of iron formation, averaging 30% total iron, are mined each year from this group of deposits, and are processed to yield about 600,000 tons of pellets with a grade of 64 % iron.

Sherman Mine, Timagami: (Moorhouse, 1946). This mine was scheduled to come into operation in 1967 with a production of 1,000,000 tons of pellets per year, involving the mining of about 3,000,000 tons of ore of average grade 22 to 25 % iron. Two main zones of iron formation, possibly representing opposite limbs of a syncline, have each been traced for about five miles in an east - west direction, and in September 1966 stripping of overburden had been commenced in three areas. The iron formation is very similar to that of the Moose Mountain area, except for the occurrence of slightly more abundant interbeds of red jasper and occasional carbonate-rich zones. Bands of black slate with spotty sulphide mineralisation (mainly pyrite) occur sporadically in the hanging wall of the main ore zone.

Adams Mine, Boston Township: (Dubuc, 1966). This mine, situated ten miles south of Kirkland Lake, is producing about 1,000,000 tons of pellets per year from 3,000,000 tons of iron formation averaging 22 % magnetic iron. This iron formation, interbedded with lean chert, occurs in a zone about five miles long, which forms the south limb of a major syncline. This zone is flanked on both sides by andesites, minor tuffs and some acid volcanics, and is cut by diabase, lamprophyre and syenite dykes. Magnetite is the dominant iron mineral in the main ore zone, but stringers, blebs and disseminated grains of sulphides, dominantly pyrite, are very wide-spread, especially in the cherty portions. There are also a few well-defined cross-cutting veins containing patches of coarse-grained sphalerite and galena.

Michipicoten Area: (Goodwin, 1966 B). In this area, lenses of massive siderite with some pyrite, up to 250 feet thick, are currently being worked by the Algoma Steel Corporation Ltd. at the G. W. McLeod Mine (underground mining) and the Sir James Mine (open cut). The ore is sintered before shipment and current production is about 2,000,000 tons of sinter per year. However, the original Helen Mine, which is now worked out, produced a hematite-goethite ore, very similar to that now being worked at Steep Rock, and there are also minor zones rich in magnetite and substantial quantities of banded chert-siderite formations and of pyritic chert. All these occurrences lie within a sedimentary succession which locally attains a thickness of about 1,000 feet, and which extends altogether over a strike length of about 40 miles. These meta-sediments overlie a major zone of acid volcanic and pyroclastic rocks, locally up to 10,000 feet thick, but the dominant rock types in the whole volcanic - sedimentary succession are again intermediate to basic volcanics, which attain a total stratigraphic thickness of the order of 30,000 feet.

In the vicinity of the existing mines, structural trends are roughly east-west; at the Sir James open cut the succession faces north, but is slightly overturned to the south.

Steep Rock Area: (Joliffe, 1966; Shklanka, 1966). In this area, two companies, - Steep Rock Iron Mines Ltd. and Caland Ore Co., - are currently mining a zone consisting dominantly of a soft goethite - hematite mixture with occasional patches of hard ore, some pyritic zones and a few inclusions of low-grade cherty banded iron formation. This zone attains a thickness of up to 300 feet and has been traced along the strike for a total distance of about eight miles. The ore is underlain by a leached zone with patchy manganese concentrations, locally known as Paint Rock, by banded carbonate-rich rocks and by local occurrences of conglomerate and grit, which appear to rest unconformably on a granite - gneiss complex. The ore is overlain by pyroclastics, locally known as Ash Rock, and by intermediate and basic volcanics. Numerous hypotheses have been advanced for the origin of the Steep Rock ore, ranging from emplacement by hydrothermal solutions to deposition as a bog iron ore or concentration as a lateritic residual deposit at an unconformity within the Archaean succession. However, current thinking (Shklanka, 1966 and G.A. Gross, personal communication) appears to favour the hypothesis that the ore was derived from a bedded iron formation, possibly a siderite - pyrite mixture like that at Michipicoten, by oxidation in its present attitude, i.e. post-folding. Circulating ground water is thought to be a sufficient agent to bring about such oxidation.

The entire ore zone was originally covered by Steep Rock Lake, and preliminary development, before mining could begin, involved the diversion of the river, draining of the lake and stripping of up to 100 feet of silt and gravel overburden by dredging. Both companies have carried out some underground mining in the past, but present production is entirely from open pits. Current production from Steep Rock Iron Mines is approximately 1,000,000 tons of ore averaging 54 % Fe, all of which is processed into pellets. At Caland, production is approximately 2,500,000 tons of ore per year, all of which is screened, with the lumps being shipped direct and the fines sintered.

<u>Theories of Origin of Archaean Iron Formations and Comparison with Australian Occurrences</u>: One of the most consistent features of all the iron formations described in the foregoing section is their close association with major occurrences of volcanic and pyroclastic rocks, and, except in the Steep Rock area, where no unanimity has been reached to date, it now appears to be generally accepted by Candaian geologists that the high concentrations of iron within these formations are due to re-precipitation of material derived from fumarolic vents related to this volcanic activity.

In Australia, Archaean banded iron formations with jaspilites (banded quartz-hematite and quartz-magnetite rocks) as the main constituents, are very wide-spread, and, as in Canada, commonly show a close association with volcanic rocks. However, most of the economically significent occurrences, such as the massive hematite ores of the Mount Goldsworthy and Koolyanobbing areas, are secondarily enriched lenses of direct shipping ore, controlled by structural features and by supergene processes related to the present or past erosion surfaces; Australian geologists have therefore generally been more concerned with the study of these structural features and supergene processes, rather than the derivation of the material in the protore (e.g. MacLeod, 1965). However, as far as the writer is aware, no features have been recorded from the Australian Archaean iron formations which could not be reconciled with at least partial derivation from fumarolic activity, possibly combined with pene-contemporaneous leaching of the volcanic rocks by either connate or circulating ground water.

Massive Sulphide Deposits associated with Archaean Volcanic - Sedimentary Successions:

This group is represented in the central portion of the Canadian Shield by the deposits of the Noranda and Mattagami areas, such as the Horne, Quemont and Lake Dufault Mines, and by the Texas Gulf Sulphur Corporation ore body at Timmins.

All the deposits in this group have a number of features in common. They all occur in rhyolite tuff or rhyolite breccia, commonly at or near the contact with stratigraphically overlying andesite or more massive rhyolite, they are broadly conformable to the attitude of the surrounding flows and often show banding parallel to this direction, and they have a consistent mineral assemblage, dominated by pyrite, pyrrhotite, sphalerite and chalcopyrite. Some of them are also associated with alteration pipes which are confined to the stratigraphically underlying rocks, several occur in areas of local thickening of the rhyolites, and some have sharp contacts, especially against the stratigraphically overlying rocks, which show little or no evidence of replacement.

These deposits are therefore thought by many local geologists to have originated contemporaneously or shortly after the formation of the host rocks and either immediately at the surface or under very shallow cover, possibly in part by direct precipitation of material from fumarolic exhalations, (Sharpe, 1965; Roscoe, 1965; Latulippe, 1966; Dugas, 1966; Hutchinson, 1965).

Lake Dufault Mine, Noranda area: This mine has a current production of about 500,000 tons of ore per year, grading 4.8% copper and 9.5% zinc. This is derived from an ore body which lies between 1,000 and 1,500 feet below the present surface, and is stated to have been found by diamond drilling largely based on structural considerations. The ore body consists of two main components: a lenticular A zone, which dips gently east, parallel to the attitude of the surrounding volcanic rocks, and a roughly globular B zone, which is regarded as the upper part of a pipe dipping steeply to the west, i.e. at right angles to the volcanic rocks.

The A zone consists essentially of massive pyrite, chalcopyrite, sphalerite and minor pyrrhotite, and occasionally shows banding, but there is no zonal arrangement of metal values. It lies at the contact of a rhyolite, in part brecciated, with an overlying andesite, which commonly shows pillow structure. Tuff bands, up to several feet thick, occur intermittently at both the upper and the lower contacts of the ore. Typically both contacts are sharp; locally the ore may invade the country rock at either contact, but this has been ascribed to re-mobilisation.

The B zone consists of the same mineral assemblage, but largely as irregular replacement bodies in the brecciated rhyolite which underlies the A zone. Near the top of the B zone, these veinlets and irregular bodies locally merge to form pockets of massive ore, which may then grade without any recognisable break into the A zone. The B zone is surrounded and underlain by zones of alteration characterised by chlorite, cordierite and occasionally garnet; on account of its distinctive spotted appearance, the cordierite-rich zone is locally known as dalmatianite.

Vauze Mine, Noranda area: This mine, which is now worked out, contained two separate ore bodies comparable to the A and B zones at the Lake Dufault Mine. One of these was a massive pyrite-chalcopyrite-sphalerite body, in part banded, which was located at the contact of a rhyolite with an overlying andesite and had a dip of about 45 degrees to the north-east, parallel to the attitude of the volcanic rocks themselves. The other ore body consisted of chalcopyrite as ramifying veinlets and disseminated grains and blebs in the upper portion of a pipe of altered chloritic rock; this pipe dips to the south-west, roughly at right angles to the attitude of the flows, but the actual contact of this pipe with the massive sulphide deposit is unfortunately not preserved because of disruption by a younger diorite intrusion.

Quemont Mine, Noranda area: This mine currently has an annual production of about 600,000 tons of ore, averaging 1.1 % copper and 2.3 % zinc; the aggregate production to date is about 13,000,000 tons of ore. This ore has been won from a series of shoots which extend from the surface to a depth of about 3,500 feet, and all of which are located within rhyolite breccia, generally close to the contact with a stratigraphically overlying porphyritic rhyolite. This rhyolite breccia is regarded as a stratigraphic unit which has been tectonically deformed, so that the ore shoots now lie at the crest and on the flanks of a structural dome. The core of this dome is intruded by quartz porphyry which is petrologically similar to the overlying porphyritic rhyolite. In the immediate vicinity of the ore, which may be massive or consist of ramifying veinlets (stringer ore), the rhyolite breccia is generally chloritised. Locally, sulphide fragments also occur in a breccia with a chloritic matrix; this may be due to selective replacement, but appears more likely to be due to brecciation of the sulphides after emplacement. The syngenetic theory by itself therefore does not account satisfactorily for the present distribution and characteristics of the ore shoots at this mine, but since this is apparently an area of considerable local deformation and post-volcanic igneous activity, it may be that these features could be explained by extensive deformation and local re-mobilisation of originally syngenetic ore bodies.

Horne Mine, Noranda: This mine, which is by far the largest in the Noranda area, consists of a number of ore bodies, of which the most important are the pipe-like Upper H and Lower H bodies, and the tabular No. 5 zone. All these now dip nearly vertically, parallel to the attitude of the surrounding volcanic rocks, and also show banding parallel to this direction. From south to north, i.e. stratigraphically upwards, the Upper H and Lower H bodies show a gradation from chalcopyrite-rich to pyrrhotite-rich and finally to pyrite-rich zones, while the No. 5 zone, which lies stratigraphically slightly above these bodies, is essentially a pyritic body with low sphalerite values. The Upper H and Lower H bodies extend from the surface to a depth of about 3,000 feet and are estimated to have contained some 50 million tons of sulphides, most of which has now been mined out; the No. 5 zone extends from about 2,500 to more than 8,000 feet below the present surface and is estimated to contain an even larger tonnage of sulphides, but only a small portion of this is of economic grade under present conditions.

All the ore bodies occur in rhyolite breccia, completely surrounded by massive rhyolite and rhyolite tuff, but major east-west faults occur immediately north and south of the mine, so that the contact with the overlying and underlying andesites are not exposed; the absence of any alteration pipe which could have acted as a vent or feeder may also be due to these faults.

Other Mines of Noranda and Mattagami areas: The writer has no personal knowledge of the remaining mines of the Noranda area (Waite, Amulet, etc.), or of those of the Mattagami area (Mattagami Lake, Orchan, New Hosco), but from published accounts their mineralogy, structure and general geological setting all appear to be very similar to the already described members of the group.

Texas Gulf Sulphur Corporation ore body, Timmins: This recently discovered ore body, 15 miles north of the town of Timmins, consists of two lenses of almost massive sulphides (chalcopyrite, sphalerite and pyrite), within a 2,000-foot rhyolite - pyroclastic - sedimentary sequence, lying between two dominantly andesitic sequences, which generally trend north - south with steep easterly dips. A small ultra-basic intrusion occurs about 2,000 feet east of the ore zone, and may be related to the emplacement of the sulphides, but this is conjectural. A band of graphitic schist, only partly replaced by sulphides, also occurs within the northern ore lens.

The ore body was originally overlain by from 10 to 80 feet of glacial clay, and was found by diamond drilling of an E.M. anomaly located by aerial survey. Reserves are currently estimated at 60,000,000 tons and production at the rate of 10,000 tons per day is planned as soon as the mill is fully operational. Underground mining is planned to commence in 1968 to supplement the production from the open pit.

Manitouwadge Area: The ore bodies of the Manitouwadge area, 550 miles west-north-west of Ottawa, show a general similarity of mineralogy and geological setting to the already described occurrences from Noranda and the Texas Gulf property, and their resemblance to the Broken Hill lode has been pointed out by King (1965 A), who suggested a possible syngenetic origin for them, although the original accounts of the area described them as hydrothermal replacement bodies (Pye, 1955; 1960). They lie within a belt of Archaean meta-volcanics and meta-sediments, of which the latter are now represented mainly by biotite gneisses, quartz-feldspar gneisses, garnetiferous gneisses and iron formation. Quartz-muscovite schist, locally referred to as sericite schist, also occurs in the immediate vicinity of some of the ore bodies and has been interpreted by some local geologists as a product of hydrothermal alteration related to the emplacement of the ore bodies.

The meta-volcanics and meta-sediments are folded into a large north-east plunging syncline, about three miles across, and are affected by several sets of faults, usually of small displacement (not more than a few hundred feet). They are also intruded by biotite granite and pegmatite, and are cut by diabase dykes.

The Geco ore body, worked by a subsidiary of Noranda Mines Ltd., with a strike length of about 2,400 feet and an average width of 65 feet, is the largest deposit in this area, and the only one visited by the writer. It is situated on the south flank of the syncline, dips almost vertically and pitches east at about 45 degrees, parallel to the regional pitch of the syncline.

This ore body consists of a zone of massive sulphides (pyrite, pyrrhotite, sphalerite and chalcopyrite), flanked by disseminated sulphides on both side, but with numerous sharply defined inclusions of unreplaced country rock even in the massive ore. The host rocks show very complex minor structures, including drag-folding, small-scale faulting and boudinage of beds and of aplite dykes. If this deposit was emplaced contemporaneously or shortly after the deposition of the surrounding sedimentary and volcanic rocks, it must therefore have undergone extensive deformation and probably some remobilisation.

Production at Geco is currently at the rate of about 3,000 tons of ore per day, and ore reserves were stated in 1964 to be 23,800,000 tons, averaging 2.1 % copper 4.5 % zinc and about 2 ozs. silver per ton. In general, the massive ore tends to be slightly richer in zinc and the disseminated ore slightly richer in copper. A slight decrease in zinc and increase in copper values is also reported with depth.

Theories of Origin: Until recently, all Canadian massive sulphide deposits, whether conformable or transgressive in relation to their host rocks, were regarded as hydrothermal replacement deposits, and the controls for their emplacement were thought to be entirely structural and lithological, although the importance of such features as the major rhyolite - andesite contacts at Noranda had long been empirically recognised (e.g. Wilson, 1941, 1948). However, as already stated, the conformable attitude of the Cu - Zn deposits of the Noranda and Mattagami areas and the Texas Gulf Sulphur Corporation ore body at Timmins, together with their consistent association with rhyolite tuff or rhyolite breccia, and the lack of evidence of replacement of stratigraphically overlying rocks, are now interpreted by most Canadian geologists as evidence for the pene-contemporaneous origin of these deposits and the enclosing rocks (e.g. Sharpe, 1965; Roscoe, 1965; Latulippe, 1966; and Dugas, 1966). This implies that the deposits must have originated either immediately at the surface or under very shallow cover, and some geologists go so far as to ascribe all the deposits to direct precipitation from fumarolic exhalations (e.g. Hutchinson, 1965). This hypothesis has also been supported by analogies with sulphide deposits associated with recent volcanic activity, especially in Japan and in the Valley of Ten Thousand Smokes, Alaska, and by the study of mineral textures and paragenesis (Stanton, 1960).

The writer feels that the "syn-volcanic" hypothesis accounts satisfactorily for most of the recorded observations at the Lake Dufault and Vauze Mines. At Texas Gulf, the occurrence of a graphitic schist band within one of the ore lenses suggests that at least a limited period of sedimentation intervened between the main period of acid volcanism and the emplacement of the ore. At Quemont, the ore bodies now show a close relation to structural features of tectonic origin, but since this is an area of relatively intense late deformation and igneous intrusion, these relations may be accounted for by re-mobilisation of the sulphides. At the Horne Mine, faulting limits observation of the rocks originally lying stratigraphically above and below the ore zone; all that can be said is that the available evidence is not inconsistent with an early origin of the sulphides, although this theory does not account for the fact that the long axes of all the major sulphide bodies at this mine are now nearly vertical. If these bodies had originally been deposited in a horizontal attitude, the long axes would be expected to show a random distribution within the plane of the flow after tilting. At Manitouwadge, the ore bodies are associated with meta-sedimentary rather than meta-volcanic rocks, and current interpretation favours a hydrothermal origin, but an analogy of these deposits with the Broken Hill lode has been suggested by King (1965 A).

For practical purposes, theories of the origin of the ore will have no immediate effects on exploration programmes in areas like Noranda, where the rhyolite - andesite contacts have long been empirically recognised as favourable locations for ore search, but they may assist in directing attention to favourable portions of other Archaean volcanic - sedimentary belts in which no major evidence of mineralisation has been discovered to date.

Comparable Occurrences in Australia and elsewhere: No base metal occurrances comparable to the Noranda or Texas Gulf Sulphur Corporation ore bodies have been found in Australia to date. In general, it appears that all the rock types recorded from the Archaean volcanic - sedimentary belts of the Canadian Shield are represented in the Australian Shield, e.g. in the Kalgoorlie - Norseman area, but that there are some differences in the major assemblages. In particular, it appears that acid volcanic rocks in Western Australia tend to be associated with major sedimentary sequences, especially of greywacke and conglomerate, rather than with basic to intermediate volcanics, as for instance in the Noranda area. Major pyrite concentrations are known from several of the Western Australian Archaean volcanic - sedimentary belts, e.g. at Norseman and Koolyanobbing, but these again show an association with sedimentary sequences, especially of banded iron formation, rather than with acid volcanic rocks, such as has been postulated for the above-described Canadian massive sulphide deposits. Nevertheless, in view of the fact that base metal deposits of the Noranda and Texas Gulf type would not be expected to give rise to prominent surface indications under the conditions of deep weathering and extensive cover of superficial deposits prevalent over most of the Western Australian Shield, some further investigations for the occurrence of this type of deposit are thought to be warranted.

Elsewhere, the copper - zinc deposits of Cyprus, although of Cretaceous age, occur in association with a dominantly volcanic succession and show many points of similarity with the above-described occurrences of the Noranda and Mattagami areas (Hutchinson, 1965); so do some Tertiary massive pyrite and pyrite-sphalerite-chalcopyrite deposits in Japan.

Deposits associated with Archaean Basic and Ultra-basic Rocks:

In the central portion of the Canadian Shield, ore deposits associated with Archaean basic and ultra-basic rocks comprise copper, copper-nickel and asbestos occurrences, especially in the Opemiska and Chibougamau areas. The only deposit of this group visited by the writer was the former Johns-Manville asbestos mine in Munro Township, which has produced some 10 million tons of ore, over a period of about 15 years. This mine consists of an open cut in a complex of dunite, pyroxenite, peridotite and gabbro, totalling about 1,000 feet across the strike. This complex is intruded into volcanic rocks, dominantly andesites, and is cut by younger diabase dykes. All the rocks of the complex are extensively altered, giving rise to zones rich in serpentine, talc and carbonates, but commercial fibre is only found in the dunite.

In Australia, the only major mineral deposits known to be associated with Archaean basic or ultra-basic rocks are the recently discovered high-grade nickel deposits of the Kambalda area, south of Kalgoorlie. The nearest equivalents to these in the Canadian Shield are probably the Cu-Ni deposits of Thompson and Lynn Lake in Manitoba, but these are not personally known to the writer.

Gold and associated Mineral Deposits of the Timmins, Kirkland Lake and Val D'Or areas:

The gold deposits of the Timmins, Kirkland Lake and Val D'Or areas, and the associated occurrences of bismuth, molybdenum, lithium, beryllium, etc. cover a wide range of conditions from replacement bodies associated with major systems of shears in dominantly volcanic or sedimentary sequences, to more localised systems of quartz veins and pegmatites intimately associated with particular granitic or syenitic intrusives.

In their geological setting, these deposits show a general similarity to the major gold occurrences of the Western Australian greenstone belts, but the writer did not see enough of these deposits to suggest detailed comparisons. The only members of the group visited by the writer were the Francoer Mine in the Noranda area, and the Lamaque Mine and the Molybdenum Corporation of Canada property in the Val D'Or area.

At the Francoer Mine (Hawley, 1948), which is a former small gold producer, about to be re-opened, the ore occurrences consist of a series of shoots in a major shear zone, dipping at about 50 degrees, which cuts a series of andesitic and minor rhyolitic flows. The shear zone is silicified and carries disseminated pyrite and specular hematite.

At the Lamaque Mine (Wilson, 1948), which is currently the largest gold mine in Quebec, with a production of about 700,000 tons of ore per year, averaging 3.5 dwts. of gold per ton, the ore occurs as a series of quartz veins occupying small reverse faults in a composite diorite - granodiorite plug. This plug is intruded into Archaean volcanic rocks, dominantly andesites, and is associated with minor quartz-porphyry dykes; several other, smaller plugs of similar composition are also known within one mile of the main workings. The main plug, with horizontal dimensions of about 800 by 400 feet, has been traced to a depth of more than 3,500 feet with a steep northerly pitch; within it the veins commonly strike east-west to north-east - south-west, and dip south at angles of 40 to 60 degrees, so that most of them lie approximately at right angles to the axis of the plug. The displacement of any of the reverse faults does not usually exceed 100 feet, and the spacing between the veins, although rather variable, is also generally of the order of 100 feet. The width of individual veins ranges up to 20 feet and most of them die out rapidly at the edges of the plug, but a few of the strongest persist for several hundred feet beyond the margin of the plug and make ore whenever they cross a slightly more competent member of the andesite suite or a quartz porphyry dyke. Occasionally, whole zones of closely spaced veins within the main plug or within one of the quartz porphyry dykes can be worked as a unit. In addition to quartz and free gold, most of the veins carry tourmaline, scheelite, pyrite, minor chalcopyrite and rare sphalerite. In spite of some differences in the mineralogy of the veins and the character of the host rocks, the over-all setting of this deposit bears a striking resemblance to some of the mines of the Woods Point - Walhalla area of Victoria, which occur in Devonian diorite dyke bulges.

At the mine of Molybdemun Corporation of Canada (Norman, 1948; Vokes, 1963), situated about 20 miles north of Val D'Or, approximately 250,000 tons of ore are produced annually from veins associated with a pipe of fine grained granite, approximately 1,000 by 400 feet in horizontal dimensions, which pitches to the south-west at an average angle of 30 degrees and is intruded into biotite schist of probably Archaean age. Two main sets of veins occur in the area. One of these strike dominantly east - west and dip moderately to steeply south at the surface, but flatten somewhat at depth; they commonly occur in the biotite schist just north of the granite contact and die out as they enter the granite. The other set strike approximately north - south and dip steeply either to the east or to the west; they generally occur within the granite itself. The east - west set are essentially quartz veins, while the north-south set are typically pegmatitic. In addition to molybdenum and minor bismuth minerals, both sets may contain non-economic amount of copper and beryllium. Muscovite is present in both sets and is generally regarded as a favourable indication.

Uranium Deposits of the Elliot Lake area:

(Roscoe, 1957 B; Pienaar, 1963; Lang, Griffiths & Stacey, 1962). The uranium deposits of the Elliot Lake area, in the Blind River district of Ontario, consist essentially of uraniferous pyritic conglomerates at or near the base of the Huronian (Lower Proterozoic) sedimentary succession, and constitute one of the world's largest known uranium concentrations. The total recoverable reserves of the area have been variously estimated at between 190,000 and 350,000 tons of U_3O_8.

The stratigraphy of this area is known in considerable detail, but there are a number of differences between the nomenclature currently in use by the G.S.C. (Pienaar, 1963; and Roscoe, pers. comm.), and that adopted by the Ontario Department of Mines (Robertson, 1966).

G.S.C.				Ont. Dept. Mines.	
Group.	Formation.	Lithology	Thick-ness	Formation.	Group.
Cobalt	Lorrain	Quartzite Jasper Congl. Qtz.pebble congl. Arkose	6,000' &	Lorrain	Cobalt
	Gowganda	Quartzite Conglomerate	2,000' &	Gowganda	
Quirke	Serpent	Quartzite Conglomerate Arkose	Up to 900'	Serpent	Bruce
	Espanola	Limestone Greywacke	Up to 600'	Espanola	
	Bruce Limestone		Up to 200'	Bruce Conglom.	
	Bruce Conglomerate		Up to 400'		
Hough	Mississagi	Arkose Greywacke	Up to 1750'	Upper Mississagi	
	Pecors	Argillite Greywacke	Up to 800'	Middle Mississagi	
	Wiskey Conglomerate				
Elliot	Nordic	Greywacke Argillite	Up to 200'	Lower Mississage	
	Matinenda	Manford,incl. Quirke & <u>Denison Reefs</u> Stinson Quartzite & polymictic <u>conglomerate</u> Ryan, incl. Stanleigh & Buckles Reefs	Up to 750'		
Residual Deposits			Up to 50'		
Basement					Basement

At Elliot Lake, the succession has been folded into a major open west-pitching anticline and syncline, each about 20 miles across, with dips on the limbs generally of the order of 20 degrees. All the known economic concentrations of uranium are in conglomerates of the Matinenda Formation, within a few hundred feet of the base of the succession and sometimes, as at the Pronto Mine, resting directly on basement rocks. These conglomerates are well sorted and contain practically no pebbles other than glassy quartz, generally from one to two inches in diameter, which are well rounded and relatively closely packed. Pyrite, which is confined to the matrix, comprises up to 10% and occasionally up to 20% of these beds. By contrast, conglomerates in the Gowganda and Bruce Formations are generally poorly sorted and contain a high proportion of granite boulders, commonly poorly rounded and not closely packed.

The major occurrences of economic uranium concentrations within the Matinenda Formation fall within three main south-easterly trending zones, within which the conglomerates and the Formation as a whole attain maximum thicknesses, and which coincide with depressions in the reconstructed pre-Huronian surface. The direction of transport during the deposition of these beds, from cross-bedding and pebble orientation, is thought to have been from the north-west.

The Denison Mine with an annual production of about 1,000,000 tons of ore averaging 2 to 3 lbs. U_3O_8 per ton, is the largest mine currently operating in the area. Most of the ore is won from room and pillar workings at depths of 1,500 to 2,500 feet, using trackless mining equipment and extensive underground conveyor belt systems. The ore zone is commonly of the order of 12 to 20 feet thick and generally consists of two closely spaced conglomerate beds, separated by a band of low-grate quartzite; the average dip is at 15 to 20 degrees to the south. Uraninite and brannerite are the main uranium minerals in the ore. Most of the geologists currently working in the area appear to acdept the origin of these deposits as placers, but this concept has been vigorously opposed by Davidson (1957; 1964), and the question cannot yet be regarded as being finally settled. Briefly, the main arguments for a syngenetic origin are the very consistent association of ore occurrences with a particular rock type - the oligomictic quartz pebble conglomerate, - and the apparent control of their distribution by depositional features, such as zones of maximum thickness of the Matinenda Formation. On the other hand, an epigenetic origin is favoured by the prevalence of pyrite and brannerite, neither of which are typical constituents of modern placers, and the relative scarcity of magnetite, monazite, zircon, etc., which normally are major constituents of such deposits. For further details, see Lang, Griffiths & Stacey (1962).

In Australia, the Lower Proterozoic Crater and Beestons Formations of the Rum Jungle area show certain similarities in their lithological characteristics and general geological setting to the host rocks of the Canadian deposits. They are weakly radio-active, but the radio-activity in the weathered zone is due to thorium rather than uranium, and the character of the primary mineralisation has not yet been established because of deep weathering, - locally in excess of 600 feet. Some further investigation of these beds appears, however, to be warranted.

Another Australian sequence showing a number of similarities to the above-described Canadian beds is the basal portion of the Fortescue Group of Western Australia, which contains several beds of pyritic auriferous conglomerate, formerly known as the "Nullagine Conglomerate". No significant concentrations of radio-active minerals have been located in these rocks to date, and they show generally poorer sorting and poorer rounding of fragments than those of the Elliot Lake area, and contain a wider range of rock types, including granite, chert, reef quartz, basic volcanic rocks and fragments of pre-existing conglomerates. Nevertheless, in view of the deep weathering, which is likely to have destroyed any near-surface indications of uranium concentrations which may have existed in these rocks, some further investigations may again be warranted.

<u>Ag - Co Veins of the Cobalt area</u>:

(Thomson, 1957; Boyle, 1966). In the Cobalt and Gowganda area, narrow but rich silver- and cobalt-bearing veins have been extensively worked. The Silverfield Mine at Cobalt was the only one of these visited by the writer. With a production of 200 tons of ore per day, averaging 20 ozs. of silver per ton, this is at present the largest operating mine on the field.

At this mine, the country rocks consist of Archaean greenstones, overlain by 120 feet of Cobalt Series sediments (Huronian) and 240 feet of post-Huronian diabase. The Cobalt Series sediments consist of at least three conglomerate bands separated by quartzite and greywacke, locally grading into argillite. The bulk of the high-grade ore occurs within these sediments, although the vein system persists into the greenstones below and the diabase above, and the deepest workings at the mine are about 500 feet below the present surface. A total of 15 separate veins have so far been recognised on the property, all striking about 070° and dipping within 5° of vertical. The width of individual veins ranges from less than ½ inch to a maximum of about six inches, but occasionally zones of closely spaced stringers and disseminated ore in the wall rock can be mined over total widths of up to 20 feet. The veins consist largely of arsenopyrite, cobalt and nickel sulphides and arsenides, native silver and argentite in a quartz - carbonate gangue. Pyrite, chalcopyrite and galena occur sporadically.

In the past, it has generally been assumed that the mineralisation of this area is derived from the diabase, but recent investigations (Boyle, 1966) have shown that the diabase itself is not abnormally rich in base or precious metals, and it has been suggested that the constituents of the present veins may originally have been derived from certain interflow bands in the underlying Keewatin (Archaean) greenstones, with the diabase intrusion possibly supplying the necessary conditions for the selective re-mobilisation and concentration of these constituents. These interflow bands, comprising mainly black slates, cherts and pyroclastics, are locally very rich in lead, zinc and copper sulphides, and often in silver, arsenic and bismuth, and there is reported to be a consistent concentration of rich Ag - Co veins in the immediate vicinity of some of these bands.

Ni - Cu Deposits associated with the Sudbury Irruptive:

(Cooke, 1948; Hawley, 1962; Kirwan, 1966). Some 18 mines with a total production capacity of more than 60,000 tons of ore per day are now in production or in an advanced state of development in this area. These are situated around the margin of a body of norite, grading into micropegmatite, which outcrops as an elliptical ring, generally 2 to 3 miles wide, and with axes of about 35 by 15 miles. The outer contact of this norite complex dips nearly vertically on the south rim of the structure, and dips inward at an average angle of about 45 degrees on the north rim.

The over-all structure of the area, however, is still subject to widely differing interpretations, one of the key problems being the age of the volcanic and sedimentary rocks within the norite ring. (These rocks were formerly referred to as the Whitewater Series). The Onoaping Tuff, at the base of this succession, is ignimbritic and might have originated from a ring fracture now occupied by the norite complex, but the overlying Onwatin Slate and Chelmsford Sandstone, although gently dipping, are intensely cleaved and indurated, at least in part, and it has been suggested by some workers that they pre-date the norite complex and may be as old or older than some of the rocks immediately adjoining this complex to the south (Thomson, 1957). One theory which is at present being given serious consideration by some workers would account for the whole Sudbury structure as an astrobleme, i.e. the product of a large meteorite impact (Dietz, 1964).

The only mine in this area visited by the writer was the Boundary Mine of Falconbridge Nickel Mines Ltd. at Onaping, 20 miles north-west of Sudbury. At this mine, the bulk of the ore occurs in brecciated granite gneiss, from a few tens of feet to several hundred feet from the norite contact. This ore ranges from massive to disseminated, occasionally showing banding due to selective replacement of some layers of the gneiss, but more frequently replacing the matrix of the breccia and leaving unreplaced rock fragments as inclusions. Such ore as occurs within the norite is also in brecciated zones, so that the emplacement of the ore at this mine must at least post-date the crystallisation and brecciation of the norite. However, good evidence for the settling-out of sulphides from the norite, including the existence of two immiscible phases (droplets of sulphides in a silicate matrix and vice versa), is reported to occur in some of the mines on the south rim of the irruptive; the ore in occurrences like that at the Boundary Mine must therefore represent re-mobilised material, or the mineralisation process must have covered a considerable time range, overlapping the period of consolidation of the irruptive itself.

The Gunflint Iron Formation:

(Goodwin, 1960; Moorhouse, 1960). This is a generally flat-lying formation of Animikie (probably late Lower Proterozoic) age, with a thickness of up to 800 feet, which occurs intermittently over an area of about 100 by 30 miles in the vicinity of Port Arthur, and which has been correlated with the Lake Superior iron formations of the U.S.A. (G.A. Gross, pers.comm.) The dominant rock types are banded chert, argillite and taconite, with minor jasper, pyritic black shale and silicified algal limestone. In places a basal conglomerate, up to 10 feet thick, rests directly on Archaean rocks with a strong angular unconformity.

The banded cherts commonly show intense brecciation and small-scale deformation, possibly as a result of slumping during the early stages of diagenesis. In places, chert bands up to an inch thick have been broken into fragments 3 to 6 inches in diameter, which are now embedded in an iron-rich or carbonate-rich matrix. Allowing for differences in weathering, these are very reminiscent of the material sometimes referred to as "chert breccias" in Northern Australia.

The argillites are fissile shales, possibly tuffaceous in part, and are very wide-spread throughout the formation. Pyritic black shales are less common; they usually contain fine-grained pyrite and marcasite following bedding planes, as well as coarser-grained blebs and concretions of the same sulphides.

The taconites are essentially rocks with a granular texture, possibly in part oolitic. The granules average 1 to 2 mm in diameter and may consist of iron silicates, carbonates, oxides or sulphides, or of mixtures of any of these, generally in a carbonate, chert or clay matrix.

According to Canadian usage, the whole assemblage is referred to as an iron formation, because substantial portions of it contain more than 15% iron. However, the succession contains no jaspilites (thin-banded rocks composed essentially of alternating layers of silica and iron oxides) and shows no obvious similarity to any major Australian iron formations, except for a possible resemblance of the taconite members of the Gunflint Formation to some of the lower-grade portions of the Upper Proterozoic Constance Range ferruginous beds (with which the writer is not personally familiar). On the other hand, the general rock assemblage is strongly reminiscent of the black shale - chert - algal limestone sequences of the Rum Jungle, Brocks Creek and MacArthur River areas, associated respectively with uranium, gold and lead-zinc mineralisation. In this connection, it may be of interest that a large number of small silver occurrences have been recorded from the Gunflint Formation, although it is possible that these are genetically related to younger diabase dykes and sills which are very widespread in the area.

A more general discussion of Proterozoic iron formations in Canada and in Australia will be undertaken in a later section of this report.

Mineral Deposits of the Grenville Province.

Only the western portion of this Province, in the vicinity of Ottawa, is personally known to the writer, and this contains a large number of mostly small mineral occurrences, including contact metamorphic and replacement magnetite bodies and pegmatitic mica, feldspar, beryl, apatite and uranium deposits. The nearest equivalent assemblage known to the writer from Australia is that of the Arunta Block in Central Australia, and it may be significant that this also appears to be an area which has undergone repeated granitic intrusion and metamorphism.

Mineral Deposits of the North-West Territories

Giant Yellowknife Gold Mines: (Campbell, 1948; Dadson & Bateman, 1948; Boyle, 1961). This mine is situated in a belt of Archaean meta-volcanics and meta-sediments, about three miles from the town of Yellowknife, and is worked from three shafts, the deepest being 2,000 feet. The ore occurs as rather irregular lenses and veins within a group of north and north-east trending shear zones, up to several hundred feet wide, which are characterised by the occurrence of chlorite, albite, sericite, quartz, carbonates and various sulphides, dominantly pyrite and arsenopyrite. Some of the shoots are highly siliceous and have sharp boundaries, others are characterised by high arsenopyrite concentrations and these generally have more gradational boundaries.

Away from the zones of shearing and alteration, the host rocks can be seen to consist of tightly folded dacitic and basaltic lavas, commonly composed of alternating massive and pillow-rich layers, often with gradational contacts. Minor intercalated slates, cherts and tuffs, and intrusive but probably related diabase dykes and meta-gabbro plugs have been recognised in places, and there are also a number of younger (post-ore) diabase dykes.

Production is currently at the rate of about 1,000 tons of ore per day, and reserves were stated at the end of 1964 to be 2,300,000 tons averaging 0.74 ozs of gold per ton.

In spite of some differences in mineralogy, there is a fairly close resemblance between these deposits and some of the Western Australian gold occurrences, such as the Kalgoorlie and Wiluna deposits.

Pine Point Mines:

(Campbell, 1957, 1966; Norris, 1965). These mines are situated south of Great Slave Lake, approximately 120 miles south of Yellowknife, in the Presqu'Ile Formation of Middle Devonian age. This information has been referred to as a reef, but wherever it is exposed in the existing workings, it consists of a cavernous, medium- to coarse-grained buff dolomite, up to 120 feet thick, which shows coarse but quite unmistakable bedding. It has a low regional dip to the south-west and is reported, on a regional scale, to pass laterally into shales to the north-west and into evaporites to the south-east. Away from the areas of mineralisation, the Presqu'Ile Formation typically contains traces of native sulphur and of bituminous material.

Three ore bodies have been exposed in pits to date; these all occur in areas where the only overburden consists of glacial deposits from 50 to 100 feet thick. Several other mineralised zones at depths of up to 1,500 feet are still under investigation in areas where the Presqu'Ile is overlain by other Palaeozoic formations.

The exposed ore bodies range up to 1,000 by 400 feet in horizontal dimensions and occupy almost the whole thickness of the Presqu'Ile Formation. In the O 42 ore body, which is the best exposed at the present time, a core of almost massive galena is surrounded by a zone of disseminated galena and sphalerite, and this in turn by a zone carrying only pyrite and marcasite. These zones are generally quite sharply defined, with irregular but more or less vertical boundaries, and the transition from high-grade ore to barren dolomite in places occupies less than 50 feet. The whole body is surrounded by a zone in which the colour of the dolomite is changed from buff to grey, and the porosity is reduced due to recrystallisation or addition of material.

The suggested origin of the ore body is by lateral secretion, possibly from the postulated laterally equivalent shales to the north-west. All the known ore bodies lie directly above the projected extension of the MacDonald Fault system, which is well exposed in the Precambrain rocks of the East Arm area, about 50 miles north-east of Pine Point, but the role of these faults in the localisation of the ore bodies is still a matter of some controversy. Most of the geologists at present working in the area seem to consider that the MacDonald Fault system has not been active in post-Precambrian times, but that a fault-line scarp in the Precambrian surface may have been responsible for a number of minor co-linear depositional and structural features within the Palaeozoic succession. Thus the O 42 ore body is associated with a gentle west-south-west trending arch, the axis of which is marked by a small breccia zone. Both these features trend parallel to the projection of the MacDonald fault, but the long axis of the ore body lies at a slight angle to this direction.

At the discovery locality, which has been known for more than 50 years, minor galena-sphalerite blebs and stringers are exposed in numerous shallow pits and trenches, but the nearest major ore body is more than a mile from this locality, and all the known major bodies are credited to geophysical methods of prospecting. ~~The~~ A recent (1965) published figure for the total ore reserves of the field is 17,500,000 tons, averaging 4.8% Pb and 7.4% Zn, but this is bound to increase substantially as additional information becomes available from some of the deeper mineralised areas which are now under investigation.

The nearest Australian equivalent to these deposits appears to be the "Devonian" lead mine in the West Kimberley district, which has a similarly simple mineralogy, occurs in generally similar rocks, and also is located in close vicinity to a Precambrian basement complex. In spite of the very limited size of the known ore shoots at this mine, some further investigation of this area may therefore be warranted.

<u>Echo Bay Mines</u>: These workings are situated about one mile from Port Radium on Great Bear Lake, about 250 miles north-north-west of Yellowknife, in an area of much altered hypabyssal and volcanic rocks of ? Lower Proterozoic age with minor intercalated sediments. At least four sub-parallel lode systems are known in the mine area, the largest of which has so far been traced for a length of about 800 feet. This lode typically consists of a central vein, up to two feet wide, associated with a network of stringers which gives a total mineable width of up to six feet. The main ore minerals are chalcopyrite, galena and argentite in a gangue of quartz, clay and carbonates. Occasional blebs of native silver also occur, and the central vein frequently contains vughs and open fissures. Production is currently at the rate of about 100 tons per day.

A number of old workings on veins of the same general type also occur in the Camsell River area, about 20 miles south of Port Radium.

Indian Mountain Lake: This prospect is situated 120 miles east-north-east of Yellowknife, about 15 miles north of the East Arm of Great Slave Lake, and consists of a massive lens of coarsely crystalline sphalerite, galena and pyrite at the contact of rhyolite and ? calcareous tuff with overlying meta-sediments (quartz-biotite-garnet schists), all of Archaean age. An estimated 1,000,000 tons of ore are reported to have been outlined by diamond drilling in this area.

Mineral Deposits of British Columbia

The mineral deposits of British Columbia, as previously mentioned, show a marked zonal arrangement from east to west. The eastern belt consists largely of lead-zinc deposits in a Proterozoic - Lower Palaeozoic sedimentary succession; the Sullivan Mine is the outstanding producer in this area.

The central belt is characterised mainly by disseminated copper and molybdenum deposits associated with Jurassic to Cretaceous acid and intermediate intrusive rocks. These range from classical porphyry-type copper deposits such as Bethlehem, to skarn-type replacement deposits, mainly in sedimentary and volcanic rocks of the Triassic Nicola Group, such as Phoenix and Craigmont on the one hand, and to deposits carrying molybdenum to the virtual exclusion of copper, such as Boss Mountain and Endako, on the other hand. In addition, this area also contains a number of properties which are at present in various stages of testing or development, such as Lornex near Bethlehem, a potential molybdenum producer at Alice Arm, and potential large tonnage low-grade copper producers in the Babine Lake and Stikine River areas.

Recent thinking by geologists concerned with the exploration and development of these deposits appears to play down the uniqueness sometimes attributed to porphyry copper deposits in the past; all the disseminated copper and molybdenum deposits are attributed to late hydrothermal activity associated with the intrusion of near-by acid to intermediate igneous rocks, and the precise final form of the deposit is thought to be largely controlled by the interaction of the volume and activity of available solutions, the extent and intensity of fracturing within the igneous rocks and their immediate environment, and the availability of various types of potential host rocks, such as limestones. This type of approach may be relevant to further exploration in parts of Eastern Australia, where ore bodies such as Mount Lyell and Mount Morgan show tonnages and grades comparable with known porphyry copper occurences, although their geological setting differs to some extent from that of typical examples of the group.

In the western or coastal belt of British Columbia, replacement deposits in Triassic and Jurassic rocks become the dominant types, but the intrusive rocks to which they are thought to be related are younger than those in the central belt, - dominantly Cretaceous to Tertiary. Massive sulphide deposits and hematite - magnetite deposits with some copper and minor gold are characteristic of this belt; the deposits of Vancouver Island, Queen Charlotte Islands and Brittania Beach are typical.

Pb-Zn Deposits.

Sullivan Mine: (Swanson & Gunning, 1948; Freeze, 1966). This mine, operated by Cominco (Consolidated Mining and Smelting Co. Ltd.) has a current production of about 2,500,000 tons of ore per year, and is still the outstanding mine of the Province in terms of cumulative production. The ore body consists of a main ore zone, up to 200 feet thick, and several small hanging wall zones up to 15 feet thick, all lying within the Aldridge Formation of ? Middle or Upper Proterozoic age. The ore zones are broadly conformable to the enclosing rocks and form part of a gentle arch with average dips of about 20 degrees to the north and north-east, but there are some rapid variations in thickness in the main zone, probably due to deformation subsequent to the introduction of the sulphides, including some overthrusting and probably some plastic flow.

The total horizontal dimensions of the ore body are of the order of 3,000 by 4,000 feet, and it shows a marked variation from a central zone composed essentially of massive pyrrhotite with minor galena and sphalerite, to a marginal zone composed essentially of alternating galena-rich and sphalerite-rich bands. Pyrite tends to take the place of pyrrhotite in these marginal portions. There is also some cassiterite in the central pyrrhotite-rich portion of the ore body and associated with a number of steeply dipping faults and fracture zones in the footwall rocks.

The Aldridge Formation in the vicinity of the ore body consists of argillites and graded greywackes (formerly described as quartzites), together with some probable slump breccias (formerly called conglomerates), all of which have in part been affected by later tectonic brecciation and have been locally tourmalinised, mainly in the footwall zone, or albitised, mainly in the hanging wall zone. The sequence is intruded by diorite dykes and sills, dated at 1,100 million years, but the age of the lead in the ore body has been tentatively determined as 1,360 million years, which does not correlate with any known period of igneous activity in the vicinity of the mine. Pyrite and pyrrhotite are widely disseminated through the sedimentary rocks in the vicinity of the mine, partly as small transgressive veinlets and partly as discrete grains which tend to be concentrated at the base of the graded greywacke beds.

The majority of published accounts appear to take a replacement origin of this ore body for granted, e.g. Swanson and Gunning (1948), and the most recent account (Freeze, 1966) still favours a replacement origin, largely on account of the zonal variations on metal values. However, by analogy with current theories of ore genesis as applied to ore bodies of the Noranda type on the one hand, and the Mount Isa type on the other hand, it may be worth while considering the possibility that the Sullivan ore body may represent a transitional stage between a replacement and a depositional environment, with the central massive portion representing material deposited almost directly from solutions or exhalations brought up through a vent or vents, such as the fractures associated with some of the tin-bearing zones in the footwall rocks, and the marginal banded portions being deposited from material which had been temporarily taken into solution and for which the re-precipitation may have been controlled by conditions in the sedimentary environment or even in part by biological processes.

Cu-Mo Deposits

Bethlehem Copper Corporation Ltd. (Carr, 1966). This mine, situated about 150 miles north-east of Vancouver, consists of a number of ore zones in brecciated or fractured zones at the contact of the Guichon quartz diorite (Jurassic) and the Bethlehem quartz diorite (? Cretaceous). Mineralisation consists of chalcopyrite, bornite, minor pyrite and some quartz and rare calcite, all in narrow veinlets and as disseminated grains, although small erratically distributed high-grade patches are occasionally encountered. In the vicinity of the ore zones, the host rocks are commonly chloritised and occasionally show local development of epidote. However, owing to the paucity of pyrite there is no zone of secondary enrichment, and many specimens show no obvious sulphide contents.

The known ore zones include the East Jersey (now mined out), the Jersey (currently producing), and the Huestis and Iona shoots (under development). Current production, from the Jersey open pit, is at the rate of about 10,000 tons of ore per day, the average grade being 0.6% copper and a trace of molybdenum.

Lornex Mining Corporation Ltd. This property, situated about five miles south-west of Bethlehem, is at an advanced stage of development, but no production has been obtained to date. As at Bethlehem, a series of ore shoots have been located in a mineralised zone which roughly follows the contact of a quartz diorite and a granodiorite, but some of the mineralisation also occurs in a pale-coloured rock, locally referred to as a felsite, which may be a bleached phase of the granodiorite. Several of the ore shoots have been outlined by pattern diamond drilling, and an underground test programme is currently in progress, although any large-scale exploitation of the ore bodies would have to be by open pit workings.

South Seas Mining Co. (formerly Trojan). This property, situated three miles north-west of Bethlehem, consists of a number of rather irregular, locally high-grade chalcopyrite-bornite shoots in a sheared, chloritised and locally tourmalinised igneous rock, possibly originally a diorite. No production has been recorded to date, but the ore zone is currently being tested by small-scale underground workings.

Craigmont Mines Ltd. (Carr, 1966).

This mine, which is a member of the Placer Group of Companies is situated at the southern margin of the Guichon batholith, about 25 miles south of Bethlehem, and consists of a flat-pitching group of ore shoots in a series of impure calcareous beds of the Triassic Nicola Group. This group also includes cherts, greywackes and ? andesites or andesitic tuffs; in the vicinity of the ore zone all these rocks have been extensively altered and the minerals resulting from metamorphic and metasomatic processes include actinolite, garnet, hematite, magnetite and chalcopyrite. At the time of the visit (February 1967), about 5,000 tons per day of stockpiled ore was being treated in the mill, but no mining was in progress, as the mine was changing over from open pit to underground workings. Published reserves amounted to 20 million tons of ore, averaging 1.84% copper.

Boss Mountain Mines. This mine, which is a subsidiary of Noranda Mines Ltd., is situated 100 miles north of Bethlehem at an elevation of more than 5,000 feet and currently has a production of about 1,000 tons of ore per day, averaging 0.4% molybdenum. The main ore zone which plunges to the south at an average angle of about 50 degrees, consists of a brecciated zone, in part quartz-filled, in a ? Jurassic quartz diorite. A high-grade quartz vein, up to four feet wide, lies to the east of the main ore zone; in addition, mineralisation locally extends into a group of younger lamprophyric dykes, and disseminated pyrite and molybdenite also occur in the surrounding massive quartz diorite.

Prospecting for disseminated copper and molybdenum deposits in British Columbia. Many of the properties described in the preceding sections of this report have been developed as a result of detailed investigations in areas to which attention had originally been directed by the occurrence of small high-grade prospects; some of these prospects had been known for more than 50 years before the occurrence of the associated large low-grade occurrences was established. Both geochemical (including bio-geochemical) and geophysical (including I.P. and magnetic) surveys have been used on a number of these properties to delineate favourable zones for final evaluation by diamond drilling; in some areas, however, concentrations of pyrite, pyrrhotite and/or magnetite occur separately from the ore bodies, so that local conditions have always to be taken into account in the interpretation of I.P. and magnetic anomalies.

For regional prospecting, if areas of more than a few square miles have to be covered, stream sediment geochemical surveys are reported to have given good results in many areas.

Mineral Deposits of other areas

Esterhazy Potash Mine. (Klingspor, 1965; Sasketchewan Department of Mineral Resources, 1965). This mine, situated in Sasketchewan, 120 miles east of Regina, is operated by International Minerals and Chemical Corporation, and is currently producing about 2,000,000 tons of ore per year, grading more than 25% K_2O equivalent. The ore is obtained from the Prairie Evaporite Formation, which has a total thickness of about 600 feet and consists largely of halite (NaCl) and sylvite(KCl), with minor carnallite ($KCl.MgCl_2.6H_2O$), anhydrite and clay.

The Evaporite Formation is part of the Middle Devonian Elk Point Group, which also includes carbonates and red beds (shales), and extends over a total area of about 120,000 square miles. The regional dip of the Group is to the south-south-west at about 30 feet per mile, but it is everywhere unconformably overlain by Mesozoic and younger rocks, and is not known at depths of less than about 2,000 feet below the present surface.

In the Esterhazy area, three main potash-rich zones occur in the upper portion of the Evaporite Formation, but only one of these, at a depth of about 3,150 feet from the surface, is at present being worked. This is being mined by room and pillar methods over a vertical height of 7 ft. 6 ins., giving about 40% extraction. Continuous mining machines with 7 ft. 6 in. diameter rotary cutting heads are used at the working faces, and the ore is moved by shuttle cars and conveyor belts to a loading pocket at the shaft. The ore ranges in grain size from 0.1 to about 1.5 inches, and does not usually show fine bedding; a clay-rich band, about two feet from the floor of the workings, is used to line up the mine workings on a day-to-day basis.

Separation of sylvite from halite is by flotation; to date the halite has no commercial value and is stock-piled. A second shaft, which will enable production to be doubled, was expected to go into operation during 1967.

The deposits were originally discovered in the course of exploratory drilling for oil, and gamma ray logs are said to give the most reliable indications of potash-rich zones in exploratory drill holes. For the whole of Sasketchewan, workable deposits (beds from 5 to 10 feet thick, grading not less than 25% K_2O equivalent, at depths of less than 3,500 feet) are estimated to contain 6,400,000,000 tons of ore. An even larger tonnage is thought to occur at depths of more than 3,500 feet and may be available for solution mining (Sasketchewan Department of Mineral Resources, 1965).

<u>Oke Columbium Deposits</u>. (Rowe, 1958; Gold, 1963; Gold et al, 1967). The "Oka Complex" is situated about 20 miles west of Montreal city; it occupies an area of about 4 by 2 miles and consists of two ring structures, each made up of a very large number of concentric layers of alkaline igneous rocks and calcite-rich rocks. Among the igneous rocks, ijolite, jacupirangite, okaite and various lamprophyric types are characteristic, while the calcite-rich rocks have been classified according to the predominant associated minerals, which include apatite, biotite, magnetite, olivine, pyroxene, garnet and occasional sulphides, as well as pyrochlore (niobate and fluoride of calcium and rare earths), niocalite (niobium calcium silicate), and niobium-bearing perovskite (calcium titanate). Most of these calcite-rich rocks show prominent banding parallel to their contacts with the inter-layered igneous rocks, which in turn are parallel to the trends of the ring complexes as a whole. The origin of these calcite-rich rocks is not yet fully understood, and they have been variously described as carbonatites, Grenville marbles or metamorphosed Palaeozoic limestones, but the high niobium and rare earth contents, the structural setting and the association with alkaline igneous rocks all appear to be characteristic of a carbonatite occurrence. The complex as a whole is thought to be of Palaeozoic age, probably Devonian, and is intruded into Precambrian gneisses and granulites.

Two main ore zones, each with horizontal dimensions of the order of 500 by 100 feet are at present being mined by open pit and underground methods by St. Lawrence Columbium and Metals Corporation. Production is at the rate of about 400,000 tons of ore per year, averaging 0.5% Cb_2O_5, from which a concentrate grading 50% Cb_2O_5 and less than 1% Ta_2O_5 is prepared. The highest grade ore is found in some of the calcite-rich rocks intercalated between major layers of ijolite and okaite, but smaller amounts of niobium are present in practically all the rocks of the complex, and several other companies hold areas within the complex which are capable of large-scale development if the demand for the metal should warrant it.

No columbium-bearing alkaline complexes have been recorded in Australia to date, but there are several areas which may warrant testing for occurrences of this type. Of these, the most promising is thought to be the vicinity of the Mud Tank apatite-magnetite-zircon prospect in the Strangways Range, N.T., which recent work by the writer (publication in prep.) has shown to have many of the characteristics of a carbonatite, although its niobium and rare earth contents, as far as is known at present, are well below economic concentrations. Other areas of possible interest include the syenite-trachyte complexes of the Benambra area in north-east Victoria, the Port Cygnet (Tas.) and Mount Dromedary (N.S.W.) alkaline complexes, and the volcanic plugs (lamproites) of the Fitzroy Basin (W.A.).

Mineral Deposits of the Appalachian Region

No mineral deposits in this region were visited by the writer, and information is restricted to published data. Apart from the asbestos deposits of the Thetford area, current economic development in this region appears to be centred on complex base metal sulphide deposits such as those of the Bathurst area, New Brunswick, which are regarded by some geologists as syngenetic deposits, generically related to near-by volcanic or pyroclastic rocks (Stanton, 1959, 1960), and which appear to have some features in common with the deposits of Captains Flat and with some of the minor base metal sulphide lodes of the New England district. The deposits of the Cobar region also show some features characteristic of this group of deposits, although published accounts do not record any major occurrences of volcanic or pyroclastic rocks among the immediate host rocks of these deposits (e.g. Russell and Lewis, 1965).

SOME RECENT THEORIES OF ORE GENESIS IN RELATION TO IRON FORMATIONS AND MASSIVE SULPHIDE DEPOSITS IN CANADA AND AUSTRALIA.

Iron Formations.

Both in Canada and in Australia, a number of significant differences can be recognised between iron formations of Archaean and Proterozoic age. The only Canadian Proterozoic iron formation seen by the writer was the Gunflint Formation of the Port Arthur area, as described in an earlier section of this report. However, it is clear from published accounts that the major North American Proterozoic iron formations and iron ore deposits, including the occurrences of the Lake Superior region and the Labrador Trough, closely ressmble the Australian occurrences of the Middleback Ranges and the Hamersley Ranges, while differing considerably in several important respects from the already discussed Archaean occurrences. Essentially the Archaean occurrences (Algoma type of Gross, 1965), as already stated, are of limited lateral extent and are closely associated with major sequences of volcanic rocks, while the Proterozoic occurrences (Superior type of Gross, 1965) are generally of much greater lateral extent and typically occur within major sedimentary sequences which include quartzite, carbonaceous shale, dolomite and chert, with only very subordinate volcanic rocks, if any. As already described, a derivation from fumarolic exhalations or volcanic hot springs appears to be generally accepted for occurrences of the Algoma type in Canada, and a comparable origin for the Australian Archaean occurrences is possible. However, in the case of the Proterozoic (Superior type) occurrences of both countries, the great lateral extent of many relatively minor stratigraphic units shows that the major constituents of theses beds, such as iron and silica, were very evenly distributed throughout large portions of the sedimentary basins, and this appears to be a strong argument against the derivation of these constituents from purely local sources, such as centres of volcanic activity.

However, irrespective of the ultimate derivation of these constituents, it seems to the writer that the most promising approach for a better understanding of the genesis of these formations lies in a study of the exact conditions of sedimentation, especially in relation to such features as the variation in iron - manganese ratio and the relation of iron formations to iron-free chemical precipitates, such as cherts and dolomites, and to clastic sediments, such as shales.

In this connection, it would be of interest to have some systematic comparative data on the distribution of trace elements in some of these formations and in associated rocks, particularly (1) in magnetite- and siderite-bearing members of individual areas and in associated pyritic cherts and pyritic black shales, (2) in deposits of Archaean age (Algoma type, associated with volcanic rocks) and of Proterozoic age (Superior type, remote from volcanic rocks), and (3) in pyritic cherts and pyritic black shales associated with iron formations and in comparable rocks associated with massive sulphide deposits.

Massive Sulphide Deposits.

As indicated in earlier sections of this report, the adjective syngenetic has been applied to a number of major massive sulphide ore bodies, both in Australia and in Canada, but there are important differences in the setting of some of these deposits and in the processes which are thought to have been involved in their emplacement. Thus, although there is some overlap and there are some deposits which do not fit easily into this classification, these deposits may be divided into three main groups.

1. Cu - Zn deposits directly associated with major volcanic sequences, especially with sequences showing an alternation of acid pyroclastic rocks and intermediate pillow lavas. These may be of various ages, but many of the best examples are found in the Archaean greenstone belts of the Canadian Shield, including the previously described Lake Dufault, Vauze, Quemont, Horne and Texas Gulf deposits. No comparable deposits have so far been recorded in Australia, but pyritic Cu - Zn deposits associated with Cretaceous volcanic rocks on Cyprus are regarded as members of this group (Hutchinson, 1965).

2. Pb - Zn - Cu deposits associated with shales, tuffs and agglomerates, typically of Palaeozoic age, e.g. in the Bathurst area of New Brunswick and the Captains Flat area of N.S.W. A very full account of the syngenetic theory applied to this group of deposits has been given by Stanton (1959, 1960), who emphasised that two factors are essential for the formation of such deposits: Firstly an adequate supply of the matallic constituents, which may have been derived largely from fumarolic activity, and secondly suitable conditions for the re-precipitation and preservation of these constituents, which are thought to be provided most readily by an off-shore reducing environment with fairly slow clastic sedimentation,

such as would be characterised by a black shale facies, possibly associated with tuffs or tuffaceous shales and limestones or dolomites.

This group therefore provides a link between Group 1, which are directly associated with major volcanic sequences, frequently to the virtual exclusion of any clastic sedimentary rocks, and Group 3, in which a recognisable sedimentary environment is a characteristic feature, but which show only a very tenuous association with volcanic or tuffaceous rocks.

In addition to the examples listed by Stanton, deposits which show some of the features characteristic of this group include the Cobar deposits of N.S.W. and the Pb - Zn - Cu deposits of the Sudbury Basin.

3. Pb - Zn deposits, frequently in a black shale environment, commonly associated with limestone or dolomite. This group has received most attention in Australia, since it includes the large deposits of Mount Isa, MacArthur River (N.T.) and Broken Hill (N.S.W.). In historical sequence, a syngenetic origin was first suggested for the Broken Hill lode (King & Thompson, 1953), and then for Mount Isa (Knight, 1957; Fisher, 1960). However, the MacArthur River deposit (Cotton, 1965), which occurs in the least altered and deformed rocks, will probably supply the best evidence for the syngenetic origin of this group of deposits when it is fully exposed. This deposit lies within a Middle Proterozoic black shale formation closely associated with dolomite and dolomitic reef breccia.

At Mount Isa, the assemblage is very similar, especially if the silica-dolomite, which is the host rock of the copper mineralisation, is regarded as largely derived from a sedimentary formation, possibly even a reef formation (Bennett, 1965).

At Broken Hill, extensive deformation and high-grade metamorphism have destroyed much of the evidence regarding the depositional environment of the host rocks of the lode, which are now largely sillimanite gneisses, but the succession also contains some beds of banded iron formation, which are generally accepted as being of sedimentary origin, and which show that conditions were favourable for the deposition of at least some metal-rich sedimentary formations (Carruthers, 1965).

In Canada, there are several deposits which show varying degrees of resemblance to one or other of the above-described ore bodies.

The Manitouwadge deposits have been described a hydrothermal replacement bodies by Pye (1955, 1960), but certain similarities between the host rocks of these deposits and those of Broken Hill lode have been pointed out by King (1965 A). In composition, however, the Manitouwadge deposits are more nearly comparable to those of Group 2 (Cu, Zn, some Pb), or even to Group 1 (Cu, Zn only).

The Broken Hill lode has also been compared to occurrences at Franklin (New Jersey), Balmat and Edwards Mines (New York), New Calumet Mine (Quebec), and the Anacon Mine (Montauban-les-Mines, Quebec), although there are some minor differences in mineralogy and in the constitution of the host rocks (King, 1958).

The Sullivan Mine, B.C., also shows a number of features characteristic of this group of deposits, although the majority of published accounts appear to take a replacement origin of this ore body for granted, e.g. Swanson & Gunning (1948), and the most recent account (Freeze, 1966) still favours a replacement origin, largely on account of zonal variations in metal values.

A number of minor Pb - Zn sulphide occurrences have also been recorded from a Proterozoic black shale environment in the Ungava Bay area of Quebec (Gilbert, 1960), but the attitude of the lodes to the host rock was not described.

In Australia, another group of deposits which show some similarity with the Mount Isa and MacArthur River occurrences are the uranium and base metal deposits of the Rum Jungle and South Alligator areas, N.T., for which a largely syngenetic origin has been proposed by Condon and Walpole (1955).

Recapitulation: The Syngenetic Concept in Canada and Australia

The origin of both banded iron formations and conformable massive sulphide deposits has been extensively investigated both in Canada and in Australia during recent years, but there are noticeable differences in the approach to these topics in the two countries, due to the fact that the major deposits, on which most studies are based, differ in several important respects.

In Canada, such studies have been concerned largely with the Cu - Zn sulphide deposits of the Noranda area and the iron formations of the Michipicoten area, all of which are closely associated with thick volcanic sequences and some of which, such as the Lake Dufault and Vauze deposits, are closely associated with alteration pipes which show all the expected characteristics of fumarolic vents.

In Australia, on the other hand, the conformable Pb - Zn deposits of Broken Hill, Mount Isa and MacArthur River, and the Proterozoic iron formations of the Middleback Ranges and the Hamersley Ranges have dominated recent concepts of ore formation. Most of these deposits are associated with some rocks of volcanic or tuffaceous origin, but the dominant features of the environment in each of these areas are sedimentary successions, in some instances with a marked development of a black shale - limestone or dolomite association.

For these groups of deposits, suitable conditions of sedimentation, probably in an off-shore reducing environment, are thought to have been a necessary condition for the development of significant metal concentrations, and investigations in Australia have accordingly been largely concentrated on this aspect of the problem and on the possible part played by bacterial action in the precipitation of heavy metal sulphides (e.g. Baas Becking and Moore, 1961). The ultimate derivation of the metals is in most cases rather conjectural; a fumarolic origin is generally not ruled out (King, 1965A and B), but this would be almost impossible to demonstrate conclusively.

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TABLE A

Tentative Classification and Correlation of some mineral deposits in Canada and Australia referred to in this report

Age	Type of deposit and rock association	Canadian examples	Australian examples
Mesozoic-Tertiary	Disseminated Cu and Mo deposits associated with acid and intermediate intrusive rocks	Bethlehem (Cu) Endako (Mo) and other deposits of B.C.	? Mt Lyell and Mt Morgan (Palaeozoic)
Palaeozoic	Massive Pb-Zn deposits in limestone	Pine Point, N.W.T.	Devonian Mine, W. Kimberley area
Dom. Palaeozoic	Conformable Pb-Zn deposits in black shale - pyroclastic succession	Bathurst, N.B. ? Sudbury Basin	Captains Flat; ? Cobar
? Middle Proterozoic	Conformable Pb-Zn deposits in dominantly sedimentary successions	Sullivan, B.C. ? Ungava Bay	Broken Hill, Mt Isa, Rum Jungle, MacArthur River
Lower Proterozoic	Ni-Cu deposits associated with norite	Sudbury	
Lower Proterozoic	Vein deposits assoc. w. Nippissing diabase (dolerite in Australian usage)	Cobalt area (Ag-Co) Sault Ste. Marie - Sudbury area (Au-Cu)	
Lower Proterozoic	Iron formation in shelf-type sedimentary succession (Superior type)	Gunflint Formn. (no ore grade concentrations). Labrador Trough	Hamersely Ranges, Middleback Ranges
Lower Proterozoic	Deposits in conglomerates at or near base of succession	Elliot Lake (U)	Nullagine (Au), Crater Beds (only minor radioactivity known to date)
Late Archaean	Au and associated deposits related to acid and intermed. igneous rocks	Timmins, Kirkland Lake, Van D'Or (Au, Mo, Bi)	Kalgoorlie, Norseman, Wiluna, etc.
Archaean	Deposits associated w. basic and ultra-basic intrusives	Chibougamau (Cu)	Kambalda (Ni)

Age	Type of deposit and rock association	Canadian examples	Australian examples
Archaean	Conformable Cu-Zn deposits in dominantly volcanic successions	Noranda and Mattagami areas, incl. Quemont, Lake Dufault and Upper and Lower H bodies of Horne Mine. Texas Gulf Body, Timmins. ? Manitouwadge deps.	
Archaean	Pyritic deposits associated w. dom. volcanic successions	No. 5 zone of Horne Mine	? Norseman and Koolyanobbing
Archaean	Iron Formation in dominantly volcanic successions (Algoma type)	Lowphos, Adams and Sherman Mines, Michipicoten and Steep Rock areas	Mount Goldsworthy, Koolyanobbing
?	Pyrochlore (Nb) deposits assoc. w. carbonatite - alkaline igneous complexes	Oka	? Mud Tank apatite deposit, Strangways Range

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