COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS

RECORDS:

1967/8

A BRIEF COMPARISON OF THE PRECAMBRIAN OF AUSTRALIA AND THE CANADIAN SHIELD

by

K.E. Eade

15928/65

A BRIEF COMPARISON OF THE PRECAMBRIAN OF AUSTRALIA AND THE CANADIAN SHIELD

by

K. E. Eade

Records 1967/8

CONTENTS

INTRODUCTION

Any comparison of the Australian and Canadian Precambrian based on our present knowledge is bound to be superficial as large areas are still unmapped in both countries and detailed studies are limited to small areas. These notes are based on brief visits to most of the key areas of Precambrian rocks in Australia and a variable knowledge of the Canadian Precambrian, in some parts a detailed personal knowledge and elsewhere, familiarity with the literature only.

It has been necessary to depend extensively on the literature for information on both countries and the accompanying References are only a partial list of sources consulted. Unfortunately, publication is always slow and as a result, outdated information may be quoted in some places. Another difficulty in using literature is the tendency for the same terms to acquire somewhat different meanings in different countries. This has been partly overcome by visits to the field with local geologists.

In these notes it is not my intention to describe any geology as such except to the degree necessary for purposes of comparison. The details of the geology are available, or will be, in the appropriate reports, records, bulletins, memoirs, etc. No new geological information is presented; it simply brings together known data in a new context that may bring forth new interpretations. It must be remembered too that interpretations and what seems distinctive, depend on an individual's personal geological experience.

A glance at the geological maps of the two countries shows that the outlines of exposed Precambrian rocks in Canada and Australia are markedly different. In Canada, the Precambrian Shield forms an entity with a reasonably well defined outline shaped like a huge ellipse whose axis trends about northwest. The ellipse includes Baffin Island but there is a hole in the centre marked by Hudson Bay and probably covered by a thin layer of Phanerozoic rocks. Precambrian outcrop areas in Australia are dispersed in irregular patches with rather vague outlines, separated by overlying younger rocks, in some cases a relatively thin cover but elsewhere in deep basins or troughs. The largest of the Australian blocks, the Yilgarn Nucleus, which is also one of the oldest, forms the greater part of the southwest of Western Australia.

It is estimated (David, 1950) that the Precambrian in Australia occupies an area of not less than 500,000 square miles. Of this, more than 60% is in Western Australia. This estimate, made before the advent of radiometric dating, is probably not reliable. Prider (1965) states the Western Australia part of the Australian Shield occupies an area of approximately 500,000 square miles. The Canadian Shield includes 1,575,000 square miles in mainland Canada, 196,000 square miles in the Arctic Islands, and 93,000 square miles in the United States, a total of 1,864,000 square miles (Harrison, in Stockwell, 1957).

In this discussion, only the main mass of Precambrian rocks in Canada, the Canadian Shield, will be considered. This will exclude the Precambrian of the Cordillera of Western Canada and in the Appalachian region of the east. Similarly only the larger areas of Precambrian in Australia are considered, excluding for example the Precambrian of Tasmania and north-eastern Queensland.

The Canadian Precambrian can be divided into geological provinces (see Figure 1), each with characteristic structure, age, and to some extent assemblages of rock types and mineral deposits. In Australia, more detailed divisions are made, for example the Kimberley Basin, Gawler Platform, Adelaide Geosyncline, Yilgarn Nucleus (see Figure 2),but broader subdivisions cannot or have not been made. The nomenclature of these structural elements is confused; a variety of terms are used in the literature. Most terms used in these notes are those of Hills (1965).

Some generalizations or personal impressions of the state of mapping of Precambrian areas in the two countries can be given. For a number of reasons there is a difference in the extent and type of map coverage. Variations in the responsibilities of the various government organizations, i.e. political reasons in the broadest sense, are an important factor. The Geological Survey of Canada is active throughout Canada but the Bureau of Mineral Resources is restricted to certain parts of the Continent. In Australia companies have not pressed for regional studies but for more detailed work in limited areas whereas in Canada the attitude has been to leave the detailed work to the companies,and government organizations should concentrate on the framework or outline of the geology. This difference in philosophy of private companies has had an effect on the approach to mapping by the government organizations. Means of access, by vehicle or by aircraft, has influenced the scale of mapping.

The basic scale of mapping in Australia is 1:250,000 while in Canada it is 1:500,000. The result is that more is known in a general way of the Canadian Precambrian but in Australia, where there is information, it is more detailed. It is interesting that this same approach has been used in the two countries in their programs of isotopic dating,i.e. broad reconnaissance vs. more restricted detailed studies. Regarding geophysical data in Precambrian areas, in proportion to area, coverage is probably about the same although aeromagnetic coverage may be better in Canada.

There is more published information on the Canadian Precambrian even when one takes into account relative areas. Something lacking in the Australian literature is any recent, continent-wide authoritative description of the geology.

Topography

Topography of the Canadian Shield is more variable than that of the Australian Precambrian. In Canada it ranges from flat, featureless plains to the mountainous country of the Torngat Mountains of Labrador with 5500 foot elevations within a few miles of sea level or the mountains of eastern Baffin Island. Such elevations are reached nowhere in the Australian Precambrian but local topography is in general more rugged. Australian Proterozoic rocks commonly form dissected, rugged ranges of hills. Far more of the Precambrian in Canada is relatively flat and featureless than in Australia. This may in part be a reflection of the relative abundances of rock types in the two countries as crystalline rocks which form gently rolling topography are more abundant in Canada.

Topography is a function not only of lithology but of past and present climatic conditions. Deep chemical weathering and the filling of low areas by

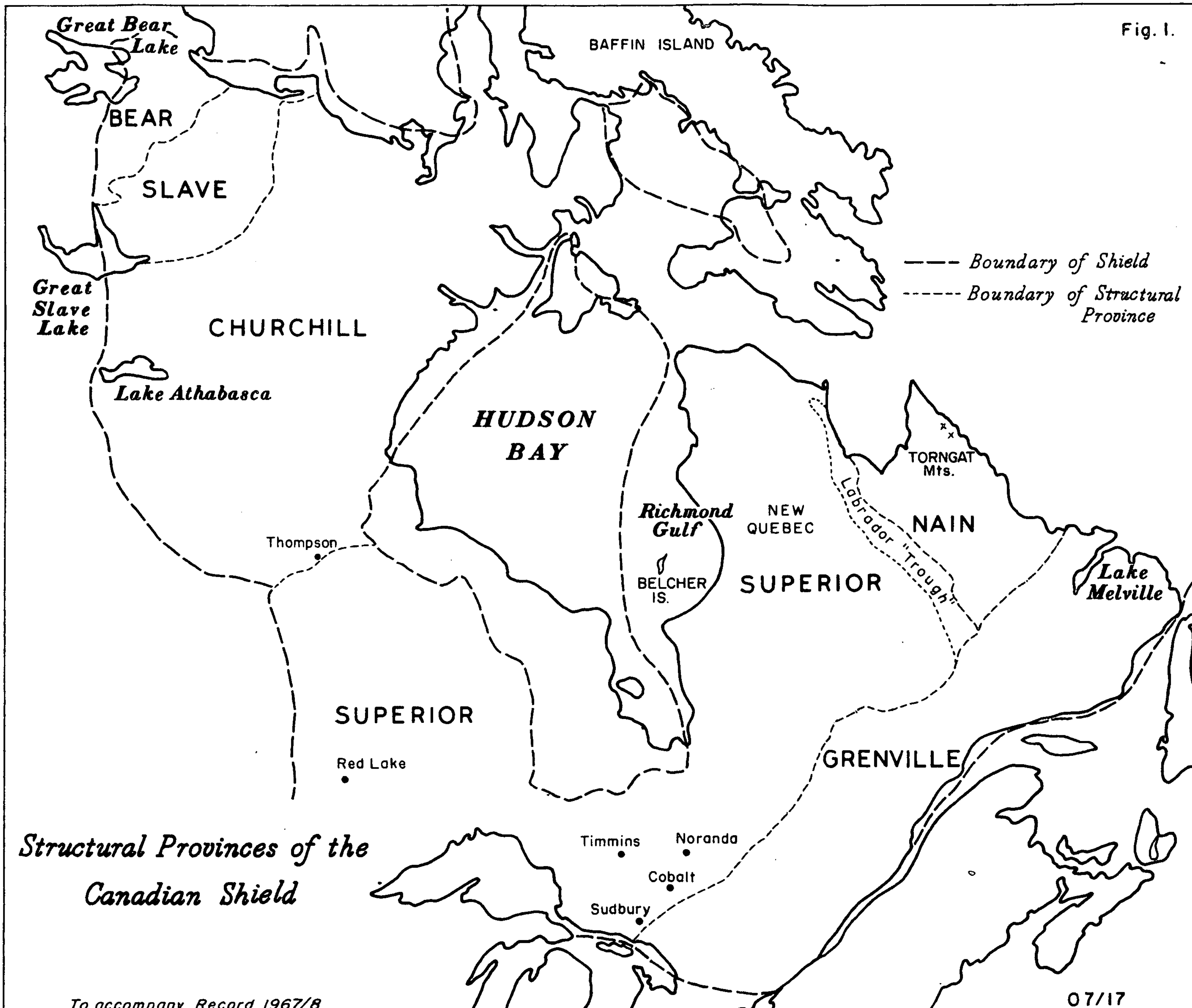
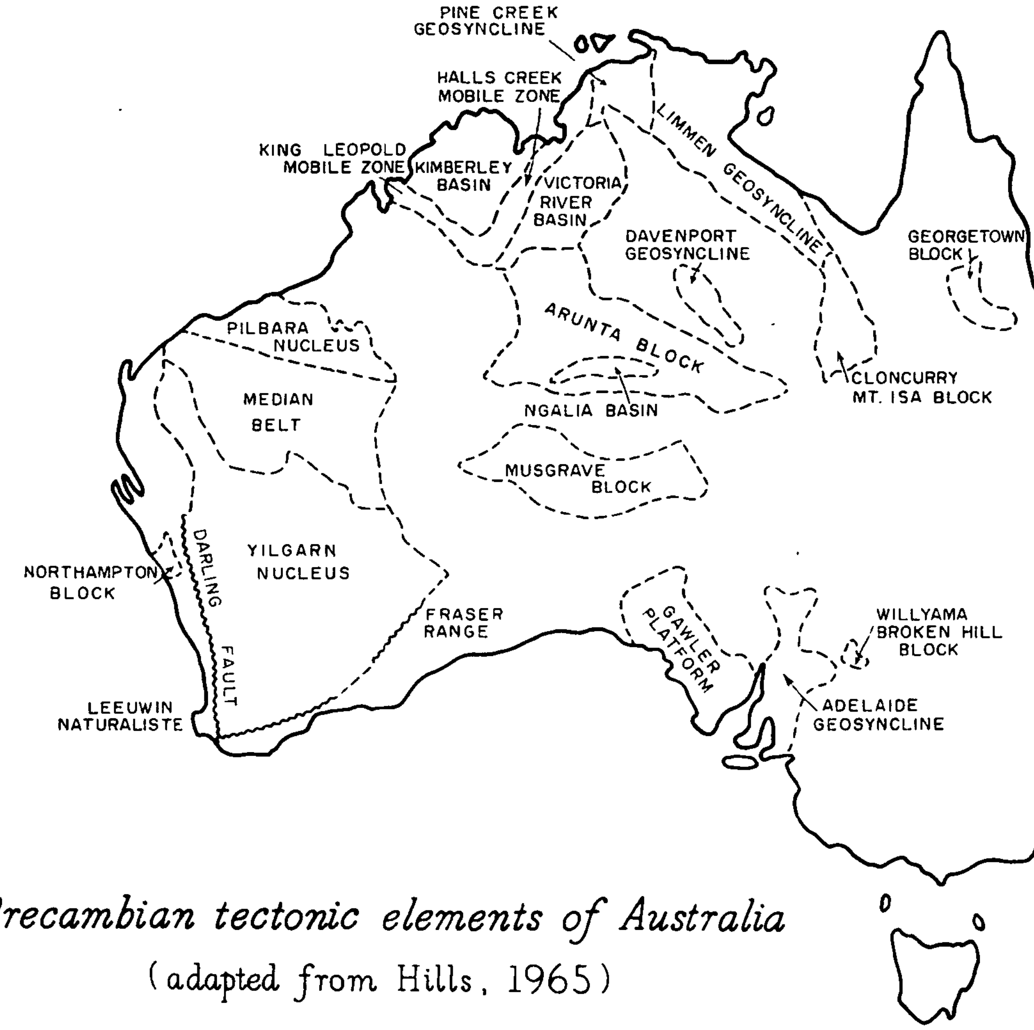


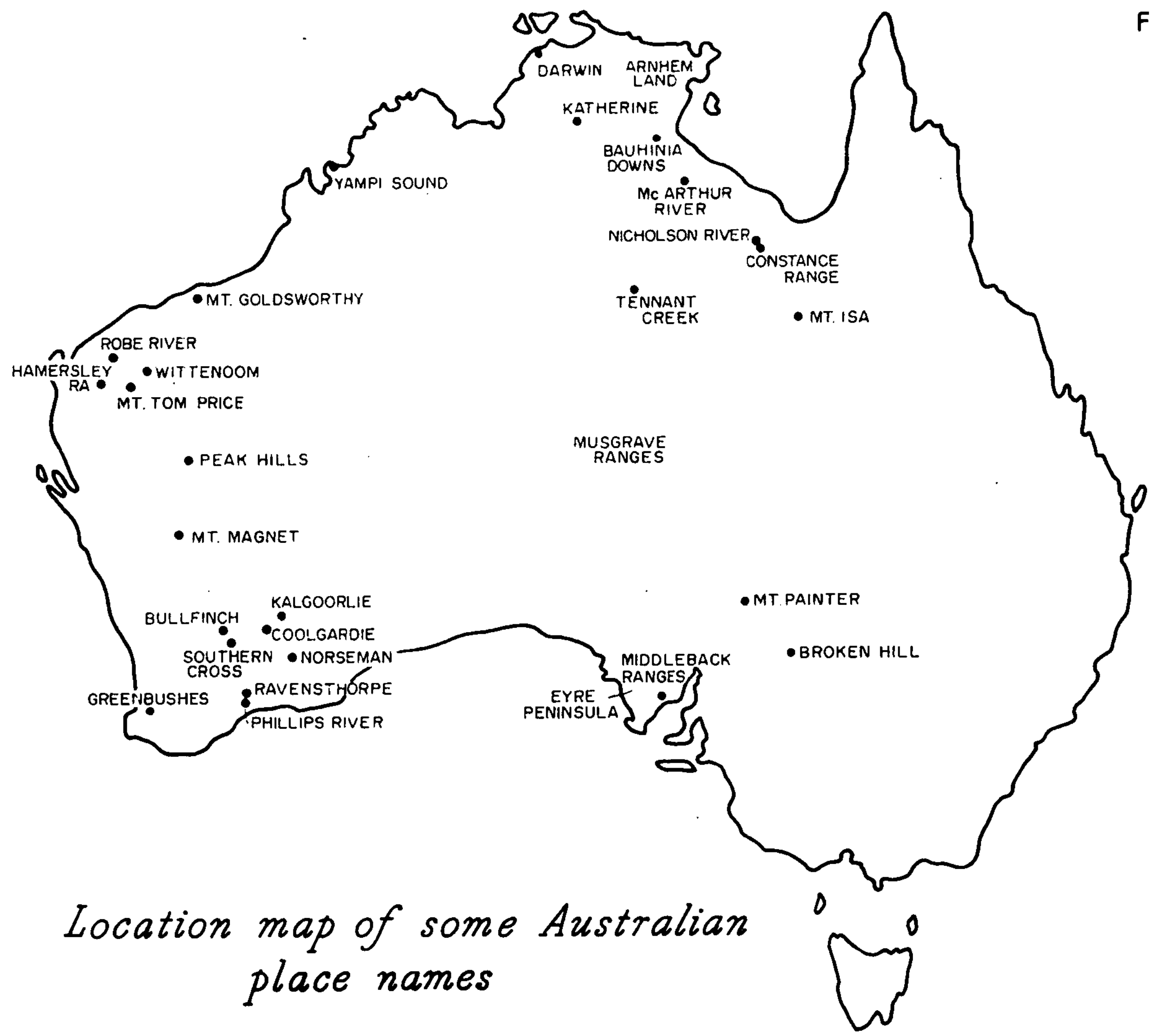
Fig. I.
Great Bear Lake
BEAR
SLAVE
Great Slave Lake
CHURCHILL
Lake Athabasca
BAFFIN ISLAND
Boundary of Shield
Boundary of Structural Province
HUDSON BAY
TORNGAT Mts.
Labrador "Trough"
NAIN
Lake Melville
Richmond Gulf
NEW QUEBEC
BELCHER IS.
SUPERIOR
Thompson
SUPERIOR
Red Lake
GRENVILLE
Timmins
Noranda
Cobalt
Sudbury
Structural Provinces of the Canadian Shield
To accompany Record 1967/8
07/17

Fig. 2A



Precambian tectonic elements of Australia
(adapted from Hills, 1965)

Fig. 2B



Location map of some Australian place names

To accompany Record 1967/8 AUS/A2/79

alluvium or colluvium are prominent factors in the present topography of Australia whereas in Canada the Pleistocene glaciation episode was a prominent factor in creating the present topography. The Precambrian in both countries has been peneplained many times over but evidence of such peneplains is probably better preserved in Australia.

It is difficult to assess the percentage of exposed bedrock in the two countries. In Archaean terrains there would appear to be little difference but Proterozoic rocks are probably better exposed in Australia.

Subdivision of the Precambrian

Isotopic geochronological data, of increasing importance in Precambrian studies, varies in quantity and type in the two countries. In Canada, a large number of K/Ar dates and few Rb/Sr dates are available but in Australia a moderate number of both types are available. The large number of dates in Canada, even though they date only the most recent orogenic or metamorphic event and can be misleading, have been useful in erecting a preliminary framework for all of the Precambrian. In Australia, dates are not so abundant; in some large areas they are lacking, particularly in older rocks, but precise data is available elsewhere, especially in the younger Precambrian. The Rb/Sr dates, and even more effectively Pb determinations on zircon, can record original events, even through a mask of younger metamorphism.

The division of the Precambrian into Archaean and Proterozoic is apparently valid on both continents and there is general agreement on the age of this division. The Proterozoic in both countries is divided into three parts but the divisions are not analogous. In Australia, the base of the "Nullaginian" (Lower Proterozoic) is presently dated at 2300 m.y. although the youngest Archaean orogenies are dated at 2600 m.y. and it is possible that rocks older than 2300 m.y. may yet be found in the Lower Proterozoic. In Canada, the boundary between the Archaean and Proterozoic is placed at 2390 m.y. The Proterozoic in Canada is divided into the Aphebian, the Helikian, and the Hadrynian (Stockwell, 1964) from oldest to youngest. In Australia, the Proterozoic is tentatively divided into "Nullaginian" (Lower Proterozoic), Carpentarian, and Adelaidean (Dunn, Plumb and Roberts, 1966). The date of the base of the Carpentarian is about 1800 m.y. The boundary of the Aphebian and Helikian is placed at 1640 m.y. although the mean age of the Hudsonian orogeny that marks the end of the Aphebian is 1735 m.y. Thus the "Nullaginian" in Australia and the Aphebian are close to being analogous. The estimated date of the base of the Adelaidean is about 1400 m.y. and the Adelaidean extends to the base of the Cambrian at approximately 600 m.y. In Canada, the base of the Hadrynian is 880 m.y. and it extends to the base of the Cambrian. Thus Carpentarian time is not comparable to the Helikian nor Adelaidean time to the Hadrynian.

The division that separates Carpentarian time and Adelaidean time in Australia has no direct equivalent in the Canadian Precambrian although possibly the break between Palaeohelikian and Neohelikian at 1280 m.y. might be analogous. The Grenville orogeny, with a mean age of 945 m.y. and which is the basis of the break between Helikian and Hadrynian, has no apparent equivalent in the Australian sequence although ages of about 1000 m.y. have been noted in granites and pegmatites bordering the Yilgarn Nucleus.

The difference in approach to the division of the Proterozoic in the two countries, in Canada based on orogenies and in Australia on time-stratigraphic units, is primarily the result of the rock types present in each country. However, the difference in dating programmes, reconnaissance versus restricted detailed studies, has also affected this evolution.

A problem in Canada resulting from the extensive use of K/Ar dates is the lack of recognition of ancient remnants in younger crystalline rock terrains. An example of this is the probable existence of old Archaean remnants in the Churchill structural province that have experienced Hudsonian orogeny and therefore give Aphebian dates. A similar problem may exist in Australia in the Arunta Complex. More Rb/Sr determinations would possibly assist in this regard, but on both continents far more radiometric ages are needed for a better understanding of the Precambrian.

The Archaean

The great majority of Archaean rocks in Australia occur in Western Australia. They are in two main areas, the larger Yilgarn Nucleus and the smaller Pilbara Nucleus. Smaller areas of Archaean or possible Archaean are scattered throughout Australia, the King Leopold - Hall's Creek Mobile Zones in the north of Western Australia, small inliers in the Katherine - Darwin and Tennant Creek areas of the Northern Territory, possibly some small areas in the Mount Painter area and the Gawler Platform of South Australia and the Arunta Block of central Australia may include some Archaean. In Canada, Archaean rocks comprise much of the bedrock in the Superior structural province of Quebec, Ontario and Manitoba and the Slave structural province in the Northwest Territories. Archaean remnants are probably present in the younger Churchill and Grenville structural provinces.

Archaean lithology in the two countries is remarkably similar, metasedimentary and metavolcanic rocks, schists and gneisses derived from these, and granitoid rocks, gneissose or massive. The similarity is particularly striking between the volcanic-sedimentary association in the Yilgarn and Pilbara Nucleii and the Superior and Slave provinces. These rocks occur in belts, usually of some length commonly complexly folded and cut by intrusions with a wide range of composition. In detail the belts are irregular in size, shape and trend although regionally certain trends are always pronounced. It is still a matter of argument whether the belts are roof pendants in a sea of younger granitic material or whether the volcanics and sediments are infolded remnants on an ancient crust, intruded by younger rocks.

In the Canadian Archaean, relationships between sedimentary and volcanic rocks vary considerably from area to area and in fact may vary in a single large belt of these rocks. Most commonly the main sedimentary unit overlies the volcanic unit. Goodwin (1966) in considering the origin of the volcanic - sedimentary belts in Canada suggests they are of slightly different ages and that they grew outward and together, with the aggregation of a number of separate and distinct protocontinents. Such an origin would explain the varying relationships found between sedimentary and volcanic rocks. Information about the surface on which they were laid down always seems to be lacking as the granites and gneisses seem to be intrusive into them. In many areas, metamorphism and deformation have largely destroyed the sedimentary and volcanic structures and textures which give the relative ages of the stratigraphic units. The lack of good structural information leaves most determinations of the thickness of the volcanic-sedimentary sequences open to question but in some localities reasonably good evidence indicates that tremendous thicknesses, in the order of tens of thousands of feet, were accumulated.

In the volcanic piles themselves, the relationship of basic to acidic types varies considerably and one wonders if there is a typical volcanic pile. Furthermore, the stratigraphy indicates interchanging volcanic and sedimentary conditions. The volcanic rocks, basalt or andesite to rhyolite and their fragmental equivalents, commonly are accompanied by intrusive rocks, gabbro, diorite and acid porphyries. The most abundant sedimentary rocks are greywacke - slate alternations: typical jaspilite iron formation is a characteristic but quantitatively limited component and some very minor carbonate units are present. In many areas it is difficult to distinguish greywacke from volcanic tuff as they grade from one to another.

Wilson et al. (1965) concluded the Archaean lavas in the Canadian Precambrian are continental rather than oceanic and suggested a primitive continent or island arc system was present during the volcanism. Baragar (1966) however indicates the Yellowknife volcanics fall between oceanic and continental lavas in composition.

Detailed information on the Archaean volcanic - sedimentary belts in Australia is limited. The sedimentary - volcanic belts of the Yilgarn block are similar in lithology to those of the Canadian Archaean; they are generally oriented in one direction but in detail are variable in trend. The same varying relationships between the volcanic and sedimentary rocks exist as in the Canadian belts. Horwitz and Sofoulis (1965) and Ryan and Kriewaldt (1964) have recently described successions in the Kalgoorlie and Pilbara regions respectively and the descriptions of the lithologies and relationships indicate the close similarity to rocks in the Canadian Archaean. The lithology of the iron formation, 'jaspilites', is particularly striking as in both countries they are so similar and distinct from the Proterozoic iron formations. As yet no detailed chemical work is available on the volcanic rocks in Australia.

Schists and gneisses derived from the Archaean sedimentary and volcanic rocks are abundant in both Australia and Canada, and include the typical "greenstones" of both countries, metamorphosed equivalents of basic volcanic rocks. The greenstones are particularly well known because of their association with gold mineralization. Increasing metamorphism and metasomatism result in the abundant granitic gneiss of the Archaean terrains. Associated with the granitic gneisses are massive granite. It appears that the granitic gneiss - granite association is relatively more abundant in the Canadian Archaean than it is in the Australian.

Geologists in the two countries appear to put different emphasis on the origin of the granitoid rocks. In Canada some of the granites, particularly the post-kinematic granites, are regarded as intrusive and magmatic, but much of the granite is considered palingenetic in origin, developed by metasomatic - metamorphic processes, in particular the syntectonic granites. In Australia more of the granites, both post-kinematic and syntectonic, seem to be regarded as magmatic granites. It is impossible to determine the relative abundance of syntectonic and post-kinematic granites in the two countries, but it could be that the presently exposed Archaean of Australia has more post-kinematic granite than does the Canadian Archaean. In the southwest part of the Yilgarn Nucleus in particular, post-kinematic granite seems to be more abundant than anywhere in the Superior or Slave provinces. In the Australian Archaean, unfoliated granitoid rocks are relatively more abundant than gneisses as compared to the Canadian Archaean. It is possible too, that the overall composition of the granitoid rocks in Australia is closer to granite while in Canada it is closer to granodiorite.

To summarize, it is suggested that in Australia the volcanic-sedimentary bands are relatively more abundant: massive, high-level post kinematic granite is more abundant; and banded gneisses, granite gneisses, migmatites and syntectonic granite are less abundant, as compared to the Canadian Archaean. The stage of mapping in both countries precludes making even a semi-quantitative estimate and these are impressions only. If the above should be the case however, it is suggested that the reason might be different levels of crust being exposed, that the Australian Archaean represents a slightly higher level of crust. In the accompanying sketch, Figure 34, the difference in exposing different crustal levels is indicated, in a theoretical section of crust. This is the broadest of generalizations only; even within the Superior province of the Canadian Archaean, crustal levels vary considerably, for example the high crustal level of the Red Lake area of Ontario compared to the deep crustal level of eastern New Quebec.

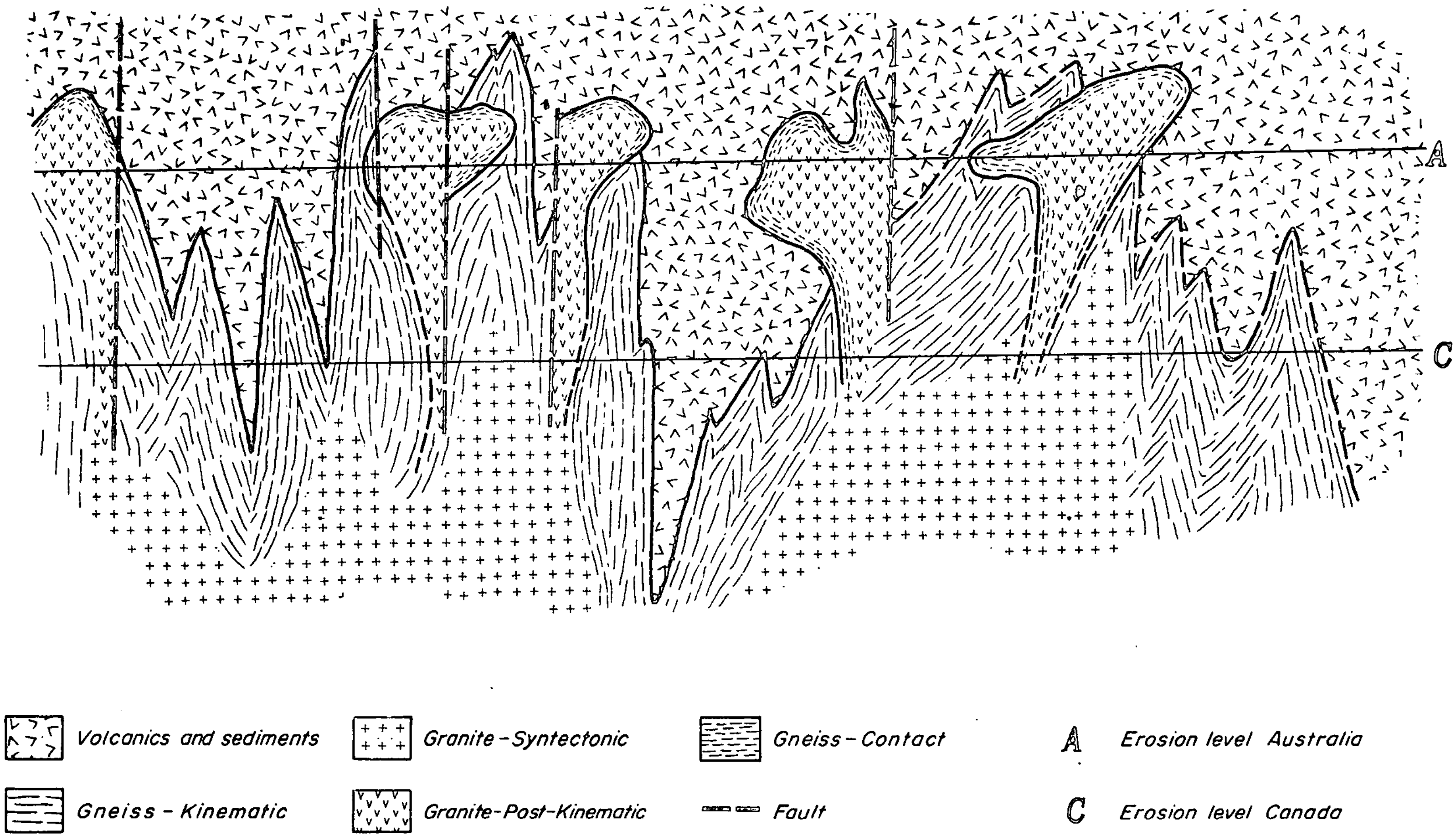
Thus, although the Archaean volcanic and sedimentary rocks in Canada and Australia are very similar, their relative abundance varies and the lithology and abundance of the accompanying rocks varies.

The Proterozoic

A striking feature of the Precambrian in Australia is the remarkable preservation of relatively unmetamorphosed and only gently deformed Proterozoic sedimentary rocks. This is particularly true of the "Nullaginian" rocks of the Hamersley and Ophthalmia Ranges of Western Australia, the Mount Bruce Supergroup, composed of the Fortescue Group, Hamersley Group and Wyloo Group, in ascending order. The lithology of the supergroup is broadly similar to that of the Aphebian age Kaniapiskau Supergroup of the Labrador "Trough" except for the thick sequence of basic volcanics at the base of the Mount Bruce. The lower part of the sedimentary section consists of clastic sediments, overlain by primarily chemical sediments, including the important iron formations, with some clastic sediments in the upper part of the section. In both Canada and Australia younger Proterozoic rocks overlie them unconformably. Basic volcanic rocks are present in the Labrador section, but basic intrusions are more abundant. In both regions the chemical sediments, in particular the iron formation, show remarkable persistance. The Western Australian rocks are only slightly metamorphosed and are only slightly deformed. The Canadian rocks are extensively faulted, folding is intense, and along the eastern side of the section the rocks have been metamorphosed to gneisses. Possibly the different tectonic setting may explain some of these differences. The Mount Bruce Supergroup accumulated in the Median Belt between the two old stable nucleii, the Yilgarn and the Pilbara. The

Fig. 3

Theoretical Section of Crust



To accompany Record 1967/8

AUS/A2/78

Kaniapiskau Supergroup rocks were deposited in a marginal geosyncline bordering the old Superior nucleus and were subjected to an orogenic phase following deposition. Thus although there are remarkable lithologic similarities, the tectonic setting was completely different.

Certain other Aphebian sedimentary rocks of the Superior province are similar to the "Nullaginian" of Western Australia. The Mistassini Group around Lake Mistassini in Quebec consists of clastics in the lower part with overlying chemical sediments, including iron formation. The Belcher Group of the Belcher Islands in Hudson Bay has very similar lithology to the Kaniapiskau Supergroup, including the iron formations, basic volcanics and basic intrusive rocks. The Gunflint Formation of northwestern Ontario contains iron formation very similar to that of the Kaniapiskau Supergroup and the "Nullaginian" of Western Australia but no basic volcanics are present in the section and the total section is much thinner, with few clastic rocks represented. The Gunflint rocks are classified by Stockwell (1965) as a marginal homocline and this tectonic setting may explain lithologic differences in the section. All these Aphebian and Lower Proterozoic successions are characterized by similar, persistent iron formation horizons.

The Aphebian age Huronian rocks of Ontario and Quebec, the Bruce and the Cobalt Series, consist of quartzite, conglomerate, minor limestone and possible tillite. The very thick section of clastics, relatively pure quartzite, and the variously interpreted tillite or turbidite form a succession that seems to have no equivalent in the "Nullaginian" of Australia.

The "Nullaginian" sedimentary rocks of the Katherine-Darwin region of the Northern Territory, deposited in the Pine Creek geosyncline, have a thick clastic section at the base, much of it arkosic, with siltstone, dolomite, and greywacke overlying. Up to 20,000 feet of sediments were deposited in the deepest part of the basin. Early Carpentarian granite plutons cut the sedimentary rocks. The Aphebian age Snare Group north of Great Slave Lake in the Northwest Territories has a somewhat similar succession, quartzites and arkoses at the base, grading upward into dolomite, argillaceous rocks, and greywacke, with minor basic volcanic rocks in the upper part of the section in one part of the basin. The Snare Group is cut by younger granite and porphyry intrusions. Rocks of the Pine Creek geosyncline are unconformably overlain by younger Proterozoic sedimentary rocks but no younger rocks are found in contact with the Snare Group. The Echo Bay Group, on the east side of Great Bear Lake, a possible correlative of the Snare Group, contains almost exclusively volcanic rocks in the upper part. The Echo Bay Group is overlain by the younger Cameron Bay Group of Helikian or Hadrynian age.

In the Tennant Creek area of the Northern Territory the "Nullaginian" Warramunga Group consists of greywacke, siltstone and shale with minor grit and pebble beds. The lack of any distinctive marker horizons precludes an accurate estimate of the thickness of the section. The apparent lack of any carbonate beds distinguishes this group from other Aphebian or "Nullaginian" groups. Folded argillaceous rocks in The Granites - Tanami region of the Northern Territory are probably equivalent to the Warramunga Group. The Leichhardt Metamorphics of the Mount Isa area of Queensland are also considered to be "Nullaginian".

Dunn (pers. comm.) has pointed out an interesting feature of the "Nullaginian" sedimentary rocks in northern Australia. In Western Australia, in the Hamersley - Ophthalmia Ranges, the rocks are practically unmetamorphosed; to the east and northwest in the Katherine-Darwin, Tennant Creek and Granites-Tanami areas metamorphism is quite evident; still further east, metamorphism is intense in the Leichhardt Metamorphics of the Mount Isa area.

The major areas of "Nullaginian" sedimentary rocks in Australia are the Hamersley-Ophthalmia Ranges, the Pine Creek geosyncline, the Warramunga Group and the Leichhardt Metamorphics. The Aphebian of the Canadian Precambrian includes the previously mentioned Kaniapiskau Supergroup, Mistassini Group, Belcher Group, Gunflint Formation, the Huronian, the Snare-Echo Bay Groups, the Hurwitz Group as well as the Epworth - Goulburn Groups north of Contwoyto Lake, the Slave Group, in the east arm of Great Slave Lake, the Otish Mountains Group in New Quebec and others. Aphebian rocks appear to be relatively more abundant than the approximately contemporaneous Lower Proterozoic in Australia even taking into account the greater area of the Canadian Precambrian.

The Carpentaria region of the Northern Territory is the type area for the Carpentarian age rocks of Australia. Acid volcanic rocks occur at the base, overlain by a thick, primarily arenaceous section with minor dolomite, siltstone, and intercalated volcanics and this in turn is overlain by a group of predominantly dolomite and siltstone formations, with minor sandstone. The well exposed sections have been mapped in considerable detail. A unique feature in these rocks in the Bauhinia Downs area is the presence of a well preserved reef complex in the McArthur Group. The Carpentarian rocks extend southwest into the Mount Isa region of Queensland where they have undergone some folding and some metamorphism.

Another major area of Carpentarian rocks in northern Australia that has been mapped in some detail is in the Kimberley Basin. The section is similar to that in the type area although the Hart Dolerite sills are a distinctive feature of the Kimberley Basin. Some iron formation occurs in restricted areas, the source of the Yampi Sound iron ores. The Kimberley Basin is rather a remarkable structure, surrounded on two sides by the narrow Hall's Creek - King Leopold Mobile Belts, composed of Archaean and/or "Nullaginian" igneous and metamorphic rocks, and on the other sides by the Indian Ocean and Timor Sea. There is no similar basin of deposition in the Canadian Precambrian.

In the Victoria River - Tanami areas, the Davenport Range and the Ashburton Range of the Northern Territories, Carpentarian rocks are almost certainly present in abundance but none of these areas are yet mapped in detail.

In South Australia, rocks of probable Carpentarian age are present in the Gawler Platform. Of particular interest are the widespread Gawler Range Volcanics, a thick sequence of acid to intermediate extrusives and intrusive porphyries. Nowhere in the Canadian Proterozoic are acid extrusive and hypabyssl rocks as abundant as in this formation. In the same general region of the Eyre Peninsula are sedimentary units, such as the Corunna conglomerate, that are apparently of Carpentarian age.

Helikian sedimentary and volcanic rocks are irregularly distributed throughout the Canadian Shield. Some of the more prominent groups are as follows:

in northwestern Baffin Island a lower group, the Equalulik, with basic volcanics at the base and quartzite and conglomerate overlying, is overlain, possibly disconformably, by the Uluksan Group consisting of shale, dolomite, mudstone, siltstone and sandstone. Approximately 11,000 feet of section has been recorded. The Coppermine River series, on the western Arctic coast, has a known thickness of 28,000 feet, the lower half consisting of basalt flows, and the upper part of sandy shales, sandstone, and limestone. The Cameron Bay Group, restricted to the east side of Great Bear Lake, consists of conglomerate, arkose, sandstone, argillite and tuff, interlayered in the upper part with trachyte and andesite flows. Both the Cameron Bay and Coppermine River sequences are considered Helikian but they could be younger. The Et-then Group, overlying the Great Slave Group, consists of a thick conglomerate section with arkosic sandstone and quartzite overlying it. The widespread Dubawnt Group in the Districts of Keewatin and MacKenzie is considered Helikian though it may in part at least by Hadrynian. It consists predominantly of sandstone with minor intermediate to acid volcanic rocks and some dolomite. The group is thin considering its areal extent and appears to be a cratonic cover rock. Similarly, the widespread Athabasca Group, south of Lake Athabasca and to the southwest of the Dubawnt, essentially a sandstone unit, is a cratonic cover that mantles a huge area. In the central part of the Canadian Precambrian, the Keweenawan, around Lake Superior, consists of conglomerate, sandstone, limestone and shale, a relatively thin section overlying the Aphebian Gunflint and Animikie Formations. The Helikian is represented in the eastern part of the Canadian Shield by the Seal Lake Group in Labrador, consisting of continental and marine sedimentary and volcanic rocks. Sandstone, shale, slate and basic volcanic rocks are intruded by thick gabbro sills.

Considering the relative areas of Precambrian in Australia and Canada and that Carpentarian time (1800 to 1400 m.y.) covers a shorter period than the Helikian (1640 to 980 m.y.) Carpentarian sedimentary and volcanic rocks are considerably more abundant. The Helikian possibly contains relatively more, shallow water clastic rocks than the Carpentarian and certainly cratonic cover rocks, such as the Athabaska and the Dubawnt, are more prominent in Canada. The Carpentarian appears to be predominantly marine basin deposits.

The type area of the Adelaidean in South Australia includes both shelf and geosynclinal facies. Volcanics at the base of the section are not present everywhere. The sedimentary section shows some variation along strike but certain units are consistent, with sandstone, quartzite, siltstone, dolomite, shale and tillite all present. The Sturt tillites are a unique marker in the section. Tillites that are apparently equivalent are present in the Adelaidean section in the Kimberley Basin in the northwest of the continent. In the East Kimberleys the Adelaidean is divided into the Glidden Group, the Kuniandi Group and the Louisa Downs Group. East of the Kimberley Basin, the type Carpentarian area has Adelaidean rocks overlying, for example the Roper Group in the McArthur River area, the South Nicholson Group in the Nicholson River area and the Malay Road Group in Arnhem Land. The section in Carpentaria is composed chiefly of sandstone and siltstone with minor oolitic iron formation in some areas. In the Pilbara region of Western Australia the "Nullaginian" Mount Bruce Supergroup is overlain by the Bresnahan and Bangemall Groups; the Bangemall Group is probably Adelaidean. Elsewhere in the Australian Precambrian there are isolated areas of sedimentary rocks of probable Adelaidean age, for example the Mount Barren beds (quartzite, phyllite, conglomerate and dolomite) in the

Ravensthorpe area of southern Western Australia.

In the geosynclinal facies of the type Adelaidean in South Australia diapir structures are a unique structural feature that have not been recognized in the Canadian Precambrian. It is not apparent whether they are the result of the tectonic setting or the lithology.

Sedimentary rocks of Hadrynian age are restricted to the small area of flat-lying Double Mer sandstone on the north side of Lake Melville in Labrador.

It would appear that Carpentarian and Adelaidean sedimentary and volcanic rocks are more abundant than the analogous Helikean and Hadrynian rocks in the Canadian Precambrian.

Concerning Proterozoic volcanic rocks in the two countries, it would appear that acid to intermediate volcanics are relatively more abundant in Australia. This suggests that the tectonic - orogenic histories of the two continents differ.

The great difference between the Proterozoic of Australia and Canada is immediately apparent when you consider crystalline rocks which are far more abundant in Canada. In Australia, the narrow Esperance - Albany belt, on the south side of the Yilgarn block, dated at 1100 m.y., consists of high grade metamorphic rocks - granulites and gneisses probably derived from older sedimentary and volcanic rocks, and some granites. In the central and southern part of the Northern Territory the Arunta Complex consists of gneiss, gneissic and massive granite, basic rocks, schists and migmatite, quartzite and marble. The details of the geology and the age relations of the various rocks are not known. In the extreme west of Western Australia, two small separate areas of granulite gneisses occur west of the Darling Fault, surrounded by Phanerozoic rocks. In the southern area of the two, the Leeuwin - Naturaliste section, the granulites are dated at 650 m.y.. In the northern Greenough section, muscovite from a pegmatite in the granulites gives an age of 1000 m.y.. Both these areas are small but their occurrence west of the major fault bordering the west side of the Yilgarn block makes them significant.

In the northwestern part of South Australia and adjacent parts of Western Australia and the Northern Territory, in the Musgrave Block, gneisses and granites occur over a large area. In the Musgrave Range part of the region granulites are abundant. The ages of the rocks in this region are uncertain although a determination on granite and granite gneiss from the Petermann Ranges gives 1150 to 1190 m.y., with later metamorphism at 600 m.y. indicated. It is therefore possible that all these crystalline rocks are Proterozoic age.

In the Eyre Peninsula of South Australia the Gawler Platform includes gneisses and granites of early Proterozoic age as well as some rocks in the "gneiss complex" that may be Archaean. To the east of the Adelaide geosyncline an isolated area of high grade metamorphic rocks in the Willyama - Broken Hill Block is of uncertain age. Lead isotope ratios on ore from

Broken Hill indicate a 1620 m.y. age but K/Ar determinations on the country rocks give 500 - 900 m.y.. This may suggest either Archaean or "Nullaginian" age for these rocks with later metamorphism in the 500 to 900 m.y. period.

Intrusive granites, "Nullaginian" to Carpentarian in age, occur in the Katherine-Darwin, Mount Isa-Cloncurry, and the mobile belt adjoining the Kimberley Basin in northern Australia. Areally, a few of these are of batholithic proportions but are indicative of igneous activity in these regions.

All the above-mentioned Proterozoic crystalline metamorphic and igneous rocks in Australia do not comprise a major proportion of the total Proterozoic rocks.

In the Canadian Precambrian crystalline rocks are by far the major component of the Proterozoic. In the Churchill structural province Proterozoic gneisses and massive granitic rocks are widespread although it is possible that some of them are Archaean rocks affected by the Hudsonian orogeny. The Grenville and Nain structural provinces of eastern Canada consist primarily of Proterozoic crystalline rocks, gneisses and igneous intrusive rocks. Within the Grenville province some crystalline rocks of Archaean age have been metamorphosed by later orogenies. An outstanding characteristic of these two provinces is the abundance of anorthosite of late Palaeohelikian age, which in the Grenville province has undergone younger Grenville age metamorphism. Why anorthosite should be so abundant in this part of the Canadian Precambrian is an enigma. In the Australian Precambrian, anorthosite is rare and restricted to narrow zones, such as those in the Musgrave block of northwestern South Australia. This type of occurrence is similar to the narrow anorthosite zones in the Thompson-Moak Lake belt of northern Manitoba, close to the boundary of the Superior and Churchill provinces.

There is still some difficulty in distinguishing the ages of the gneisses in the Canadian Precambrian, but on the basis of available K/Ar determinations Proterozoic gneisses are abundant. It is suggested the relative abundance of crystalline gneisses in the Canadian Precambrian as compared to the Australian possibly indicates a deeper level of crustal erosion in Canada, following far more intense orogeny than was the case in Australia. The more abundant sedimentary rocks preserved in the Australian Proterozoic record fewer orogenic events. The presence of large areas of cratonic cover rocks in the Canadian Proterozoic suggests deep erosion in some areas with deposition on stable cratons. Similar conditions do not seem to have existed in Australia during the Proterozoic.

Basic Dykes

Recent studies (Fahrig et al., 1963, 1965) of the basic dykes that occur in many parts of the Canadian Precambrian have revealed some significant details on their geometry and age. The dykes are of gabbro or basalt composition but are commonly known as diabase dykes. The dykes are not evenly distributed throughout the Shield but occur in swarms, dykes in individual swarms having similar trends. Age determinations on dykes indicate many of the swarms are of different ages and palaeomagnetic determinations on some of the swarms indicate swarms of different ages have differing palaeomagnetic pole positions. Chemical analyses show that there are some differences in average chemical composition of swarms. Some of the swarms are up to 1000 miles long and in places more than 600 miles wide, with individual dykes more than 150 miles long.

In Australia no detailed studies have been made of the gabbro or basaltic dyke rocks, commonly called dolerite dykes. In some parts of the Australian Precambrian these dykes are abundant, in particular in the Yilgarn Nucleus of Western Australia. Notable swarms occur in the Kalgoorlie region and along the western margin of the block, with the exception of the extreme southwest corner. An unknown factor in determining the relative abundance of dykes in various parts of the block is the varying degree of map coverage. Dykes also occur in the small Precambrian area west of the Darling Fault.

In the Archaean Pilbara Nucleus dykes trending north-northeast are prominent and some northwest dykes are present. The "Nullaginian" median belt separating the two Archaean blocks is cut by some dykes but sills of similar composition are more abundant. Prider (1965) suggests that all the above described dykes in Western Australia belong to a single "Nullaginian" period of basic intrusion but as isotopic ages are not available on these rocks evidence is lacking. If such is the case it would be very different from that in the Canadian Precambrian where the swarms have a wide range of ages. Some of the dykes in Western Australia are very long if accurately portrayed on the Geological Map of Western Australia (1966). An east-trending dyke in the Yilgarn nucleus is shown to be about 180 miles long.

Dolerite dykes are abundant in the Arunta Complex where mapping is incomplete but the dykes show up well on air photographs. In the Musgrave Block there are several swarms of dykes. In both the Tennant Creek are and the Mount Isa - Cloncurry areas swarms of dolerite dykes are present but they are all short dykes. In the western part of the King Leopold mobile belt bordering the Kimberley Basin dolerite dykes, some of considerable length, are present. It is noteworthy that in the great belt of Carpentarian and Adelaidean rocks in the Northern Territory dolerite dykes are relatively rare and insignificant. Similarly, there are none in the type Adelaidean of South Australia. In the Kimberley Basin, the Hart Dolerite sill, similar in composition to dolerite dyke rocks, is a prominent formation, and in the Carpentaria region basic sills are common in places. In the Adelaide geosyncline dolerite is present in some of the diapir structures.

In areas of Archaean rocks, basic dykes are probably equally abundant in Australia and Canada. In Proterozoic areas however, dykes are more abundant in Canada than they are in Australia. Dykes seem to be more abundant in more tectonically disturbed areas and much of the Australian Proterozoic has not been subject to orogenies. Fahrig and Wanless (1963) suggest that basaltic magma, in the form of dykes, is introduced in low pressure belts resulting from elastic rebound of the crust after a period of crustal compression. The presence or absence of dykes may possibly be a function of depth exposed by erosion, in that dykes may be more abundant at lower levels in the crust, and sills or sheets at higher levels (Hawkes, 1966). In the Carpentaria area, deeper level sills are more transgressive than higher ones (Dunn, pers. comm.).

Tectonics

In Australia, the Yilgarn and Pilbara blocks were original continental nucleii but the trends of the old sedimentary and volcanic bands differ in the two blocks suggesting they were isolated from each other. The "Nullaginian" Median Belt separates them but Archaean inliers in the Belt indicate there may have been a single nucleus. Geophysical work might provide some evidence towards solving this problem.

In the Canadian Shield, the Superior and Slave structural provinces are the old nucleii and they are separated by the younger Churchill structural province, although some evidence suggests the three provinces may have been connected. Stockwell (1962) reports that scattered dates in the Churchill Province reflecting the older Kenoran orogeny are found amongst the younger Hudsonian orogeny dates and they may represent part of an old mass, most of which was destroyed by the younger orogeny. Fahrig and Wanless (1963) have suggested remnants of old basic dykes in the Churchill province may represent old dykes that extended from the Slave, through the Churchill, to the Superior province. Thus, there is some evidence to suggest that in Canada there was a single nucleus rather than two isolated blocks.

The theory of continental accretion is supported by some evidence in the Australian Precambrian. On the south side of the Yilgarn Nucleus, the Albany - Esperance Block could be considered as an accretion to the older nucleus. However, as Dunn (pers. comm.) has suggested, it seems that old Archaean blocks such as the Yilgarn and Pilbara Nucleii and smaller probable Archaean areas such as those in the Katherine - Darwin area, in Carpentaria, the Arunta Block, and the Gawler Platform, have been joined together by younger rocks, with decreasing tectonic activity westward with time, resulting in a progressive increase in the size of the stable shield with time. West of the old Pilbara - Yilgarn Nucleii however there is practically no evidence of growth.

The idea of progressive welding on of segments around old nucleii appears to have more support in the Canadian Shield in that the Nain, Grenville and Bear Provinces are added on the margins of the original Superior - Slave Nucleii.

The King Leopold - Hall's Creek Mobile Zone and Kimberley Basin in the northwest of Australia appear to have no equivalent in the Canadian Shield. The relationship of the Mobile Zone to other Precambrian areas is obscure. It is possible that to the east the Mobile Zone was marginal to an older Precambrian block now covered by younger Proterozoic sediments. To the south, Phanerozoic rocks completely mask its relations with the Pilbara Nucleus. The presence along the southern margin of young alkalic lamproite intrusions may suggest late igneous activity along an old, major structural break that would separate the Mobile Zone from the Pilbara Nucleus. Sedimentary rocks in the Kimberley Basin indicate a source to the northwest (Gellatly, pers. comm.) suggesting an older Precambrian mass probably existed in that direction and is now covered by the Timor Sea. There is, however, the possibility that the source area has since been affected by continental drift.

In the Nain and Grenville provinces of the Canadian Shield the abundance of large anorthosite masses, indicative of deep crustal material, suggest tectonic conditions of an extraordinary kind that are not duplicated in the Australian Precambrian. A profound tectonic event would be required to raise this material from great depths, into the upper crust.

Tectonically, the most striking difference between the Australian and Canadian Precambrian is the fact that the Canadian Precambrian has not been affected by Phanerozoic tectonism. The Canadian Shield has been from time to time inundated as witnessed by the scattered outliers of Palaeozoic rocks. Tectonically however it has been stable since the end of Proterozoic time. In several regions in Australia there is evidence of Palaeozoic tectonism affecting the Precambrian rocks. The Adelaide geosyncline has been folded and intruded during a lower Palaeozoic orogeny and in central Australia, the Precambrian Arunta Complex has been folded and faulted, with possible nappe structures, during the Devonian tectonism that affected the adjoining Ngalia Basin. Dunn(pers. comm.) suggests Phanerozoic movement on the Australian Precambrian platform is confined to old mobile zones.

The variation in lithology of the Proterozoic in Canada and Australia, with the great emphasis in the Canadian Proterozoic on crystalline rocks, suggests that in Proterozoic times the Canadian Precambrian was far more tectonically active, with great orogenies and mountain building and development of widespread cover rocks on the stable cratons during the process of degradation that succeeded the mountain building. In contrast, the Australian Proterozoic appears relatively undisturbed, downward and upward warpings recorded in the thick sedimentary sequences and the adjacent source areas but only limited orogenic mountain building. In the "Nullaginian" of northern Australia some orogeny took place and it increased in intensity from west to east, reaching intense levels in the Mount Isa - Cloncurry region. The Halls Creek - King Leopold Mobile Zone is a minor exception for in limited areas metamorphic rocks reach granulite facies. In the south of Western Australia in the Albany - Esperance block there was orogeny and mountain building around 1100 m.y.. In the Canadian Precambrian, after the violent activity of the Proterozoic, it settled down to a stable shield area but in Australia, the tectonism continued on into Palaeozoic times. Possibly the apparent abundance of acid extrusive rocks in the Proterozoic of Australia, as compared to Canada, has some significance in relation to the different tectonic styles.

It is interesting to speculate whether the different histories of tectonism in the Proterozoic of Canada and Australia have any bearing on the problem of continental drift. The fact that the Canadian Shield seems to form an entity, with a suggestion of formation by accretion or building on of segments, with orogenies and mountain building followed by degradation and stability, suggests the Canadian Precambrian behaved as a unit. In Australia, the fragmentary nature of the Precambrian, the limited and scattered evidence of mountain building in the Proterozoic and the evidence of Phanerozoic tectonism might suggest that Australia or parts thereof, have moved as a result of continental drift and that the Australian Precambrian was not necessarily a unified structural entity.

Mineral Deposits

This subject is too vast to cover in any detail and the following are only some random comments and suggestions. Some deposits are obviously very similar in the Australian and Canadian Precambrian but as well some mineralization appears to be unique to one country or the other.

The gold deposits in the Archaean of Western Australia, Kalgoorlie, Norseman, Coolgardie, Bullfinch, Southern Cross and so on, bear a marked resemblance to those in the Canadian Archaean, Red Lake, Porcupine, Noranda-Rouyn, Val d'Or, Chibougamau, of the Superior province in Ontario and Quebec, and the Yellowknife area of the Slave province. All the deposits are associated with Archaean belts of basic intrusives and extrusives and sedimentary rocks. At Kalgoorlie, some of the mineralization is connected with the Golden Dyke basic sill and this relationship with a basic sill should be remembered in interpreting some of the Canadian deposits. Goodwin (1966) has proposed that the Canadian Shield has developed by accretionary growth and eventual aggregation of a number of separate and distinct seed-continents or proto-continents and the Superior province represents the preserved remnant of one such proto-continent. He suggests that mineralization is selectively distributed within the proto-continents. There is a change in chemistry of the volcanic belts forming the proto-continent and a change in physical dimensions of the belts which both may affect the localization of mineral deposits. He also suggests that mineral deposits seem to be associated with certain volcanic features such as vents, collapse calderas, feeder pipes, ring dykes, etc.. More detailed studies on the Archaean of both continents are required to thoroughly test these proposals.

An association of gold mineralization with the low grade quartz-magnetite iron formation accompanying the Archaean volcanic rocks, is known in both countries, in Western Australia at Mount Magnet and small deposits near Norseman, and in Canada the Pickle Crow deposits are associated with iron formation, the recently discovered Contwoyto Lake deposits are in "amphibolite" that is probably metamorphosed low grade iron formation and in the eastern District of Keewatin gold is found in low grade iron formation. The possible syngenetic relationship of gold and iron in sedimentary deposits should be considered in both countries as a possible exploration clue.

It is surprising that non-ferrous base metal deposits in the Archaean of Australia are relatively rare, limited to the Ravensthorpe copper, the lead-copper deposits of the Northampton field, west of the Darling fault, and the recently discovered Kambalda nickel deposit south of Kalgoorlie. This is very much in contrast to the rich base metal deposits of Noranda, Malartic and Mattagami in Quebec, the new Kidd deposit near Timmins, and the copper - nickel deposits of Manitoba. At Mattagami, Sharpe (1965) suggests the sulphide masses are entrapped along the contact between two volcanic groups and the mineralization seems to have a close spatial relationship to regional volcanic stratigraphy. Roscoe (1965) states that at Noranda many ore deposits are at the contact of andesite and underlying rhyolite and that many copper-bearing strata-bound sulphide deposits appear to be characterized by high Co:Ni ratios and relatively high Sn content. The contacts of acid volcanic rocks appear particularly to be the loci for these deposits. Possibly further mapping in the Archaean belts of Western Australia, with attention to the stratigraphy, so that extrusive volcanic piles within the belts of greenstone can be recognized, would be useful for further exploration. The importance of Archaean acid volcanic rocks in connection with mineralization has been recognized in Canada and as these rocks occur with the basic volcanic rocks in the Archaean of Western Australia special attention should be focussed on them. It seems quite possible that more non-ferrous base metal deposits will be discovered in the Yilgarn and Pilbara Nucleii. There is,too,remarkable regional tectonic parallelism when the location of the volcanic belts and the fault bordering part of the Grenville province in Canada is compared with the volcanic belts of the Yilgarn Nucleus and the Stirling Range Fault.

The major non-ferrous base metal deposits in the Australian Precambrian, Broken Hill, Mount Isa and McArthur River, have no equivalents in the Canadian Shield. The Proterozoic Mount Isa and McArthur River deposits, associated with black slates in thick sedimentary sequences, are of particular interest. In both there are some indication of volcanic activity in the form of thin tuff horizons in the slates. Possibly in some Canadian Proterozoic sequences, perhaps the Kaniapiskau Supergroup where there are indications of Pb-Zn mineralization, and some similarity of lithology, there is a chance of finding similar mineralization. However, Hogg (1966) states there is little evidence of sulphide deposition by sedimentary or bacterial action in this region. It is possible that in Canada where metamorphism is generally more intense, such deposits might be modified and less easily recognized. The Broken Hill deposit seems to be quite unique but its occurrence in high grade metamorphic-sedimentary rocks indicates the possibility of deposits in such terrains and they should not be ruled out as is the tendency in Canadian exploration thinking.

Lead - zinc mineralization in carbonates, the 'Tri-State' type of deposits, in contrast to the black shale association of Mount Isa and McArthur River, are known in the Canadian Proterozoic in northern Baffin Island and near Richmond Gulf on the east coast of Hudson Bay although at present, neither are economic deposits. It is worth considering that in the well preserved sedimentary sequences of the Australian Proterozoic, such deposits might exist.

The iron deposits of Western Australia are derived from iron formations similar to those of the Canadian Precambrian. The iron deposits themselves may be different, reflecting the variations in erosional or weathering histories of the iron formation. The Robe River type of deposit in Western Australia, for example, a pisolitic type of ore developed by weathering in Mesozoic or later times, is a type of deposit unknown in Canada. The hematite - goethite deposits of Western Australia, e.g. Mount Tom Price, are very similar to the Schefferville deposits of Labrador - Quebec. Metamorphosed iron deposits, such as those at Carol Lake and Gagnon in Labrador and Quebec, have not been found in Western Australia but are perhaps comparable in some respects to the deposits of the Middleback Ranges of South Australia. Iron deposits developed from Archaean iron formations, such as the Mount Goldsworthy and Koolyanobbing deposits in Western Australia and the Lowphos and Jones Laughlin deposits in Ontario are similar, although the Canadian deposits are lower grade in most cases.

It is striking that on both continents iron formations of the same age are similar, the Archaean jaspilite types, the older Proterozoic banded iron formations, and in the younger Proterozoic, oolitic iron formation. Oolitic iron formation is relatively rare in Canada, there is some in the Great Slave Group, but in northern Australia it is abundant in the Adelaidean sediments of the Carpentaria area. It seems possible that the type of iron formation depends in large measure on its age and is governed by world-wide conditions, perhaps the atmosphere prevailing at the time.

Manganese deposits occur in the Precambrian of the Pilbara and Peak Hills regions of Western Australia as the result of weathering of manganiferous Proterozoic sediments. On the south coast of Western Australia, in the Philips River area, weathering of a manganiferous Archaean jaspilite results in some small manganese deposits. In practically all these manganese deposits, supergene enrichment has taken place so the erosional history of the Western Australian Precambrian is responsible for them. Any deposits of this type that might have developed in Canada would have been removed by the Pleistocene glaciation. Some iron ore in Canada is relatively high in manganese content, e.g. the Sawyer Lake deposits of the Schefferville area, but none are a source of manganese as such.

The origin of the crocidolite present in the "Nullaginian" iron formation near Wittenoom, in Western Australia, is uncertain. Occurrences of crocidolite are known in iron formation of the Kaniapiskau Supergroup and possibly when studies of the Australian deposits are completed and something known of their origin, it may be practical to search for other occurrences in Canada.

With the abundance of well preserved sedimentary sections in the Australian Proterozoic, it would be interesting to know to what extent conglomerate horizons in the many groups have been tested for radioactivity. Many areas have been covered by airborne scintillometer surveys but it is possible some likely conglomerate units have been overlooked. Considering the productiveness of the Huronian conglomerates in Ontario as a source of uranium, it would probably be worthwhile compiling data on lithologically similar conglomerates in Australia to determine if all are barren of radioactive minerals. Derry (1961) indicates uraniferous conglomerates tend to occur in the lower part of middle to younger Precambrian sedimentary series overlying an Archaean nucleus.

Silver production from the Australian Precambrian is confined to that from the base metal mines such as Mount Isa and Broken Hill. Similarly, in Canada much of the production is by-product but there is some present production from the Cobalt area, formerly a rich silver camp. The origin of the rich silver lodes is still uncertain but they are always found near the Nipissing diabase (or dolerite) sill. The sill intrudes gently dipping sedimentary rocks of the Cobalt series but where silver is found, the underlying Archaean basic volcanics are also nearby. The deposits appear to be fault controlled for the most part. The dolerite or diabase sill is considered by many people to be the source of the silver mineralization and the lithology and structure too control the locus of deposition. Some of the thick dolerite sills intruding "Nullaginian" sediments in the Median Belt between the Yilgarn and Pilbara Nucleii might be the locale of similar mineralization.

Tin and tantalite have been produced from both lode and alluvial workings in the Greenbushes area in the Precambrian of the southwest of Western Australia. The principal production of cassiterite has been from the alluvial workings. The deeply-weathered bedrock consists of schists, gneisses and greisens. No tin has been produced from the Canadian Precambrian although cassiterite occurs rarely in some pegmatites near Yellowknife. It is possible that more detailed work in Canada may reveal tin-bearing greisens but at present no such metallogenic province is known. Lack of deeply weathered zones (due to glaciation) means no enrichment by weathering will be found.

Molybdenite deposits occur over a considerable area of the Grenville province in Canada, but most production is from those associated with the Archaean Preissac-LaCorne granite batholith. This post-kinematic batholith is similar to some in Western Australia but the accompanying disseminated molybdenite mineralization has so far not been found in Australia. A molybdenite metallogenic province may be absent in Western Australia but the possibility should be kept in mind. The same Preissac-LaCorne batholith has economic deposits of lithium-bearing spodumene associated with it. The only important occurrences of lithium-bearing minerals in Australia are confined to pegmatites, particularly some near Kalgoorlie and Coolgardie.

Carbonatite intrusions are unknown in the Australian Precambrian but in Canada there are several occurrences, containing pyrochlore, an ore of columbium. At present, the deposit of Oka, near Montreal, is the only one in production. On the Tectonic Map of the Canadian Shield (1965), alkaline intrusions, including carbonatites, are shown and there seems to be certain relationships apparent from their distribution. In the Grenville they seem to occur along the margins of the province or adjacent to old nucleii boundaries within the province. In the Superior province, the bodies have a preferred distribution along anomolous Bouguer highs, suggesting an association with major deep-level tectonic features. In Australia, on the south side of the King Leopold mobile belt are alkaline lamproite intrusions of Jurassic age. Prider (1960) describes these bodies, some of which are intrusive rocks, and others consisting of breccia which he thinks originated as diatremes. Although they show an irregular non-linear distribution, their location close to a major tectonic feature suggests affinities with some of the Canadian intrusions. Possibly other major tectonic boundaries in the Australian Precambrian, such as the boundary between the Yilgarn Nucleus and Albany-Esperance block might be the location of intrusions of this type. When a regional gravity map of Australia becomes available the major Bouguer highs would be of interest in relation to these rocks. However, it is entirely possible carbonatites are absent in Australia.

It is obvious that exploration techniques or tools will differ in the Precambrian of Australia and of Canada. The deeply weathered profile in Australia as compared to the fresh rock surfaces and glacial drift in Canada will require different approaches in the application of geochemistry and some geophysical methods. Detailed exploration programmes are going to evolve along different lines and discrimination must be used in selecting proper techniques.

Summary of Conclusions

The Precambrian Canadian Shield is a compact entity in contrast with the dispersed occurrences of Precambrian rocks in Australia. Archaean rocks in the two countries are in a broad way similar, but the abundances of the various rock types is different. The bands of meta-volcanic and meta-sedimentary rocks are strikingly similar in all respects but possibly more abundant in Australia. Massive granites, in particular high-level, post-kinematic types appear to be more abundant in the Australian Archaean, but banded gneisses, granitic gneisses and migmatites are more common in the Canadian Archaean.

Aphebian age sedimentary rocks are relatively speaking, slightly more abundant than analogous "Nullaginian" rocks in Australia. Some sequences of these rocks are remarkably similar on the two continents, particularly those containing banded iron formation but both countries have some unique sequences. Sedimentary rocks of Carpentarian and Adelaidean age are considerably more abundant than are those of Helikean and Hadrynian age. Canadian sedimentary rocks of this age include many clastics, particularly cratonic cover rocks whereas marine basin sediments predominate in Australia.

Acid to intermediate volcanic rocks of Proterozoic age seem to be far more abundant in Australia than they are in Canada.

Proterozoic crystalline rocks, gneisses and massive granitoid rocks, are far more abundant in Canada than they are in Australia. The extensive anorthosite masses in Canada have no equivalent in Australia.

Basic dykes of both Archaean and Proterozoic age are present in swarms throughout the Canadian Shield. Similar dyke swarms of Archaean age occur in Australia but dykes of Proterozoic age are relatively rare.

The Yilgarn and Pilbara are the old nucleii of the Australian Precambrian and in Canada the Superior and Slave Provinces are the much larger original nucleii. In both countries some evidence suggests the separated nucleii may originally have been single blocks. The Canadian Precambrian possibly offers better evidence in support of continental accretion than does the Australian Precambrian. The tectonics in the Archaean of both countries appears to have been rather similar. During the Proterozoic however the Canadian Shield underwent mountain building orogenies followed by deep erosion, to reveal the crystalline roots of the mountains and deposition of cratonic cover rocks in intercratonic areas. Since the Proterozoic the Canadian Shield has been essentially stable and unaffected by Phanerozoic tectonics, although inundated by seas from time to time. Evidence of orogenies in the Australia Proterozoic is limited to restricted areas and the Proterozoic is typified by abundant, well preserved, relatively unmetamorphosed and undeformed sedimentary sequences. The relative scarcity of Proterozoic dolerite dykes in Australia is perhaps explained by the lack of tectonism. However, Phanerozoic tectonism has affected the Australian Precambrian, a basic difference between it and the Canadian Shield.

Similarities and differences in mineral deposits in the Precambrian of the two countries are obvious, but there appears to be some possibility of usefully applying comparisons of the two terrains. For example, in Australia consideration should be given to the possibility of finding base metal deposits in Archaean volcanic belts, by careful study of their stratigraphy and structure, in the light of Canadian experience in similar volcanic belts. In Canada some thought should be given to the possibility of finding syngenetic base metal deposits of the Mount Isa - McArthur River type, in Proterozoic sedimentary sequences. On the other hand, it is a remote possibility that the tin metallogenic province of Australia will be duplicated in Canada and it is unlikely that a molybdenite metallogenic province equivalent to that in Canada will be found in Australia.

Acknowledgements

The writer gratefully acknowledges the assistance which he has received from geologists of the Bureau of Mineral Resources, the Geological Survey of Western Australia, the South Australia Geological Survey and of various mining companies visited. Discussion with them was invaluable in gaining some knowledge of the Australian Precambrian. Particular thanks are due to P.R. Dunn and K.A. Plumb who critically read the manuscript and offered many suggestions, some of which have been incorporated.

References

BARAGAR, W.R.A., 1966 - Geochemistry of the Yellowknife Volcanic Rocks; Cdn. Jour. Earth Sc., Vol. 3, No.1, pp. 9-30.

DAVID, T.W.E., 1950 - The Geology of the Commonwealth of Australia, Vol. 1; Ed. Arnold and Co., London.

DERRY, D.R., 1961 - Economic Aspects of Archaean - Proterozoic Boundaries; Ec. Geol., Vol. 56, No. 4, pp. 635-647.

DUNN, P.R., PLUMB, K.A., ROBERTS, H.G., 1966 - A Proposal for Time-stratigraphic Subdivisions of the Australian Precambrian; Jour. Geol. Soc. Aust., Vol. 13, Pt. 2, pp. 593-608.

FAHRIG, W.F., GAUCHER, E.H., LAROCHELLE, A., 1965 - Palaeomagnetism of Diabase Dykes of the Canadian Shield; Cdn. Jour. Earth Sc., Vol. 2, No. 4, pp. 278-298.

GEOLOGICAL MAP OF WESTERN AUSTRALIA, 1966 - scale 1:250,000 - Geol. Surv. West. Aust.

GOODWIN, A.M., 1966 - Archaean Protocontinental Growth and Mineralization; Cdn. Min. Jour., Vol. 87, No. 5, pp. 57-60.

HARRISON, J.M., in Stockwell, C.H., editor, 1957 - Geology and Economic Minerals of Canada; Geol. Surv., Canada, Ec. Geol. Series, No. 1 (Fourth Edition).

HAWKES, D.D., 1966 - The Petrology of the Guiana Dolerites; Geol. Mag., Vol. 103, No. 4, pp. 320-335.

HILLS, E.S., 1965 - Tectonic Setting of Australian Ore Deposits; in Geology of Australian Ore Deposits, Publications, Vol. 1, Eighth Comm. Min. Met. Cong., pp. 3-12.

HOGG, G.M., 1966 - The Exploration of a Sulphide - bearing Belt, Labrador and New Quebec; Bull. Cdn. Inst. Min. Met., Vol. 59, No. 653, pp. 1085-1092.

HORWITZ, R.C., SOFOULIS, J., 1965 - Igneous Activity and Sedimentation in the Precambrian between Kalgoorlie and Norseman, W.A.; Aust. Inst. Min. Met. Proc., No. 214, pp. 45-59.

PRIDER, R.T., 1960 - The Leucite Lamproites of the Fitzroy Basin, Western Australia; Jour. Geol. Soc. Aust., Vol. 6, Pt. 2, pp. 71-118.

PRIDER, R.T., 1965 - Geology and Mineralization of the Western Australian Shield, in Geology of Australian Ore Deposits, Publications, Vol. 1, Eighth Comm. Min. Met. Cong., pp. 56-65.

ROSCOE, S.M., 1965 - Geochemical and Isotopic Studies, Noranda and Mattagami Areas; Bull. Cdn. Inst. Min. Met., Vol. 58, No. 641, pp. 965-971.

RYAN, G.R., KRIEWALDT, M., 1964 - Facies Changes in the Archaean of the West Pilbara Goldfield; Geol. Surv., West. Aust., Ann. Rept., 1963, pp. .

SHARPE, J.I., 1965 - Field Relations of Matagami Sulphide Masses Bearing on their Disposition in Time and Space; Bull. Cdn. Inst. Min. Met., Vol. 58, No. 641, pp. 951-964.

STOCKWELL, C.H., in Lowden, J.A., 1962 - Age Determinations Geological Survey of Canada, Report 3; Geol. Surv., Canada, Paper 17-62.

STOCKWELL, C.H., 1964 - Fourth Report on Structural Provinces, Orogenies and Time Classification of Rocks of the Canadian Precambrian Shield; Geol. Surv., Canada, Paper 64-17 (Pt. II), pp. 1-21.

TECTONIC MAP OF THE CANADIAN SHIELD, 1965 - Geol. Surv., Canada, Map 4-1965.

WILSON, A.F., COMPSTON, W., JEFFERY, P.M., RILEY, G.H., 1960 - Radioactive Ages from the Precambrian Rocks in Australia; Jour. Geol. Soc. Aust., Vol. 6, Pt. 2, pp. 179-195.

WILSON, H.D.B., ANDREWS, P., MOXHAM, R.L., RAMLAL, K., 1965 - Archaean Volcanism in the Canadian Shield; Can. Jour. Earth Sc., Vol. 2, No. 3, pp. 161-175.