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THE RELATION OF MINERAL DEPOSITS TO EARLY CRUSTAL EVOLUTION

by

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ABSTRACT

The Archaean accounts for approximately half the recorded history of the Earth, comprising over 2 000 m.y. of geologic time. The first ∿ 800 m.y. are virtually lost from the record and events on the surface of the planet can only be speculated over. It is probable that this formative episode was magmatically turbulent and culminated with the final stages of meteorite bombardment ∿ 3 900 m.y. ago. The next events, for which there is geologic evidence, involved the regions now represented by the high-grade gneiss terranes wherein the first mineralization was developed. Ore deposits are not well-represented in these regions for one, or a combination of the following reasons: (i) mineral concentrations may have been recycled or destroyed during the initial turbulent episode of proto-continental development (ii) mineralization may have been destroyed by later tectono-thermal events that characterize the high-grade mobile belt regimes or (iii) mineralizing events or conditions may not have evolved sufficiently for metal concentrations to have formed in significant amounts.

The period of the Archaean beginning ∿ 3 500 m.y. ago and terminating ∿ 2 500 m.y. ago witnessed the development of the low-grade granite-greenstone terranes of the shield areas. An examination of the principal components of these regions is undertaken following an existing model whereby greenstone sequences are subdivisible into a basal unit comprising mainly mafic/ultramafic rock types, followed by an upper mafic-to-felsic volcanogenic succession, the latter succeeded by an essentially sedimentary group of rocks.

The nature and distribution of Archaean mineralization associated with the granite-greenstone terranes is described and it is shown that there is a strong genetic link between mineral types and rock compositions. Evolutionary trends in the nature and geochemistry of magma types are discussed and these are considered to reflect changing conditions of heat flow, changes in the nature of the atmosphere and hydrosphere, and progressive modification of the Earth's crust resulting from proto-continental nucleation and development. Magma types ranging from komatiitic basalts and peridotites to calc-alkaline series basalts-dacites-rhyodacites-rhyolites suggest changing geotectonic conditions not only within individual greenstone belts but also over the time-span of the entire Archaean. Available information suggests that the island-arc or trench-back arc-marginal basin system provides the closest modern analogue to the ancient greenstone sequences. However, sufficient differences exist to caution direct correlation with plate tectonic mechanisms operating at present and it is suggested that the early Archaean greenstone sequences may have been involved more with vertical tectonics in response to gravitational differences resulting from sinking volcanic piles and diapirically rising granitoid complexes. In later Archaean times conditions might have approached those currently favoured for Phanerozoic orogenesis.

Finally, it is suggested that Archaean ore deposits are essentially secondary in origin, having formed mainly as a result of superimposed processes of igneous intrusion, metamorphism, structural disturbance and chemical alteration acting on suitable host rocks during or subsequent to their formation and deposition.

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I. INTRODUCTION

The distribution of ore deposits and the nature and styles of mineralization in time and space suggests to many economic geologists that there has been an evolutionary trend in the concentration of metals as well as in the diversity of morphological types of mineral occurrences (Anhaeusser and Button, 1976; Goodwin, 1971; Pereira and Dixon, 1965; Watson, 1973). The time-tectonic-stratigraphic interrelationships of volcanogenic massive sulphide deposits have, for example, received particular attention and investigations by Hutchinson (1965, 1973, 1976, 1978a, b) and Sangster (1972) indicate distinct evolutionary changes through Archaean, Proterozoic and Phanerozoic massive sulphide occurrences. These changes have, furthermore, been convincingly related to evolutionary processes of crustal development through geologic time. Employing a different approach Naldrett (1973) and Naldrett and Cabri (1976) showed that nickel sulphides and platinum-group elements are almost exclusively associated with ultramafic and mafic rocks and that the differences in character of the mineral deposits depends heavily on the class of these rocks and the tectonic environment into which they were emplaced. In addition to the tectonic setting, the age of the host rocks determine certain trends in the nature and composition of the mineralization, again suggesting some evolutionary metallogenic influences.

Although much can be made of the evolution of mineral deposits through geologic time it is the task, in this contribution, to reflect on the relation of mineral deposits to the early crustal history of the Earth. So as not to confuse the reader it is necessary to define precisely what segment of Earth history will be referred to in the following pages.

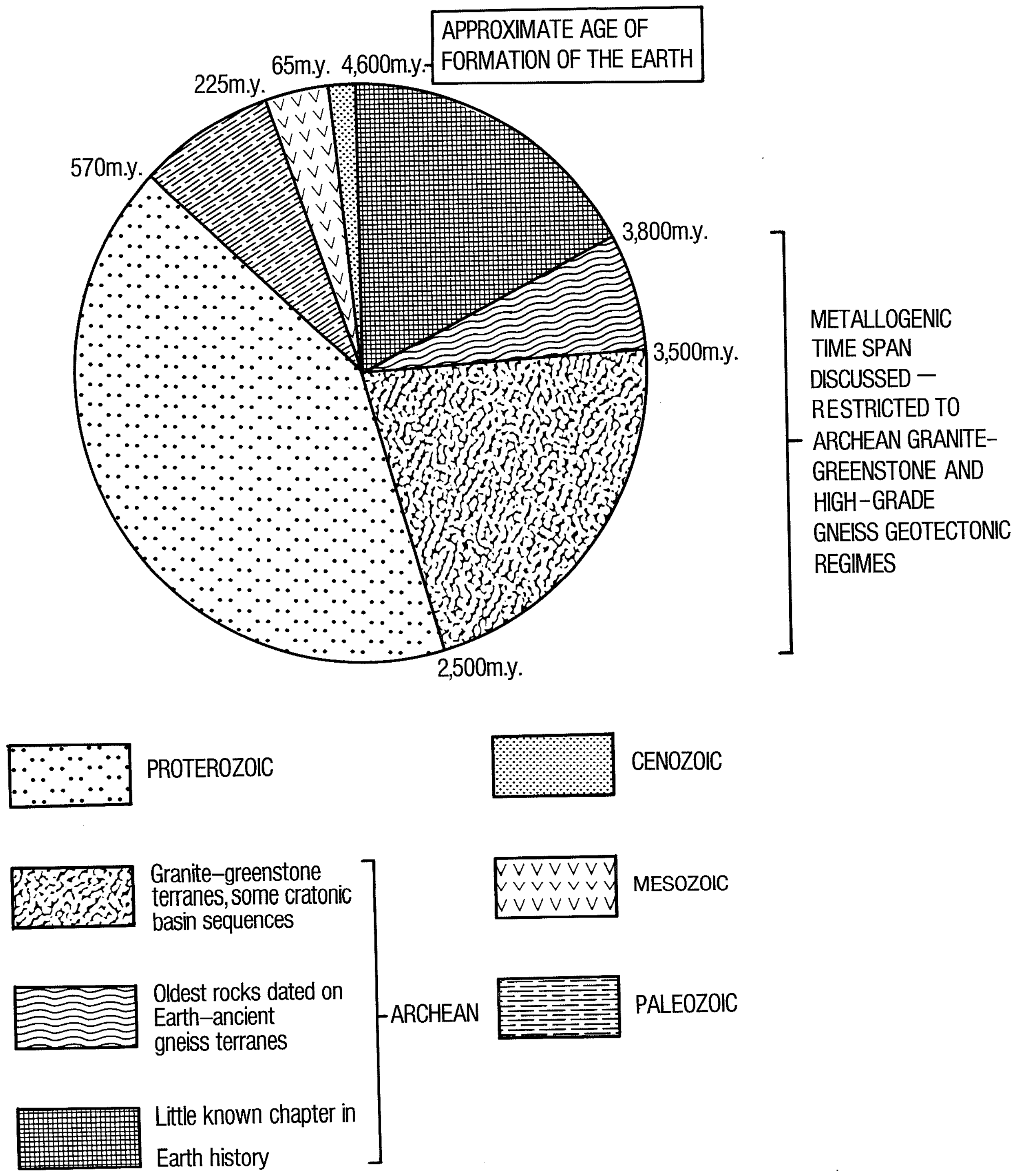
Three macro-episodes of crustal evolution have been defined to accommodate periods of major geological significance in Earth history. These are the Archaean (> 2 500 m.y. B.P.), the Proterozoic (> 570 m.y. B.P.) and the Phanerozoic (made up of the Palaeozoic, > 225 m.y., the Mesozoic > 65 m.y., and the Cenozoic ∿ 65 m.y. to present). The Proterozoic and Archaean eras together comprise the Precambrian which accounts for approximately 90 per cent of geologic time. Much of what is to follow falls within the Archaean macro-episode which, to date, can only be traced back to about 3 800 m.y. B.P. We are faced with the realization that close on 1 000 million years of Earth history are irrecoverably lost to the geologic record as the chances no longer appear encouraging that rocks older than those reported in West Greenland, Labrador, the Minnesota River Valley and the Limpopo Belt in southern Africa will ever be located. Any advances in our understanding of this formative period in Earth history may have to await contributions from lunar and planetary studies. What transpired from the time the Earth was formed approximately 4 600 - 4 700 m.y. ago to about 3 800 - 4 000 m.y. ago must remain open to speculation. Beyond what appears to have been a scenario of high-temperatures and considerable igneous activity, as adduced from events on the Moon (Lowman, 1972, 1976), as well as plausible arguments suggesting that the Earth as well as the other "silicate planets" (Mercury, Mars and Venus) were all subjected to severe impact cratering (Frey, 1980; Lowman, 1976), little positive information is available about the Earth's primitive crust and the development of continents and oceans. Grieve (1980) concluded that the net effect of the intense, pre-3 900 m.y. impact flux was to localize and accelerate endogenic activity, thereby triggering mechanisms that were to generate extensive concentrations of differentiated crust (proto-continental nuclei). Green (1972) further argued that such impact events may even have continued until much later in order to give rise to the development of the ultramafic komatiite-type magmas occurring in the Archaean greenstone belts, for which unique petrogenetic conditions must have prevailed.

Although this early chapter in Earth history undoubtedly influenced the events that were to follow the link is tenuous at this stage and, furthermore, there are no indications that mineralization would have concentrated sufficiently to form ore deposits in what appears to have been a turbulent environment. Had metals accumulated it is doubtful whether they would have survived what was probably a rapid cannibalistic episode of destruction during the early Archaean. For these reasons, therefore, no further attention will be given to this pre-3 800 m.y. hiatus in the geologic record.

The Archaean, by most definitions, has an upper age limit of 2 500 m.y. B.P. whereupon it is followed by the Proterozoic era. In general, the use of the term Archaean has become largely (if not entirely) synonomous with ancient crystalline granitic terranes, the latter incorporating early Precambrian greenstone belts. Anomalies within this framework appear in different parts of the world (for example in southern Africa) where cratonic sedimentary basin deposits ranging in age from 2 700 - 2 800 m.y. (Witwatersrand-Dominion sequences) to approximately 3 000 m.y. (Pongola Supergroup) are developed (Anhaeusser, 1973). Despite their Archaean ages these successions have characteristics more in keeping with counterparts of Proterozoic age. As it is the intention to restrict this discussion to mineral deposits in the granite-greenstone systems, and their high-grade gneiss-granulite equivalents, no consideration will be given to ore deposits in the Archaean cratonic sedimentary basin regimes. In short, this paper gives attention to the relation of mineral deposits to early crustal processes between 2 500 and 3 800 m.y. ago (Figure 1) but restricts the discussion to events that are recognizable components of the granite-greenstone systems and some of the older Archaean high-grade migmatitic terranes comprised of granitic gneisses, amphibolitic gneisses and metasedimentary sequences.

II. ARCHAEAN HIGH-GRADE REGIONS

The Archaean high-grade rocks occur in a wide variety of environments and range in age up to 3 600 - 3 800 m.y. ago. The commonest rocks are generally granulite-to-upper amphibolite facies gneisses but contain the remains of some of the earliest volcanic and sedimentary rocks as well as layered igneous complexes. These comprise tectonic lenses and layers of a variety of plagioclase-enriched anorthosite-leucogabbroic bodies in addition to mafic-ultramafic complexes (consisting of pyroxenites, serpentinized peridotites, and amphibolitic rocks).



<u>*Figure 1*</u> : *Pie-chart showing the subdivision of Earth history into eras. The Archaean, which accounts for approximately half of recorded time, is further divided into three time segments : the earliest comprising ∿ 800 m.y. of little known activity on the Earth's surface, followed by an ∿ 300 m.y. segment reflecting early high-grade migmatite-gneiss terranes. The third chapter of the Archaean, mainly dealt with in this paper, comprises the low-grade granite-greenstone geotectonic regime of the shield areas.*

The general complexity encountered in the Archaean high-grade regions makes it difficult to determine the original nature of many of the units and provides a major problem in deciphering the origin of the sequences. Quartzo-feldspathic gneisses containing biotite and/or hornblende, hypersthene (with or without diopside), plagioclase, potash feldspar and quartz, constitute the most common rock type. As outlined by Windley (1977) the origin of these gneisses poses a major problem but it is possible to establish satisfactorily that many of the amphibolites were originally volcanics (with pillow structures) or dykes (with apophyses and discordances), that the anorthosites were igneous (on the basis of texture, the presence of chromite-layering and rock geochemistry) and that the quartzites, marbles and iron-formations were of sedimentary origin.

The complex structural and metamorphic histories exhibited by the high-grade regions have destroyed or distorted clues to the environments of formation of rock-types developed in the mobile belts and few conceptual attempts have been made to reconstruct or model the geotectonic environments. Windley (1977), in reviewing the high-grade occurrences from around the world, pointed to several marked similarities common to most of the regions. Most distinctive, he showed, is the presence in the gneisses of layers and lenses of meta-basic, meta-ultrabasic and meta-anorthositic rocks that are the remains of layered igneous complexes. These complexes are bordered by recrystallized shelf-type sediments (including mica schists, quartzites, marbles, banded iron-formations) and probably were intruded into the sedimentary sequences prior to the advent of severe deformation and high-grade metamorphism (Bridgwater et al., 1974).

Suggestions have been made that the high-grade environments represent the reworked equivalents of neighbouring cratonic material, with or without infolded supracrustal rocks (Anhaeusser et al., 1969; Glikson and Lambert, 1976; Rivalenti, 1976; Viswanathan, 1975). This interpretation does not appear to be altogether favoured but has not been entirely rejected nor superceded by any generally acceptable alternative viewpoint.

Clearly, the geological make-up of the two types of region are vastly different but, is this not merely a reflection of the geotectonic evolution of the two environments?

III. MINERALIZATION IN ARCHAEAN HIGH-GRADE REGIONS

Few mineral deposits have been found in Archaean high-grade regions. This is in marked contrast to the large number and variety of ore deposits known to occur in the lower grade environments, and is regarded by some as one of the lines of evidence for rejecting the idea that the high-grade regions are structurally and metamorphically reworked granite-greenstone terranes. A counter to this argument has always been that if, prior to deformation and metamorphism, the rocks in the mobile belts had contained mineral concentrations these would have, either been destroyed by the metamorphic/tectonic processes or in some way dispersed by recycling events. Either way there is no clear solution. The few deposits known in these environments do suggest a general paucity of mineralization, but the added factors of often poor exposure, coupled with structural complexity and an inadequate knowledge of the transformed stratigraphy of the mobile belts, may have contributed to the lack of mineral exploration successes. In discussing the metallogeny of the Limpopo Belt in eastern Botswana, Lear (1977) concluded that mineral occurrences are qualitatively fairly extensive throughout the region but are subeconomic, occurring either as disseminated showings or as massive sulphide lenses of no great extent. A wide range of mineral types were reported, including occurrences of copper, copper-nickel, copper-lead-zinc-silver, chromite, iron-sulphides (pyrite-pyrrhotite) and iron-oxides (magnetite quartzites and banded iron-formations).

The most important deposits in the Limpopo Belt are the copper-nickel ore bodies in the Selebi-Pikwe area (Gordon, 1973; Lear, 1979) where the sulphides (pentlandite-chalcopyrite-pyrrhotite-pyrite) are considered to share an intrusive magmatic origin with the host amphibolite derived from mafic/ultramafic parental material.

Almost all the mineral occurrences in the high-grade environments are associated with either mafic/ultramafic host rocks or anorthosites. This applies particularly to Ni-Cu as well as to chromite deposits. One of the most prominent developments of chromite occurs in the Fiskenaesset Complex in West Greenland where Ghisler and Windley (1967) described anorthosites at the top of a layered sequence containing chromite seams that locally attain thicknesses of 20 m throughout the 500 km strike length of the complex. Similar metamorphosed and deformed chromitite bodies have been reported from India (Subramaniam, 1956; Leelanandam, 1967) and in the Limpopo Belt (Söhnge et al., 1948) where the mineralization occurs in ultrabasic or hornblendite layers associated with meta-anorthosites. Chromite deposits have also been mined from serpentinized pyroxenites that occur with quartz-magnetite rocks, meta-gabbros, pyroxenites and dunites in the high-grade north-marginal zone of the Limpopo Belt in Zimbabwe (Rhodesia) (Worst, 1962). These occurrences yielded chromite containing between 32-53 per cent Cr_2O_3 with Cr/Fe ratios ranging between 1 and 3, whereas those associated with the anorthosites from elsewhere are of considerably lower grade and have Cr/Fe ratios of about 1. The higher grade chromite occurrences in the serpentinized pyroxenites mentioned above appear to be in relic greenstone xenoliths flanking the Rhodesian craton and provide support for the suggestion that the high-grade metamorphic rocks of the Limpopo Belt are, at least in part, the reworked equivalents of the flanking granite-greenstone basement.

Iron-formations make up a further important component of some high-grade metamorphic regions. The oldest reported occurrence of banded iron-formation is located in the pre-3 700 m.y. old Isua supracrustal belt in West Greenland where Appel (1980) was able to subdivide the iron-formations into different facies. These coincide with the facies subdivisions (oxide, carbonate, silicate, sulphide) of younger Archaean and Proterozoic iron-formations which they greatly resemble. Despite the similarities, the Isua iron-formations display notable differences in the distribution of Fe and Cu sulphides in each of the facies compared to most younger iron-formations (Appel, 1979a). Furthermore, differences in the Na/K ratios (2.2) as well as lower contents of P, Ca and Al, relative to other Precambrian iron-formations were reported by Appel (1980). The carbonate facies at Isua also differs from that described by James (1954), being more a transitional facies deposited under somewhat reducing conditions. Exotic minerals recorded in the Isua iron-formations include ilmenite and grains and bands of chromite. The ilmenite is considered to be of volcanic origin and is thought to have concentrated from basaltic tuffs by aeolian differentiation (Appel, 1977). The chromite grains are rare but have been found in all four facies of iron-formation. Appel (1979b) has suggested these grains are of cosmic origin, representing traces of the major meteoritic bombardment which hit the Earth-Moon system in Early Archaean times.

Precambrian iron-formations are generally accepted as being chemical precipitates, deposited contemporaneously with their enclosing sediments and volcanics. The ancient Isua iron-formations appear to be no exception but controversy remains over the source of the iron and silica making up the iron-formations. The early Archaean atmosphere appears to have been devoid of free oxygen (Schidlowski, 1978) although the occurrence of iron oxides and calcium sulphate in primitive sediments suggests that some free oxygen may have been present very early in Earth history. Its concentration may have remained very low, however, until large volumes of the earliest sediments had been partially oxidized (Cloud, 1968; Rubey, 1951, 1955). The general paucity of oxygen may have inhibited crustal weathering and, hence, there is a preferred tendency to consider the Archaean iron-formations as having been derived from submarine exhalations or halmyrolytic mobilization. The latter process involves the circulation of heated water through basaltic lavas, thereby leaching considerable amounts of metals from the volcanic rocks. Subsequent precipitation either in the uppermost part of the volcanic pile, or on the sea-floor would ensue. Appel (1980) considered halmyrolisis to be a minor process in the formation of the Isua iron-formations. This is indicated mainly by the lack of leached basaltic rocks and from the REE distribution patterns of the oxide-, carbonate-, silicate- and sulphide facies iron-formations which show very different characteristics from those of the Isua basalts. Rather, the intimate association of many of the iron-formation layers with basaltic rocks, as well as the geochemistry of the iron-formations, suggested to him that they are of submarine exhalative derivation. Thus the oldest iron-formations on Earth appear little different from those in the somewhat younger Archaean greenstone belts where the origin of banded iron-formations has also been attributed to volcanic processes in terms of the source of the chemical components (Goodwin, 1973).

Apart from the Isua occurrence, currently being assessed as a source of iron ore, there are numerous other examples of iron-formation in high-grade metamorphic regions. These include occurrences in the Beartooth Mountains of Montana and Wyoming (Casella, 1969), the Limpopo Belt (Söhnge et al., 1948), southern India (Naidu, 1963) and the southwestern portion of the Yilgarn Block in Western Australia (Wilde, 1980). The iron-formations may be of the banded variety, or they may occur as magnetite quartzites (Limpopo Belt) or quartz-magnetite ± hypersthene iron-formations (Yilgarn Block). In many cases these rocks are associated with meta-sediments or amphibolites and their origin is obscure. Some are probably linked to volcanogenic processes but the magnetite quartzites may also represent metamorphosed detrital sediments.

In summary, therefore, there are few deposits in the high-grade metamorphic environments that have been exploited economically, exceptions being the Pikwe-Selebi Ni-Cu occurrence in Botswana, and chromite deposits in Zimbabwe. The remaining metal showings are either subeconomic or of academic interest only at this stage. The very oldest mineral occurrences and their host rocks may eventually tell us more about the early history of the Earth. These rocks, some of which approach 3 800 m.y. in age, may either represent primitive proto-continental regions or the tectonically devastated relics of ancient granite-greenstone crust similar to that which will be discussed later in this paper.

IV. ARCHAEAN GRANITE-GREENSTONE TERRANES

Two types of Archaean terranes are known: those dominated by high-grade gneisses and migmatites, discussed briefly in the preceding sections, and those consisting of granites and greenstone belts (low-grade cratonic areas). In the granite-greenstone terranes some of the oldest rocks recorded to date include the lower volcanic sequences of greenstone metavolcanic successions in the Pilbara Block, Western Australia (Hamilton et al., 1980) and in the Barberton Mountain Land, South Africa (Hamilton et al., 1979). Ages recorded for these rocks are approximately 3 500 m.y. whereas elsewhere in Canada, Western Australia, India, and Zimbabwe, greenstone sequences yield a wide range of ages with the majority of later orogenic and greenstone-forming events occurring in the period 2 900 - 2 700 m.y. (Condie, 1976; Windley, 1977). It is evident from geochronological as well as geochemical studies that greenstone belts and their enveloping granitic terranes reflect an evolutionary history of approximately 1 000 m.y., equal to about one quarter of the age of the Earth.

Considerable advances have been made in the knowledge of granite-greenstone terranes of the world since the early attempts at synthesis by Anhaeusser et al., (1968, 1969), Goodwin (1968), and Macgregor (1951a) and it would be beyond the scope of this paper to review the voluminous literature that has enhanced our understanding of the very early Precambrian. Those wishing for background and details may consult some of the more recent Archaean review articles including, Anhaeusser (1978, 1980), Condie (1976, 1980a), Glikson (1976, 1979), Goodwin (1977), Goodwin et al., (1972), Lowe (1980), Wilson (1979) and Windley (1977).

Greenstone belts are defined as those distinctive low-grade metavolcanic and metasedimentary assemblages ($\sim$ 2,5 $\leqq$ 3,5 b.y. old) which occur as scattered remnants in cratonic areas and which form an essential part of the latter. Numerous accounts of their geological characteristics are now available and despite differences that are apparent from one shield area to the next there remains, as stressed by Anhaeusser et al. (1969), a worldwide uniformity of the stratigraphy, structure, metamorphism, mineralization, associated granites, and geotectonic setting of the greenstone belts. Refinements to the models originally proposed centre mainly around the increased knowledge of the geochemistry of the volcanic and granitic rocks in these regions (Anhaeusser and Robb, 1980a, b; Arndt, 1976; Arth and Hanson, 1975; Baragar, 1968; Baragar and Goodwin, 1969; Glikson, 1979; Hallberg, 1972; Smith et al., 1980; Viljoen and Viljoen, 1969a, b), as well as advances in understanding the sedimentological histories of Archaean volcano-sedimentary deposits (Barley et al., 1979; Beukes, 1973; Eriksson, 1979; Glover and Groves, 1978; Goodwin, 1973; Lowe, 1980; Naqvi, 1977; Pettijohn, 1943; Walker and Pettijohn, 1971).

Broadly speaking many individual greenstone belts display evolutionary changes in the nature and geochemistry of their volcanic components from base to top of sequences (Anhaeusser, 1971; Baragar, 1968; Goodwin, 1968, 1969; Viljoen and Viljoen, 1970). There are also progressive changes that become evident when comparing the nature and geochemistry of greenstone belts of different ages. Anhaeusser (1976a) drew attention to the fact that the $\sim$ 3 500 m.y. old Barberton greenstone belt contains approximately twice the volume of rocks of ultramafic-mafic and sedimentary affinity than the average Zimbabwian greenstone belts. The available evidence suggests that many of the Zimbabwian greenstones fall in the 3 000 - 2 700 m.y. age category, although limited development of rocks as old as 3 500 m.y. have been recorded (Wilson, 1979). Anhaeusser (1976a) also compared the southern African greenstone lithologies and their proportions with data made available from the Superior Province by Goodwin et al. (1972). The Canadian greenstone belts are dominated by calc-alkaline volcanic sequences whereas rocks of ultramafic-mafic composition play a subordinate role; the average, for example, for the Abitibi and Wagiboon belts, combined, being less than half of the average value for the Zimbabwian belts, and less than one-quarter the value of similar rocks in the Barberton greenstone belt. Most Canadian greenstones range in age between 2 950 - 2 750 m.y. (Goodwin et al., 1972) with limited developments of earlier Archaean sequences ranging from 3 550 - 3 300 m.y. being recorded from neighbouring Minnesota and parts of Labrador; these, however, are high-grade metamorphic areas like those described earlier.

Generalizations invariably invide criticisms but, in the writer's experience, it is possible to subdivide most greenstone belt sequences into a lower, dominantly volcanic and an upper sedimentary group. The lower group can frequently be further subdivided into a lower or basal assemblage of primarily ultramafic/mafic rocks overlain by an upper volcanic group in which calc-alkaline, mafic-to-felsic rocks predominate (Figure 2). This hypothetical, idealized, Archaean stratigraphic column (Anhaeusser, 1971) should be viewed in a broad sense, as environments as complex and diversified as those prevailing during the Archaean are expected to exhibit deviations from one locality to the next. However, the fact that in many instances some systematic trend can be ascertained encourages the view that greenstone belt evolution took place in an orderly, if not predictable, manner from the earliest recorded Archaean events to those that were developed just prior to the advent of the Proterozoic era.

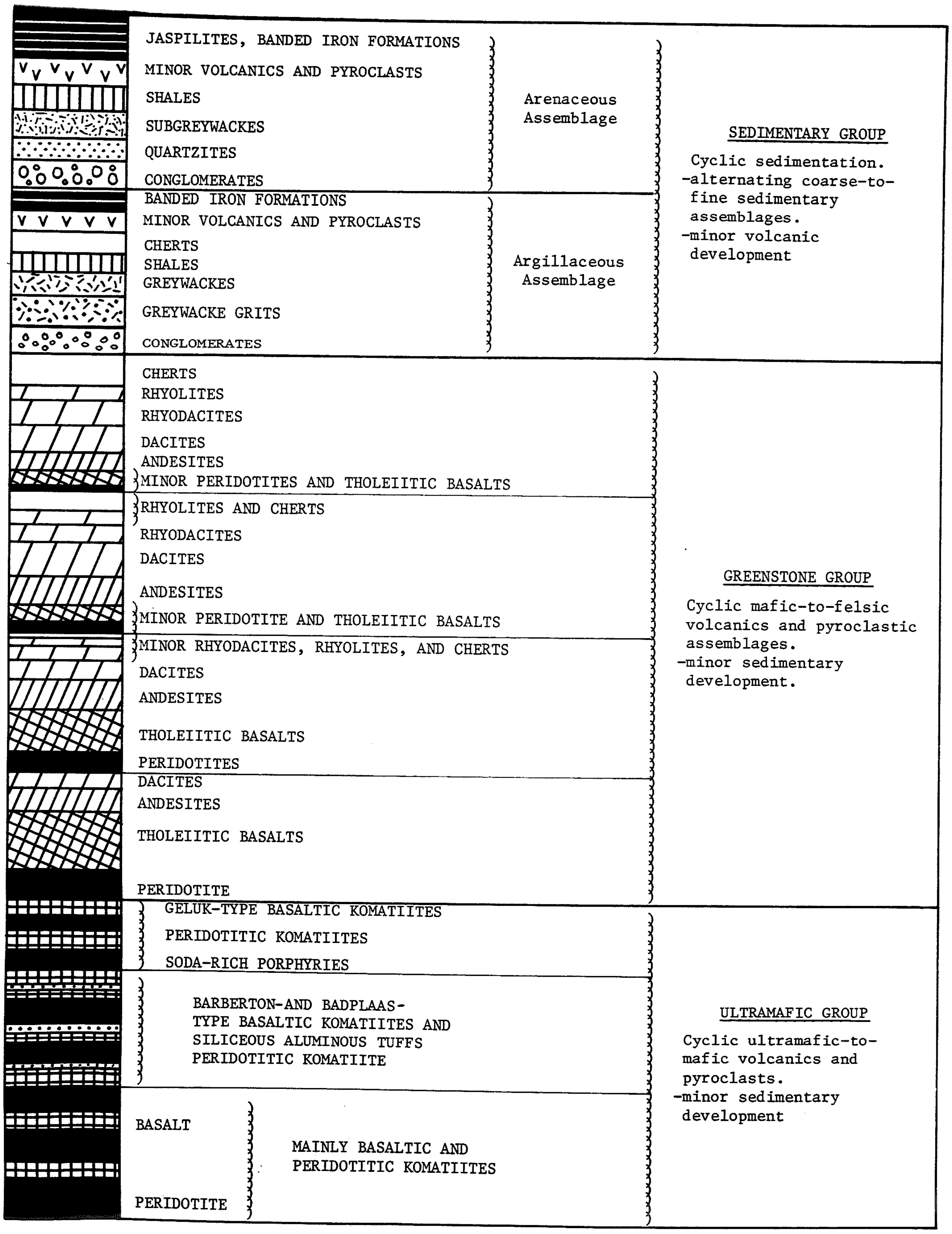


Figure 2 : *Hypothetical, idealized Archaean greenstone belt stratigraphic column (after Anhaeusser, 1971, Geol. Soc. Australia Spec. Publ. No. 3).*

The oldest greenstone sequences generally have anomalous developments of ultramafic-mafic rocks, the latter comprising high-magnesian basalts and peridotites. These rocks, which have a distinctive geochemistry (high-Mg, high-Ca/Al ratio, low alkalies) are referred to as "komatiites" (Viljoen and Viljoen, 1969a). They represent subaqueously extruded lava flows wherein pillow structures and crystalline quench textures are ubiquitously developed. The komatiites are not restricted to the older greenstones or to the basal units of volcanic piles where they usually predominate but have been recorded at various stratigraphic levels of the same pile as well as in greenstone belt sequences of younger age. In the Barberton area komatiitic basalts and peridotites account for over 90 per cent of the rocks in the lower division of the stratigraphic column but occur as limited flows within the upper, more mafic-to-felsic part of the succession (Viljoen and Viljoen, 1969a, b). In Canada numerous komatiitic volcanic rocks have also been reported, the best known examples being described from the Abitibi belt in the Munro Township area of Ontario (Arndt, 1976; Pyke et al., 1973). Rocks of similar composition, texture and age (i.e. $\sim$ 2 700 m.y.) are common in Western Australian and Indian greenstone belts (Naqvi, 1971; Nesbitt, 1971). Also in Zimbabwe, Bickle et al. (1975) have reported basaltic and peridotitic komatiites in the Belingwe upper greenstone sequence, the latter containing, in addition, a remarkably well-preserved stromatolitic unit.

The significance of komatiitic basalts and peridotites revolves around their almost total confinement to Archaean sequences. Peridotitic komatiites are at present unknown from modern environments and basaltic komatiites are extremely rare. In addition, petrogenetic aspects of komatiites require a unique mode of formation with experimental studies suggesting liquidus temperatures of such rocks approaching 1 650°C. This of 150-300 km were considered for greenstone evolution (Green, 1972). Commenting on the significance of komatiites Brooks and Hart (1974) maintained that neither the peridotitic nor the basaltic varieties are reliable tectonic province indicators due to the fact that they are generally accompanied by low-K tholeiites that are known to occur in almost every modern tectonic environment.

Despite objections, however, it would appear that support continues for equating the komatiite lavas with some form of oceanic crustal setting. This may not be like the modern oceanic ridge environment because felsic and intermediate volcanic rocks (although volumetrically subordinate) often accompany the mafic-ultramafic lavas and, as pointed out by Brooks and Hart (1974), rocks with these compositions do not appear to be forming in the modern oceanic ridge settings. An island-arc succession would seem to be another feasible modern analogue of an Archaean greenstone belt, particularly with respect to the uppermost calc-alkaline and tholeiitic basalt sequences (Engel, 1970). Basaltic rocks with compositions similar to abyssal tholeiites are known from the basal successions of island-arc sequences (Jakeš and Gill, 1970) but the absence of komatiitic rocks in these modern settings may signify sequential evolutionary development of magma types beyond those that formed during Archaean times when geothermal gradients were significantly greater than those at present (Green, 1975; Lambert, 1980).

In typical greenstone belts, rocks occurring stratigraphically higher than the mafic/ultramafic successions generally possess tholeiitic and calc-alkaline chemical affinities (Anhaeusser, 1971; Baragar and Goodwin, 1969; Glikson, 1976). Volcanic, pyroclastic and chemical sedimentary assemblages of diverse types are common and are frequently characterized by a cyclical mode of development (Anhaeusser, 1971; Goodwin, 1979; Viljoen and Viljoen, 1969b, 1970). The volcanic rocks may include tholeiitic basalts, basaltic-andesites, dacites, rhyodacites and rhyolites. Andesites are commonly encountered in Canadian greenstone sequences (Baragar and Goodwin, 1969) and in some of the greenstone occurrences of Western Australia (Giles, 1980) and Zimbabwe (Condie and Harrison, 1976). Although individual felsic units may persist over wide areas many are lenticular and display thickness variations and facies changes. The calc-alkaline volcanics in some regions show localization in discrete centres with intermediate and basic rocks appearing to have built large stratovolcanoes. Evidence for this is seen in Western Australia where Giles (1980) described the presence of abundant intercalated laharic or mud flow deposits, similar to those recorded from modern stratovolcanoes like Mt Rainier in Washington (Fiske et al., 1963), as well as marked lateral facies changes evident on the scale of several kilometres. The acid volcanics in this sequence are mostly of pyroclastic origin and include lithic-tuffs, crystal-tuffs, vitric-tuffs as well as mixtures of all three. In reviewing the characteristics of felsic volcanic sequences of greenstone belts Lowe (1980) indicated that the thickest part of felsic formations commonly reach several hundred to several thousand metres of coarse, poorly stratified, fragmental material and lava. The principal rock types include coarse breccia, tuff breccia, tuff, and coarse-grained volcaniclastic sedimentary units which collectively form cones of loose autoclastic, pyroclastic and epiclastic debris constructed around active vents.

Chemically, these volcanic assemblages are similar to the modern volcanic complexes of island-arcs, and views have been expressed that greenstone belts (particularly the upper successions) evolved partly as island-arc-like complexes in an oceanic-type geotectonic setting (Anhaeusser, 1973; Engel, 1970; Folinsbee et al., 1968; Goodwin and Ridler, 1970). Refined assessments of the volcano-sedimentary environments are continually being recorded as sedimentology and sedimentary petrography is attempted in the Archaean sequences. Lowe (1980) pointed out that documented environments of deposition now include deep-sea fan, shallow-shelf, deltaic, and alluvial and generally indicate a close association of topographically high source areas and adjacent deep basins of deposition. Erosion of volcanic complexes during waning stages of volcanism also provided broad, low relief platforms upon which were deposited a variety of shallow water sediments, including chert units that often demarcate an end to a particular volcanic cycle (Hickman, 1980; Viljoen and Viljoen, 1969b).

The lower, predominantly volcanic, assemblages of greenstone belts are frequently, but not always overlain by a wide variety of sediments (Anhaeusser et al., 1969; Lowe, 1980; Pettijohn, 1943), the latter sometimes associated with subordinate volcanism. The available chemistry of these lavas appears to reflect the changing conditions of the crust as the greenstone belts evolved (Anhaeusser, 1971). Flows of alkalic mafic trachytes and leucitic lavas and pyroclasts occur within the Timiskaming sediments near Kirkland Lake, Ontario (Cook and Moorhouse, 1969), and trachyandesites are associated with Fig Tree sediments in the Barberton area (Visser, compiler, 1956). Alkalic basalts of this type appear to be rare in the Archaean, and their position towards the top of greenstone belt piles suggests they may be the result of contamination of magma during its upward journey through a progressively thickening proto-continental crust.

The sedimentary rocks found in upper greenstone sequences generally consist of largely terrigenous detritus and include greywacke, shale, mudstone, siltstone, sandstone, and conglomerate. Other sediments include banded cherts, banded iron-formation, carbonaceous shales, carbonate layers (stromatolitic limestones, dolomite, impure calcareous muds), and evaporite sediments, as reported recently from the Pilbara Block in Western Australia and in the Barberton belt (Barley et al., 1979; Dunlop, 1978; Heinrichs and Reimer, 1977; Reimer, 1980).

Numerous investigators, listed by Lowe (1980), have found that the Archaean sedimentary environments represented (mainly defined from studies in Canada and southern Africa) are generally very like those in modern orogenic belts. Investigations demonstrate the existence of a deep-to-shallow-water clastic association dominated by extensive, thick turbiditic submarine fan or flysch-like sequences, the latter juxtaposed with subaerial alluvial-fan facies (Eriksson, 1980; Hyde and Walker, 1978).

The wide range of sediment types also reflects changing conditions in the evolutionary history of the greenstone belts. The sediments occurring as interflow units in lower portions of the volcano-sedimentary piles are mainly chemical or volcanogenic in origin with terrigenous clastic rocks entirely absent (e.g. Onverwacht Group, Barberton region, Anhaeusser, 1978) or only locally developed (e.g. Belingwe belt, Zimbabwe, Bickle et al., 1975). The chemical sediments generally include banded and ferruginous cherts, jaspilites, banded iron-formation, carbonaceous cherts and carbonate rocks. Most of the carbonate is calcite, dolomite, ferruginous dolomite, or ankerite and these units contain some of the oldest known stromatolites (those in the Belingwe belt, being about 2 800 m.y. old - Bickle et al., 1975). Even older stromatolites, approximately 3 400 - 3 500 m.y. in age, have been found in the Pilbara Block (Dunlop, 1978; Walter et al., 1980) as well as in the Fort Victoria greenstone belt in Zimbabwe (J.F. Wilson, pers. comm. 1980).

These predominantly volcanogenic and chemical sediments are often succeeded sequentially by clastic sediments (conglomerates, quartzites, greywackes, shales) derived from heterogeneous provenance areas, including granitic-metamorphic terranes. Petrologic and geochemical studies have also revealed secular increases of ensialic components with stratigraphic height, information used by Condie et al. (1970) to support arguments favouring the progressive unroofing of a prevolcanic, granite-migmatite basement. In this regard continuing investigations in the Barberton Mountain Land have yielded no unequivocal proof of any ensialic crustal material older than the earliest volcanic sequences (Anhaeusser, 1980, Anhaeusser and Robb, 1980a, b).

In summary, Lowe (1980), in his appraisal of Archaean sedimentation, concluded that sedimentary sequences deposited during the orogenic phase of greenstone belt development are grossly similar to those of many modern orogens, particularly those deposited adjacent to modern island-arcs. However, insufficient information is yet available to exclude the possibilities that greenstone belts evolved in environments similar to modern convergent plate junctions or intraplate areas sited above intracrustal fractures or mantle plumes. They may also have evolved at uniquely Archaean sites of volcanism and plutonism.

V. ARCHAEAN GRANITIC ROCKS

As a result of the controversy that still rages as to the original nature of the Archaean crust numerous studies of the granitic rocks surrounding greenstone belts have been embarked upon in recent years. A long list of contributions has emerged, the results of many of which have been reviewed by Condie (1980b) and Glikson (1979). An early account of the relationships of granitic rocks to greenstone sequences was attempted by Anhaeusser et al. (1969) who devised a broad sequential classification of granitic rocks based principally on field relations and limited geochemical characteristics. This classification still broadly applies; only vastly more information is currently available and numerous problems associated with geochronology, geochemistry, structural styles of emplacement, and genesis of the granitic rocks have been identified and are receiving attention world wide. Possibly one of the best exposed areas of Archaean granitic terrane occurs in the Barberton Mountain Land, including parts of Swaziland. A recent contribution from this region (Anhaeusser and Robb, 1980b) outlines a three-fold subdivision of numerous and diverse granite types in terms of three consecutive magmatic cycles. The three categories, it is maintained, also reflect stages in the formation and genetic evolution of the early sialic crust in this region. From personal observations in many of the shield areas of the world the writer is of the opinion that the distinctive physical, chemical and isotopic characteristics of the components of each cycle indicate that the subdivisions devised in the Barberton region provide a useful conceptual framework within which to view the evolution of Archaean granitic crust.

The earliest magmatic cycle commenced approximately 3 550 m.y. ago and involved the formation of Na-rich tonalities and trondhjemites and a complex series of bimodal gneisses and migmatites. Details of the characteristics of these rock types are given by Anhaeusser and Robb (1980a, b) and Glikson (1979), the latter writer reviewing, in depth, their various chemical and genetic aspects. In the view of these investigators the tonalite/trondhjemite events led to proto-cratonization on a far more extensive scale than might have occurred during the time span preceding $\sim$ 3 600 m.y. when the gneisses of the high-grade metamorphic regions were formed.

The tonalite/trondhjemite material is believed to have been derived by about 30-50 per cent melting of a mafic source not unlike the basal stratigraphic units encountered in the greenstone belts into which these plutonic rocks intrude. The emplacement of early sial was largely driven by gravitational overturning so that the primitive continental masses were tectonically unstable. As stated by Glikson (1979), the diachronous nucleation of tonalite/trondhjemite plutons during the Archaean is seen as the major process effecting a transformation of an early Archaean sima into sial. The intimate interaction between sial and sima was, furthermore, largely responsible for the formation of complex migmatites that are prevalent in the oldest granitic terranes.

The dominant processes of cratonization were progressively developed during the second magmatic cycle which involved the emplacement into the crust, of enormous volumes of K-rich magma such that by the end of the Archaean era the thickness of continental crust had probably reached 30-35 km. Most of these granites were emplaced relatively passively at higher crustal levels in the form of batholiths and many appear to have developed as extensive sheet-like masses over earlier-formed sialic crust (the granite-greenstone crust produced during the preceding magmatic cycle). The batholiths are multi-component bodies consisting usually of homogeneous, often medium-to-coarse-grained, in places porphyritic, granites, granodiorites or adamellites. Associated with these are pegmatitic and aplitic phases, and areas marginal to the batholiths are characterized by K-rich migmatites and gneisses representing zones of interaction between the granitic massifs and the crust into which the bodies intruded. The batholith margins seldom display sharp contacts and migmatites and nebulites give way progressively away from the edges to zones in which enclaves are increasingly abundant and where greenstone relics become clearly recognizable (Anhaeusser and Robb, 1980b).

The third event of significance was the emplacement of late, mainly K-rich granitic, adamellitic, granodioritic and syenitic plutons which did not contribute greatly either to the construction or stabilization of the early continental crust. These bodies are invariably small, discrete, post-tectonic plutons that were intruded into an already structurally cohesive cratonic environment. Their influence on their surroundings is generally minimal in terms of structural disturbance or metamorphic alteration.

The examples given from the Barberton area commenced $\sim$ 3 550 m.y. ago with the tonalite/trondhjemite development. This was followed approximately 3 200 m.y. ago by the commencement of the second magmatic cycle and, lastly, at about 2 900 m.y. the final events took place culminating in the youngest intrusions being emplaced approximately 2 600 m.y. ago. This chronological scheme may apply to other shield areas but is not a condition of the applicability of the magmatic cycle concept outlined.

As far as can be adjudged from descriptions of granitoid complexes in parts of the Superior Province of Canada (Schwerdtner et al., 1979) and Minnesota (Sims and Morey, eds., 1972) similar granitic varieties to those in the Barberton area are developed. Chronologically they may be younger than the example given above but they nevertheless retain the same physical and chemical relationship reflecting a younger stage of Archaean granite-greenstone development than in southern Africa. In some regions of the world the simplistic pattern of events may be masked by several superimposed granitic and tectonic events and the general pattern outlined here may not apply. This is possibly the case in the Pilbara Block in Western Australia (L.F. Bettenay, pers. comm. 1980) where preliminary investigations have shown that tonalite/trondhjemite rocks are not prominent in the ∿ 3 500 m.y. granite-greenstone terrane.

VI. ARCHAEAN CRUSTAL EVOLUTION

The foregoing sections have outlined the principal rock types that occur in the ancient granite-greenstone terranes of the shield areas. It was shown that the greenstone sequences appear to be sequentially-ordered volcano-sedimentary piles and that their component parts are a response to evolutionary changes in the physical state of the Earth. This may first have become significant during sustained bombardment of the surface of the planet by meteorites which could have triggered some of the earliest volcanism such as the komatiite peridotite/basalt assemblages. However, the unique nature of these early rocks as well as geochemical and radioactive decay data suggests Archaean heat flow was approximately twice that known today (Lambert, 1980). Under the conditions then prevailing it is envisaged that turbulent mantle processes were probably such that convective cells were smaller and far more abundant than in later times. In reviewing the ideas on geotectonic evolution of greenstone belts Anhaeusser (1980) noted that there were many proponents of the idea that mechanisms similar to those responsible for modern plate tectonics were operating in Archaean times. However, they generally agree that sufficient differences emerge to make direct comparisons untenable and that some form of modified Archaean plate tectonics would have to be sought to adequately explain all the points of dissension. No one has yet put a finger on a model solution to the problem so we are left to view the greenstone belt sequence in terms of (1) island-arc or trench-back arc-marginal basin analogues like those developed adjacent to convergent plate boundaries (Tarney et al., 1976; Windley, 1977), or to consider them (2) as having had unique conditions of formation that may have included isostatic mechanisms where the ancient crust evolved as a response to vertical tectonics involving the sinking of simatic lithospheric slabs accompanied by the diapiric upwelling of a succession of divergent magma types (Anhaeusser, 1980; Hargraves, 1976).

VII. THE DISTRIBUTION OF ELEMENTS IN ROCKS AND MINERALS

There is compelling geological evidence, including data of trace element distribution and isotopic ratios, that indicate the atmosphere, hydrosphere and solid Earth's crust have resulted from continued geological evolution. The behaviour and distribution of elements is thus of importance if we are to understand the mechanisms concentrating metals into economically exploitable ore deposit. An in depth account of how the elements are distributed in various environments is beyond the scope of this study and further details are provided by Krauskopf (1967), Levinson (1974) and Mason (1966), to name but a few.

Based on the chemical properties, including the intricate relationships existing in the structures of atoms, a most fundamental grouping of the elements is the periodic classification. Goldschmidt (1954) also devised a geochemical classification, coining the terms *siderophile, chalcophile, lithophile,* and, *atmophile* to describe elements with affinity for metallic iron, for sulphide, for silicate, and for the atmosphere, respectively. Some elements, however, show affinity for more than one of these groups because temperature, pressure and chemical environment dicate, to some extent, the behaviour and distribution of the elements.

Bowen's reaction series, involving differentiation, demonstrates progressive changes in composition and mineralogy (and hence element abundance variations) of magmas as they crystallize. These changes are usually gradual and result in the progressive decrease of such elements as iron, magnesium, calcium and titanium with a corresponding enrichment in silicon, aluminium, sodium and potassium in the residual liquid. With fractionation, certain major and minor or trace elements are continuously being withdrawn from the melt and partition with select, early-formed, mineral phases of high melting point, while conversely, others are able to reside in the residual liquids until they eventually get taken up in "late-formed" minerals of lower melting point. Some elements not adequately catered for in this scheme, or being originally somewhat oversaturated in the host environment, concentrate either as cumulate phases or as highly fractionated residues, like those found in pegmatites.

During the involved genesis of magmas there is therefore a tendency for certain elements to preferentially associate themselves with different minerals and, hence, different rock types. Element abundances in different rocks and minerals are available but the data is far from complete or adequate for any but the broadest of comparisons. From the viewpoint of base and precious metal distributions few details are available excepting for some of the commonest rock types (Beus and Grigorian, 1977; Krauskopf, 1976, Levinson, 1974; Mason, 1966; Taylor, 1964; Turekian and Wedepohl, 1961).

Mineral deposits are generally anomalous concentrations of elements or metals occurring either primarily, as syngenetic components of rock sequences or secondarily, as a result of superimposed influences such as may result from igneous intrusion, metamorphism, structural disturbance, or chemical and atmospheric weathering, erosion and redeposition. The secondary process, except in cases of magmatic differentiation, which would be an essentially primary concentrating process, is one of the most important mechanisms in producing ore deposits in Archaean granite-greenstone environments. In the sections that follow attempts will be made to develop the argument that the host rock composition determines to a large extent the nature of mineralization but that superimposed influences determine whether or not this mineralization will be concentrated sufficiently to constitute an ore deposit.

VIII. ARCHAEAN MINERALIZATION

In order to facilitate description, the threefold subdivision of the stratigraphy of greenstone belts, described earlier, will act as a basis for the classification of Archaean mineralization. In addition to the volcano-sedimentary sequences, Archaean granitic rocks are included as they also control the development of certain mineral deposits. The scheme outlined differs little from the metallogenic classification erected initially by Hutchinson et al. (1971) and subsequently modified by Anhaeusser (1976a) for southern African mineral occurrences. However, Hutchinson et al. (1971) defined what were termed *four families* of mineral deposits which were regarded as being of primary origin. In the first were included ores of Ni, Cu and associated Pt-group metals, asbestos deposits and deposits of chromite and magnetite, while into the second category were included the large pyritic, massive base metal sulphide deposits of Cu-Zn-Ag-Au. The third family grouped together the diverse species of iron-formation, particularly those they regarded as chemical sediments formed by a fumarolic-exhalative process and containing certain gold ores. The fourth family also included iron-formation, particularly the oxide and silicate facies, but excluded the gold associations of the exhalite variety. The various mineral deposits were placed in a tectonic-stratigraphic framework that showed the strong coincidence of metal types with host rocks and their depositional environments.

In terms of the approach adopted in this paper many of the above ore types would not be regarded as primary deposits *sensu stricto* but rather as secondary deposits formed as a result of superimposed processes acting upon the host rocks during or subsequent to their formation and deposition. Asbestos, using one example, was more than likely developed not when the host rock ultramafic complex was first crystallized but later, following (1) serpentinization of the dunites and (2) tectonic disturbance that is pre-requisite for fibre formation (Anhaeusser, 1976b).

A scheme of Archaean mineralization, initially devised to account for mineral occurrences in southern African granite-greenstone terranes, but which is believed to have universal applicability is shown in Figure 3.

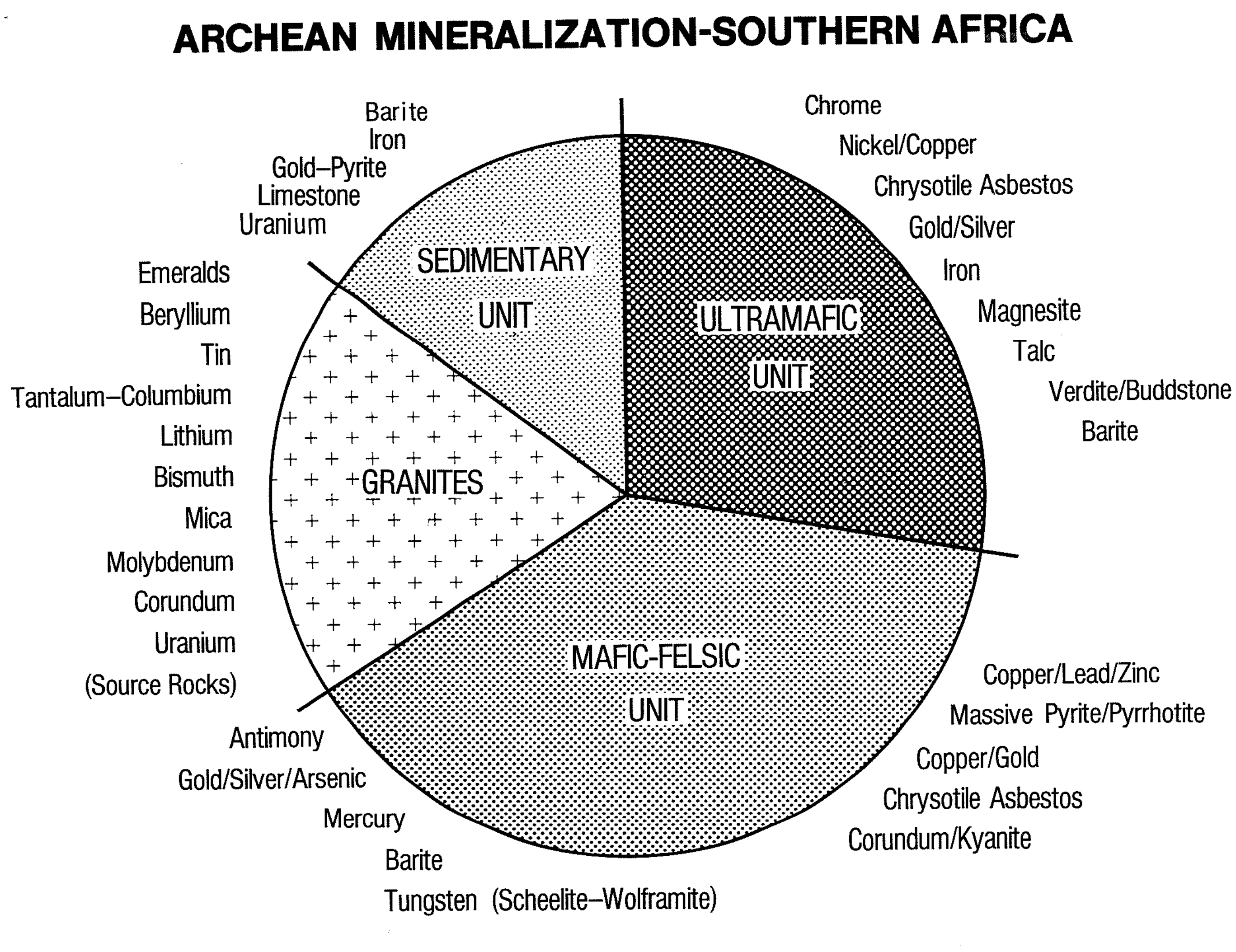


Figure 3 : *Pie-chart showing the relationship of Archaean mineralization to the four main lithologic components of ancient granite-greenstone terranes.*

Adjacent to the various Archaean lithologic units or subdivisions described earlier, are positioned the types of mineralization encountered or to be expected wherever these rocks may be developed. In some cases a particular metal is seen to occur in more than one position on the pie-chart. This applies, for example, to gold, silver, copper, uranium, corundum, barite and chrysotile asbestos. In general, this suggests that these commodities can form in more than a single rock type or in more than a single geologic setting. The diagram is incomplete in this regard because iron occurrences are found scattered throughout volcano-sedimentary sequences (Anhaeusser, 1976a; Beukes, 1973; Goodwin, 1973) and limestone is not restricted to the uppermost sedimentary unit alone; it being found in a variety of positions often associated with cherts or iron-formations in cyclical mafic-felsic volcanic sequences (Anhaeusser and Ryan, 1979). Not all iron or limestone occurrences are shown on the pie-chart because, in most cases, they do not form ore concentrations but occur as low-grade banded iron-formations or carbonate-rich stratigraphic layers.

Figure 3 in no way conveys the relative abundances of the mineral occurrences in the various segments illustrated. To demonstrate the difficulty in this regard we could single out nickel and point out that numerous ore bodies have been found in ultramafic rocks in Western Australian and Canadian greenstone belts but that in the Barberton greenstone belt, which has an anomalously high ultramafic component, no nickel ore bodies have yet been discovered. Chrome, likewise, is very prominent in the oldest ultramafic greenstone sequences of Zimbabwe (Selukwe area) but in rocks of comparable age in the Barberton belt no chrome has been located.

It must thus be borne in mind that many factors determine the nature and distribution of mineral deposits. Heterogeneities in mantle compositions appear to be one possibility we may have to contend with. This is shown by the anomalous development of chromite in southern Africa where the mineral occurs in sequences ranging from $\sim$ 3 800 m.y. to 2 000 m.y. (Sebakwian Group, Mashaba Igneous Complex, Great Dyke, Limpopo Belt, Bushveld Igneous Complex). In this region, which geographically is relatively small, successive geological complexes have, over a period of 1 800 m.y., tapped chromite from a mantle source, with the result that approximately two-thirds of the Earth's known chrome resources are concentrated in this area (Anhaeusser, 1976b).

Two other regional anomalies, not necessarily linked with mantle differences, relate to (1) the prevalence of Cu-Zn-Au-Ag volcanogenic massive sulphide deposits found throughout the Canadian Archaean (Boyle, 1976; Hutchinson, 1965, 1973, 1976; Sangster, 1972) and their paucity elsewhere, and (2) the greater abundance of Archaean gold in southern Africa relative to Canada and Western Australia (Anhaeusser, 1976c). Reasons for some of these anomalies are not easily forthcoming but may be linked to such factors as relative ages of the greenstone sequences, coupled with attendant evolutionary chemical differences both of magma-types and of the atmosphere and hydrosphere. Changing crustal conditions from early to late Archaean may have played a significant role. The remarkable similarity between Phanerozoic pyrite-sphalerite chalcopyrite deposits developed in subduction zones along continent margins and the Canadian Archaean base metal massive sulphides supports the interpretation, erected on other criteria, that these greenstone sequences may have had a type of plate tectonic history. The older greenstone sequences, like those in the Pilbara and Barberton regions, do not have significant massive sulphide ore deposits (Anhaeusser, 1976a; Reynolds et al., 1975) nor have the environmental reconstructions favoured analogies with plate tectonic models in these regions (Anhaeusser, 1980; Glikson, 1979).

In concluding this brief review on the nature of Archaean mineralization it might be worthwhile to give consideration to some of the mineral types *not* generally encountered in granite-greenstone terranes, or those only rarely developed. Those minerals linked elsewhere to ultramafic/mafic hosts that are absent or rare include : vanadium, manganese, titanium, cobalt, and the Pt-group metals. Roy (1966) reports some manganese in India but whether these deposits are Archaean or Proterozoic in age remains doubtful. In the mafic-to-felsic category lead, arsenic, antimony, mercury, and molybdenum deposits are rare, the most significant antimony-gold-mercury occurrence being found in the Murchison greenstone belt, South Africa (Viljoen et al., 1978). Mineral occurrences generally occurring in sedimentary sequences that are absent or rare in the Archaean include : uranium, placer gold, diamonds, phosphates, fluorspar, manganese and tin whereas in granitic rocks zironium, molybdenum, monazite, and cobalt are infrequently encountered. Emeralds appear to be restricted to southern African granite-greenstone terranes the mineral having been mined in Zimbabwe and in the Murchison Range area (Anhaeusser, 1976a; Robb and Robb, 1980).

Many of the mineral types listed above are prominent ore types in Proterozoic sequences suggesting they required further developments in crustal evolution that were not present in the Archaean. The early, thin, unstable proto-continental crust was, for example, unsuited to the generation of diamonds which generally form below thick, stable, continental regions.

IX. MINERALIZATION IN ARCHAEAN VOLCANO-SEDIMENTARY BELTS

In the previous section attention was focused on the wide range of mineral types characteristic of Archaean granite-greenstone terranes. Space does not permit an in depth assessment of all the varieties listed : rather it is the intention to examine some of the more important mineralization types and to reflect on their relation to early crustal evolution. In terms of value, gold, copper-nickel, and Cu-Zn-Ag-Au deposits are generally the most significant worldwide. This is followed by locally important occurrences of iron ore, chrome, chrysotile asbestos and antimony. Well down the list are the occurrences of tin, tungsten, mica, and limestone to name but a few. Minerals such as barite may not be economically prominent but the deposits tell us something of the geological environment in which they were formed. The examples discussed below will have this goal in mind.

A. Gold

In nature gold occurs in the native state as well as in a seemingly endless variety of alloys and compounds. The geochemistry, nature and distribution of the precious metal has received undivided attention for decades and a great deal is known about the substance. One of the most definitive studies was that undertaken by Boyle (1979) who reviewed its geochemistry and deposits. The metal, it was shown, occurs in virtually all rocks types, age notwithstanding, and is present in sea water and even plants and animals.

Confining our discussion to the Archaean it is evident that this period in Earth history was one of the most significant for the development of gold occurrences yet our understanding of the genesis of the many thousands of deposits worldwide remains a problem. To establish some coherence in the nature and distribution of gold numerous classification schemes have been attempted, some of which are reviewed by Anhaeusser (1976c) and Boyle (1979), and will not be persued here. The fundamental questions involve the origin of the gold and its subsequent concentration into viable ore deposits. Being associated with a large variety of rock types the ultimate source of the metal is problematical. One line of argument adopted by the writer (Anhaeusser, 1976a, c) involved the relative abundances of gold in different Archaean settings worldwide and the prevalence of particular rock types. Southern African greenstone belts, relative to their counterparts in Canada, for example, contain a greater proportion of ultramafic and mafic rocks, and are deficient in rocks of intermediate-to-felsic character. It was suggested that the prevalence of these assemblages probably represented a function of the greater age of the latter successions and attention was drawn to the development of greater abundances of the siderophile elements (e.g. Au, Ni, Fe), as well as chromium, in rocks of this character. Available statistics of gold production per unit area of Archaean terranes indicates that southern Africa occupies first place thereby suggesting a close genetic tie between gold mineralization and the ultramafic/mafic stratigraphy, particularly that possessing komatiitic affinities (Anhaeusser, 1976c; Pyke, 1975; Macgregor, 1951b; Viljoen et al., 1969).

Gold mineralization is also significant in the mafic-to-felsic stratigraphic sequences and in Canada and Zimbabwe tholeiitic basalts or basaltic andesites are prominent host rocks for gold deposits. In most cases the gold occurs in epigenetic veins, lodes, stockworks, and silicified faults, fractures, and shear zones and has thus been mobilized from a primary source to be concentrated in a secondary setting. Apart from the basic and ultrabasic rocks acting as a primary host to gold, evidence is available showing that gold ore bodies are frequently associated with beds of sulphide and mixed sulphide-carbonate facies banded iron-formation considered representative of submarine chemical precipitates deposited from solutions extruded mainly from subaqueous fumarolic centres (Boyle, 1979; Fripp, 1976; Hutchinson et al., 1971).

Quantitative data now available shows that mafic rocks tend to have more gold than felsic and intermediate rocks. Furthermore, gold also tends to be more abundant in the early crystallizing minerals such as the mafic silicates and Fe-Ti-oxides than in later crystallizing quartz and feldspar (Tilling et al., 1973). Boyle (1979) reported, however, that there was *no* strikingly apparent relationship in the gold content of silicates in the series quartz-feldspar-mica-amphibole-pyroxene-olivine although there is a positive indication that minerals like biotite and amphibole contain a little more gold than others. In the dark silicate minerals gold may substitute in the iron sites but Boyle (1979) considered that much if not all the gold may be present in microscopic inclusions of pyrite and/or magnetite which these minerals often contain.

In the end, however, and stated succinctly by Tilling et al. (1973), a gold deposit is largely determined by geologic, geochemical and geophysical factors other than the concentration of gold available at various places in the mineralizing system. In greenstone belts this maxim applies as it is generally only after granite intrusion, structural deformation, and metamorphism has taken place that gold ore deposits are produced. Apart from the syngenetic, strata-bound occurrences in banded iron-formations most of the gold is epigenetic and may be relocated in any favourable lithological or structural setting anywhere in the greenstone pile or even in neighbouring granitoid rocks.

An exception to this is Archaean placer gold. These deposits are, however, not common in greenstone terranes, suggesting that at the time sedimentation took place there was little concentrated gold available for redistribution from sediment source regions. The oldest sedimentary sequences, like those in the Barberton and Pilbara areas, are probably not likely to be favourable placer gold repositories unless it can be demonstrated that the sediments found in these piles are derived from some pre-3 500 m.y. old source terrane in which an earlier cycle of gold concentration may have occurred. Greenstone belt sedimentary sequences of younger age may have proportionately greater chances of developing placer deposits (not only of gold but also tin-tantalum-columbium) provided they receive their sedimentary bed-load from mineral-enriched source regions.

B. Nickel (Copper)

The major nickel-sulphide deposits of the world are associated with either tholeiitic or komatiitic rock sequences. The first mentioned occur mainly in the large stratiform complexes of Bushveld type, and will not concern us further. The second variety, associated with komatiites are important high grade ores but deposits are small. Detailed accounts of the characteristics of Archaean nickel-sulphide occurrences have been provided by Naldrett (1973) and Naldrett and Cabri (1976), who classified the deposits and employed their findings to suggest genetical models for ore deposition. The majority of Archaean ultramafic bodies, important as nickel-sulphide host rocks, fall into two groups, namely, gravity-differentiated sills, and lenses showing little or no differentiation. As outlined by Naldrett (1973) the majority of nickel sulphide deposits are regarded as being the result of the emplacement of a sulphide magma, generally in association with a host silicate magma. This two-fold association is considered to be a consequence of the unusual tectonic conditions required to achieve the high degrees of partial melting necessary for peridotite melts to form and at the same time tap parts of the mantle containing sulphide concentrations. Furthermore, these conditions would have to sustain rapid and lengthy ascent of mantle derived magmas (Arndt, 1976).

The unique conditions alluded to in earlier sections dealing with the lower greenstone mafic/ultramafic sequences have significance in regard to early crustal evolution. Even island-arcs, which remain one of the closest modern analogues to Archaean greenstone belts, have little noteworthy nickel-sulphide mineralization (Mitchell and Bell, 1973) and hence it appears that Earth evolution has once again influenced the environment of formation of this metal.

Naldrett (1973) indicated that, in order for a nickel-rich sulphide magma to develop, it is necessary for the sulphide phase to form at an early stage, and equilibrate with the silicate magma before this has been severely depleted in nickel by the crystallization and removal of olivine. It was further suggested that the sulphide-rich nature of many komatiitic magmas is related to their derivation from deep, sulphide-rich zones within the mantle. The absence or rarity of nickel-sulphide in younger environs was explained by supposing that later partial melts of a mantle, previously depleted in sulphur during Archaean or early Proterozoic times, will have much lower sulphur contents unless an external source of sulphur was made available to be assimilated by the younger magmas.

The most important nickel (usually with some copper) deposits occur in Western Australia (Knight, editor, 1975), Zimbabwe (Viljoen and Bernasconi, 1979; Williams, 1979), and Canada (Naldrett and Gasparrini, 1971), where they are associated with peridotitic komatiite lava flows or penecontemporaneous hypabyssal sills. Anomalous with regard to this distribution is the fact that in the Barberton region, where ultramafic komatiites are themselves anomalously prevalent, there are no known nickel-sulphide ore deposits. The lack of sulphur has been offered as a reason for this discrepancy; also the age of the rocks. A further consideration might be the point raised earlier concerning a heterogeneous mantle. Just as with the distribution of chrome, so too might the nickel-sulphide association be affected by a mantle depleted in these components beneath the Barberton greenstone belt.

C. Volcanogenic Massive Sulphide Deposits (Cu-Zn-Ag-Au)

Much has been written on the subject of massive sulphide deposits in the Archaean — their characteristics, the host rock environment of the deposits, their geotectonic setting, and the similarities and differences that exist between them and massive sulphide mineralization in Proterozoic and Phanerozoic orogens (Hutchinson, 1965, 1973, 1976, 1978a, b; Hutchinson and Hodder, 1972; Mitchell and Bell, 1973; Sangster, 1972). Little can be added at this stage to what has already been said about these deposits. Almost all the mineral occurrences of this type have been found in Canadian greenstone belts with only minor ore deposits being reported from Western Australia (Reynolds et al., 1975) and none but the smallest showings being recorded in southern Africa (Anhaeusser, 1976a). Again comparisons of lithic proportions of these rocks in southern Africa and Canada prove instructive. Data from Canada (Goodwin et al., 1972) was contrasted with that obtained from Zimbabwe and the Barberton region. The ratios of basalts to andesite to felsic volcanics in the Superior Province was found to be 6:3:1 whereas in the Barberton greenstone belt the comparison is between ultramafic/mafic rocks, basalts, and felsic horizons — there being no andesites developed. The ratios were found to be approximately 7:20:1 (Anhaeusser, 1976a). From this, and similar data from Zimbabwe, it was concluded that the metallogenic potential for massive sulphide occurrences in southern Africa was poor.

Hutchinson (1973) defined volcanogenic sulphide deposits as stratabound, lenticular bodies of massive pyritic mineralization, containing variable amounts of chalcopyrite, sphalerite and galena in layered volcanic rocks generally formed subaqueously by volcanic-fumarolic activity. Comparisons made between the Archaean and younger sulphide deposits led Hutchinson (1965, 1973) to conclude that the time-tectonic-stratigraphic inter-relationships existing between three classes of deposits he was able to recognize, could be explained by evolutionary changes in volcanism, its style, and its products. The Cu-Zn ore type (also containing both Ag and Au) is most common in the Canadian Archaean but reappears in earliest Palaeozoic stages of young orogenic belt evolution (Hutchinson, 1973) where the precious metal association is mainly Au. These deposits, which are characterized by an intimate relationship to accumulations of calc-alkaline, felsic pyroclastic volcanic rocks erupted in submarine environments, have been equated by Sawkins (1976) with the Kuroko-type massive sulphide accumulations found in modern island-arc systems, the latter considered to be products of plate convergence. The fact that Pb is a notable absentee in Archaean-aged Kuroko-type sulphide deposits was explained by Sawkins (1976) as possibly reflecting a general paucity of Pb during these times due to insufficient time having been available for this element to have formed from the decay of U and Th parents.

If modern geologic settings can be used as a key to the past, consideration could be given to ophiolite terranes whose metallogeny is in some respects similar to that of some Archaean greenstone belts. Cu- and Zn-bearing massive sulphides are prominent in Cyprus-type deposits (Hutchinson, 1965) which were probably formed at divergent plate boundaries (Sillitoe, 1972). However, the occurrence of calc-alkaline andesitic and rhyolitic volcanic rocks as an integral part of most greenstone belts (in addition to other characteristics including metallogenic differences, Thayer, 1976) serves to distinguish them from ophiolite terranes. The modern analogue of converging plate boundaries, and all this implies with respect to magma-type, metallogeny, development of island-arcs, or trench-back arc-marginal basin systems, remains the strongest contender for defining conditions applicable to many Archaean greenstone environments.

D. Iron-formations

From numerous accounts of iron-formations found in ancient settings around the world the environments of development of these essentially chemical sediments appears to coincide broadly with those already discussed for the volcanogenic massive sulphide deposits. The main difference lies in the fact that the exhalative sedimentary environment (of which there is almost total acceptance), with its various facies and subfacies of iron-formation, is extremely widespread, and extends from the volcanic centres through adjacent troughs and on to ancient shelf areas in some cases (Beukes, 1973; Goodwin, 1962, 1973; Hutchinson et al., 1971). Iron-formations in general were subdivided by James (1954) into four facies - sulphide, oxide, carbonate and silicate - according to their anion content. The facies variants are gradational into one another and offer useful indicators for basin analysis studies, the shallow-to-deep order of facies development coinciding with oxide, carbonate and sulphide types of iron-formation respectively (Goodwin, 1973).

As mentioned previously, iron-formations occur throughout the greenstone piles and, in the volcanogenic setting, are commonly associated with mafic lavas which appear to have provided the main source of the iron. This was either leached from the volcanic sequences by halmyrolitic processes or was derived from volcanic exhalations. The formation of sulphide-rich facies was dependent on a supply of sulphur and a strongly reducing environment as evidenced by the frequent association of carbon or carbonate with sulphide enriched iron-formations. In many cases the iron-formations are banded, being composed of alternating silica (chert) and various iron-rich phases. This layering reflects changing conditions of Eh or pH in the depositional environment of these chemical sediments. High Eh favoured oxide facies development whereas a strongly negative Eh enabled sulphide facies iron-formation to form. The silicate and carbonate facies required intermediate Eh values. Fluctuations in the Eh or pH and the partial pressure of CO_2, coupled with variations in the amount of reduced sulphur available, determined whether hematite, magnetite, siderite, or pyrite/pyrrhotite would form (Goodwin, 1973).

Iron ore deposits occur in all facies types except the silicate facies. Most of the ore bodies mined around the world have occurred in the oxide facies. Usually the deposits mined have been enriched or upgraded by secondary processes of supergene enrichment or metamorphism. The ore bodies are generally small relative to their counterparts in the Proterozoic, again reflecting evolutionary changes with time in the availability of Fe, coupled with an increased oxygen build up in the Earth's atmosphere as well as a more stable crustal environment during deposition.

E. Chrysotile Asbestos and Chrome

Both these mineral types are developed in Archaean ultramafic sequences, and more specifically in layered ultramafic complexes having intruded penecontemporaneously as sills within the volcanic sequences. Both commodities, require for their formation, the differentiation of peridotitic magma into mineral phases resulting in the development of dunites, harzburgites and pyroxenites as well as chromitite cumulate layers in some instances. The development of chromitite deposits has been referred to earlier as a primary mineral occurrence, formed at the time the host rock cumulate assemblage crystallized. However, these deposits might equally be regarded as secondary in terms of a magma containing Cr undergoing crystallization in such a way as to allow the mineral phases to separate out leaving a residual concentration of chromite - rather than allowing the Cr to be taken up in the crystal lattices of olivines and pyroxenes. This specific ore-forming process selectively concentrates chromium from a dispersed source in a cooling magma to form chromitite ores.

Chrysotile asbestos requires the development of a high-Mg host rock, in the first instance. In the Archaean greenstone belts of southern Africa, where chrysotile deposits are of considerable importance, these take the form of layered complexes in which dunites are prominent components, together with ortho- and clino-pyroxenites, and subordinate gabbros or gabbroic-anorthosites (Anhaeusser, 1976b). Economic fibre development in these host rocks required that they have been serpentinized (probably accomplished during the emplacement of granites) and deformed in a manner conducive to the generation of a tensional environment in which optimum fibre growth could be achieved. All these primary and superimposed requirements are dependent upon the geotectonic setting of the host rocks and the subsequent evolutionary history of the environment, the latter generally involving tectonism and the diapiric emplacement of granitoid complexes. They are also conditional (in the case of southern African chrysotile asbestos deposits) on the unique geochemical characteristics of the parent magmas giving rise to the layered complexes. Bulk chemistry calculations undertaken for many of the layered complexes in the Barberton region, for example, have shown compositional characteristics identical to those of the peridotitic komatiite lava sequences developed in the surrounding areas (Anhaeusser, 1976b).

F. Barite

Archaean barite deposits, although of minor significance economically, do nevertheless provide clues relating to the environment in which greenstone sequences were developed. The occurrences may be subdivided into those interlayered with volcanic sequences, and for which a volcanogenic origin appears to be highly probable, and those that have affinities with sedimentary sequences, where the role of volcanism is subordinate. These categories are interrelated, as deposits associated with volcanic rocks can still largely be deposited as sediments whereas those in sedimentary sequences might originate from distal volcanic sources. Of significance have been the findings, recently, of stratiform barite occurrences associated with cherts and carbonate units that together suggest an origin linking them with evaporite sequences. Both in the Pilbara region and in the Barberton greenstone belt reports of barite pseudomorphically replacing gypsum have been made (Dunlop, 1978; Heinrichs and Reimer, 1977; Reimer, 1980). These findings, if correctly interpreted, together with desiccation features and stromatolites, suggest that shallow water and/or subaerial conditions appear to have occurred in juxtaposition with turbidite submarine fan or flysch sequences involving deep water sedimentation.

G. Tin (Tantalum-Columbium)

Tin mineralization, together at times with tantalum-columbium, is an example of a mineral type associated mainly with granitic rocks or the alluvial and eluvial products of their erosion or physico-chemical breakdown. Archæan tin occurrences are generally small by world standards and are mainly found in the Pilbara and south-western Yilgarn regions of Western Australia as well as in Zimbabwe and Swaziland in southern Africa. Many of the deposits mined have been alluvial or eluvial concentrations largely derived from pegmatite dykes and veins in granitic rocks of potassic composition. This suggests the tin-bearing granites are generally late in the evolutionary scheme of granite development as outlined by Anhaeusser and Robb (1980b) and discussed earlier.

Tin, together with Ta, Nb, Li, Bi, and Be together form a group of relatively incompatible elements that commonly occur together or separately as the late fraction (residual liquids) of a cooling granitic intrusive body. These residual phases generally occur as pegmatites or aplitic dykelets and may themselves constitute ore bodies or, as is the case with much of the Archaean tin, give rise to alluvial or eluvial concentrations from otherwise uneconomic or subeconomic sources. Tin, therefore, provides a further example of a mineral that owes its origin to an evolutionary sequence of events in Archaean terranes, being capable of appearing at any stage, timewise, in the development of granitic rocks but being largely associated with the end phases of crystallization of granodioritic, adamellitic or granitic (*sensu stricto*) intrusive bodies.

X. SUMMARY AND CONCLUSIONS

In tracing the relation of mineral deposits to early crustal evolution it has been necessary to examine briefly the geological environments that existed during early Earth history. It was shown that little evidence exists on today's continents of the geologic history of the planet prior to approximately 3 800 m.y. ago. Information concerning this formative, turbulent, episode will probably have to await clues from space and planetary sciences.

The oldest rocks so far recorded are all in high-grade metamorphic terranes and range in age from approximately 3 500 - 3 800 m.y. Geologically, these terranes display many similarities suggesting a common heritage linking them to events which may have followed the final stages of major meteorite bombardment of the

Earth's surface approximately 3 900 - 4 000 m.y. ago (Grieve, 1980). These terranes, it has also been suggested, may represent the structurally and metamorphically reworked equivalents of early proto-continental material like that found in the oldest granite-greenstone areas of the shields. Mineralization in these high-grade regions is minimal, reflecting either non-development of mineral species, early recycling and destruction of early-formed sequences and their contained mineralization (Veizer and Jansen, 1979), or later recycling or redistribution, brought about by geotectonic and thermal influences in the high-grade mobile belt environments.

The Archaean granite-greenstones developed between approximately 3 500 - 2 500 m.y. ago provide most of the information available on early Earth history. The characteristics of these volcano-sedimentary sequences and their enveloping, intrusive, granitic surrounds is discussed in terms of a generalized model of greenstone stratigraphic evolution. This involves a subdivision of lithologic units into a basal assemblage of primarily ultramafic/mafic rocks overlain by an upper sequence of volcanogenic rocks of mafic-to-felsic affinity. The model greenstone belt sequence terminates with sedimentary rocks derived from the evolutionary progression of volcanism, granite intrusion and erosion in an environment of early proto-continental nucleation and consolidation.

A wide spectrum of data, including geochemical, isotopic, and sedimentological findings, suggests that the greenstone belts evolved progressively over the 1 000 m.y. of the Archaean era for which there is geological information available. Early Archaean greenstone belts have characteristics sufficiently different from those in younger Archaean areas to support a concept of Archaean geotectonic evolution that may have included isostatic mechanisms whereby ancient crust evolved as a response to vertical tectonic behaviour of rocks of different densities in a thermal regime where heat flow properties were probably twice those of the present. These conditions were unique and led to the eruption and emplacement of komatiitic basalts and peridotites and granitic diapirism in a manner only rarely found developed in some younger orogenic environments. These younger equivalents of Phanerozoic age have led to the maxim "the present is the key to the past" and the tendency has been to regard the younger Archaean greenstone sequences (particularly those similar to the Canadian examples) in the same light as orogenic areas produced as a result of modern plate tectonic mechanisms. Sufficient differences between the Archaean and modern environments occur to caution direct comparisons between the two but there is consensus that the island-arc system provides the closest modern analogue, especially to upper greenstone sequences containing calc-alkaline volcanism. Trench-back arc-marginal basin analogues are also favoured alternative geotectonic settings.

Mineralization in the Archaean is extremely varied and there is generally a direct relationship between metal type and host rock composition or environment of deposition. In terms of the simplistic stratigraphic breakdown outlined in the paper the mineral types can be subdivided into those that favour development or association with ultramafic/mafic rocks (mainly gold, nickel, chrome, asbestos), those that occur predominantly in mafic-to-felsic successions (mainly massive sulphide deposits containing copper, zinc, silver and gold as well as iron-formations) and those that favour development in sedimentary sequences (mainly iron-formations, limestone, barite and placer deposits of gold and tin). Lastly, there is mineralization that is virtually restricted to the granitic rocks, having generally been concentrated in residual liquids that developed as pegmatites and other late granitic veins and apophyses.

Finally, it is concluded that mineral deposits in the Archaean are related intimately to their host rocks, and to the geotectonic environment in which these rocks were developed and deposited. In some cases mineral concentrations are due to primary factors such as magma differentiation, or sulphide-silicate immiscibility. However, many if not all ore concentrations are due to secondary influences superimposed upon the volcanogenic greenstone belt environment, thereby resulting in the release of elements or metals often entrapped in crystal lattices of minerals developed in the lava piles. Subsequent mobilization, brought about by granite intrusion, deformation, metamorphism and a range of chemical processes, are largely the cause of the solution and reprecipitation of metals into sites that may be exploited ultimately as ore deposits.

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REFERENCES

Anhaeusser, C.R., 1971, Cyclic volcanicity and sedimentation in the evolutionary development of Archaean greenstone belts of shield areas: Geol. Soc. Australia Spec. Pub. 3, p. 57-70.

Anhaeusser, C.R., 1973, The evolution of the early Precambrian crust of southern Africa: Royal Soc. London Philos. Trans., ser. A., v. 273, p. 359-388.

Anhaeusser, C.R., 1976a, Archaean metallogeny in southern Africa: Econ. Geol., v. 71, p. 16-43.

Anhaeusser, C.R., 1976b, The nature of chrysotile asbestos occurrences in southern Africa: a review: Econ. Geol., v. 71, p. 96-116.

Anhaeusser, C.R., 1976c, The nature and distribution of Archaean gold mineralization in southern Africa: Minerals Sci. Engng., v. 8, no. 1, p. 46-84.

Anhaeusser, C.R., 1978, The geological evolution of the primitive earth - evidence from the Barberton Mountain Land, *in* Tarling, D.H., ed., Evolution of the earth's crust: Academic Press, London, p. 71-106.

Anhaeusser, C.R., 1980, Geotectonic evolution of the Archaean successions in the Barberton Mountain Land, South Africa, in Kröner, A., ed., Precambrian plate tectonics: Elsevier, Amsterdam (in press).

Anhaeusser, C.R., and Button, A., 1976, A review of southern African stratiform ore deposits - their position in time and space, in Wolf, K.H., ed., Handbook of strata-bound and stratiform ore deposits, v. 5 Regional Studies: Elsevier, Amsterdam, p. 257-319.

Anhaeusser, C.R., Mason, R., Viljoen, M.J., and Viljoen, R.P., 1969, A reappraisal of some aspects of Precambrian shield geology: Geol. Soc. America Bull., v. 80, no. 11, p. 2175-2200.

Anhaeusser, C.R., and Robb, L.J., 1980a, Regional and detailed field and geochemical studies of Archaean trondhjemitic gneisses, migmatites and greenstone xenoliths in the southern part of the Barberton Mountain Land, South Africa: Precambrian Res., v. 11, p. 373-397.

Anhaeusser, C.R., and Robb, L.J., 1980b, Magmatic cycles and the evolution of the Archaean granitic crust in the eastern Transvaal and Swaziland: Geol. Soc. Australia Spec. Pub. (in press).

Anhaeusser, C.R., Roering, C., Viljoen, M.J., and Viljoen, R.P., 1968, The Barberton Mountain Land: a model of the elements and evolution of an Archaean fold belt: Geol. Soc. South Africa Trans., v. 71, Annex., p. 225-254.

Anhaeusser, C.R., and Ryan, P.J., 1979, "Barren" massive sulphide deposits in the Mphoengs schist belt, Rhodesia : a case history: Geol. Soc. South Africa Spec. Pub. 5, p. 181-203.

Appel, P.W.U., 1977, Aeolian differentiation of basaltic tuffs in the Early Precambrian Isua supracrustal belt, West Greenland: N. Jahrb. Miner. Mh., 1977, p. 521-528.

Appel, P.W.U., 1979a, Stratabound copper sulfides in a banded iron-formation and in basaltic tuffs in the Early Precambrian Isua supracrustal belt, West Greenland: Econ. Geol., v. 74, p. 45-52.

Appel, P.W.U., 1979b, Cosmic grains in an iron-formation from the Early Precambrian Isua supracrustal belt, West Greenland: J. Geol., v. 87, p. 573-578.

Appel, P.W.U., 1980, On the early Archaean Isua iron-formation, West Greenland: Precambrian Res., v. 11, p. 73-87.

Arndt, N.T., 1976, Ultramafic rocks of Munro Township: economic and tectonic implications, in Strong, D.F., ed., Metallogeny and plate tectonics: Geol. Assoc. Canada Spec. Paper 14, p. 617-657.

Arth, J.G., and Hanson, G.N., 1975, Geochemistry and origin of the early Precambrian crust of northeastern Minnesota: Geochim. Cosmochim. Acta, v. 39, p. 325-362.

Baragar, W.R.A., 1968, Major-element geochemistry of the Noranda volcanic belt, Quebec-Ontario: Canadian J. Earth Sci., v. 5, p. 773-790.

Baragar, W.R.A., and Goodwin, A.M., 1969, Andesites and Archean volcanism of the Canadian shield: Oregon Dep. Geol. Miner. Ind. Bull. 65, p. 121-142.

Barley, M.E., Dunlop, J.S.R., Glover, J.E., Groves, D.I., 1979, Sedimentary evidence for an Archaean shallow-water volcanic-sedimentary facies, eastern Pilbara Block, Western Australia: Earth Planet. Sci. Lett., v. 43, p. 74-84.

Beukes, N.J., 1973, Precambrian iron-formations of South Africa: Econ. Geol., v. 68, p. 960-1004.

Beus, A.A., and Grigorian, S.V., 1977, Geochemical exploration methods for mineral deposits: Wilmette, Illinois, Allied Publishing Ltd., 287 p.

Bickle, M.J., Martin, A., and Nisbet, E.G., 1975, Basaltic and peridotitic komatiites and stromatolites above a basal unconformity in the Belingwe greenstone belt, Rhodesia: Earth Planet. Sci. Lett., v. 27, p. 155-162.

Boyle, R.W., 1976, Mineralization processes in Archean greenstone and sedimentary belts: Geol. Surv. Canada Paper 75-15, 45 p.

Boyle, R.W., 1979, The geochemistry of gold and its deposits (together with a chapter on geochemical prospecting for the element): Geol. Surv. Canada Bull. 280, 584 p.

Bridgwater, D., McGregor, V.R., and Myers, J.S., 1974, A horizontal tectonic regime in the Archaean of Greenland and its implications for early crustal thickening: Precambrian Res., v. 1, p. 179-197.

Brooks, C., and Hart, S.R., 1974, On the significance of komatiite: Geology, v. 2, p. 107-110.

Casella, C.J., 1969, A review of the Precambrian geology of the eastern Beartooth Mountains, Montana and Wyoming, in Larsen, L.H., ed., Igneous and metamorphic geology: Geol. Soc. America Mem. 115, p. 53-72.

Cloud, P., 1968, Atmospheric and hydrospheric evolution on the primitive earth: Science, v. 160, p. 729-736.

Condie, K.C., 1976, Plate tectonics and crustal evolution: Pergamon Press, Inc., New York, 288 p.

Condie, K.C., 1980a, Archean greenstone belts: Elsevier, Amsterdam (in press).

Condie, K.C., 1980b, Origin and source of Archaean granites: Geol. Soc. Australia Spec. Pub., (in press).

Condie, K.C., and Harrison, N.M., 1976, Geochemistry of the Archean Bulawayan Group, Midlands greenstone belt, Rhodesia: Precambrian Res., v. 3, p. 253-271.

Condie, K.C., Macke, J.E., and Reimer, T.O., 1970, Petrology and geochemistry of early Precambrian greywackes from the Fig Tree Group, South Africa: Geol. Soc. America Bull., v. 81, p. 2759-2776.

Cooke, D.L., and Moorhouse, W.W., 1969, Timiskaming volcanism in the Kirkland Lake area, Ontario, Canada: Canadian J. Earth Sci., v. 6, p. 117-132.

Dunlop, J.S.R., 1978, Shallow-water sedimentation at North Pole, Pilbara, Western Australia: Publ. Geol. Dept., and Extension Serv. Univ. West Australia 2, p. 30-38.

Engel, A.E.J., 1970, The Barberton Mountain Land: clues to the differentiation of the earth, in Cloud, P.E. ed., Adventures in earth history: Freeman, San Francisco, p. 431-445.

Eriksson, K.A., 1979, Marginal marine depositional processes from the Archaean Moodies Group, Barberton Mountain Land, South Africa: evidence and significance: Precambrian Res., v. 8, p. 153-182.

Eriksson, K.A., 1980, Hydrodynamic and paleogeographic interpretation of turbidite deposits from the Archean Fig Tree Group of the Barberton Mountain Land, South Africa: Geol. Soc. America Bull., v. 91, p. 21-26.

Fiske, R.S., Hopson, C.A., and Waters, A.C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geol. Surv. Prof. Paper 444, 93 p.

Folinsbee, R.E., Baadsgaard, H., Cumming, G.L., and Green, D.C., 1968, A very ancient island arc, in Knopoff, L., Drake, C.L., and Hart, P.J., eds., The crust and upper mantle of the Pacific area: Geophys. Monogr., no. 12, p. 441-448, Washington, D.C.: American Geophys. Union.

Frey, H., 1980, Crustal evolution of the early earth: the role of major impacts: Precambrian Res., v. 10, p. 195-216.

Fripp, R.E.P., 1976, Stratabound gold deposits in Archean banded iron-formation, Rhodesia: Econ. Geol., v. 71, p. 58-75.

Ghisler, M., and Windley, B.F., 1967, The chromite deposits of the Fiskenaesset region, West Greenland: Rapp, Grønlands Geol. Unders., v. 12, p. 1-39.

Giles, C., 1980, Archaean calc-alkaline volcanism in the Eastern Goldfields Province of Western Australia: Extended Abst., 2nd Int. Archaean Symp., Perth, Geol. Soc. Australia, p. 54-55.

Glikson, A.Y., 1976, Stratigraphy and evolution of primary and secondary greenstones: significance of data from shields of the southern hemisphere, in Windley, B.F., ed., The early history of the earth: John Wiley and Sons, New York, p. 257-277.

Glikson, A.Y., 1979, Early Precambrian tonalite-trondhjemite sialic nuclei: Earth-Sci. Rev., v. 15, p. 1-73.

Glikson, A.Y., and Lambert, I.B., 1976, Vertical zonation and petrogenesis of the early Precambrian crust in Western Australia: Tectonophysics, v. 30, p. 55-89.

Glover, J.E., and Groves, D.I., editors, 1978, Archaean cherty metasediments: their sedimentology, micropalaeontology, biogeochemistry, and significance to mineralization: Publ. Geol. Dept., Extension Serv. Univ. Western Australia 2, 88 p.

Goldschmidt, V.M., 1954, Geochemistry: Fair Lawn, N.J., Oxford University Press.

Goodwin, A.M., 1962, Structure, stratigraphy, and origin of iron-formation, Michipicoten area, Algoma district, Ontario, Canada: Geol. Soc. America Bull., v. 73, p. 561-586.

Goodwin, A.M., 1968, Evolution of the Canadian shield: Proc. Geol. Assoc. Canada, v. 19, p. 1-14.

Goodwin, A.M., 1971, Metallogenic patterns and evolution of the Canadian Shield: Geol. Soc. Australia Spec. Pub. 3, p. 157-174.

Goodwin, A.M., 1973, Archean iron-formations and tectonic basins of the Canadian shield: Econ. Geol., v. 68, p. 915-933.

Goodwin, A.M., 1977, Archean volcanism in Superior Province, Canadian shield, in Baragar, W.R.A., Coleman, L.C., and Hall, J.M., eds., Volcanic regimes in Canada: Geol. Assoc. Canada Spec. Paper 16, p. 205-241.

Goodwin, A.M., 1979, Archean volcanic studies in the Timmins-Kirkland Lake-Noranda region of Ontario and Quebec: Geol. Surv. Canada Bull., v. 278, 51 p.

Goodwin, A.M., and Ridler, R.H., 1970, The Abitibi orogenic belt, in Baer, A.J., ed., Symposium on basins and geosynclines of the Canadian shield: Geol. Surv. Canada Paper 70-40, p. 1 - 24.

Goodwin, A.M., Ambrose, J.W., Ayers, L.D., Clifford, P.M., Currie, K.L., and others, 1972, The Superior Province, in Price, R.A., and Douglas, R.J.W., eds., Variations in tectonic styles in Canada: Geol. Assoc. Canada Spec. Paper 11, p. 527-623.

Gordon, P.S.L., 1973, The Selebi-Pikwe nickel-copper deposits, Botswana: Geol. Soc. South Africa. Spec. Pub. 3, p. 167-187.

Green, D.H., 1972, Archaean greenstone belts may include terrestrial equivalents of lunar maria? Earth Planet. Sci. Lett., v. 15, p. 263-270.

Green, D.H., 1975, Genesis of Archean peridotitic magmas and constraints of Archean geothermal gradients and tectonics: Geology, v. 3, p. 15-18.

Green, D.H., Nicholls, I.A., Viljoen, M.J., and Viljoen, R.P., 1975, Experimental demonstration of the existence of peridotitic liquids in earliest Archaean magmatism: Geology, v. 3, p. 11-14.

Grieve, R.A.F., 1980, Impact bombardment and its role in proto-continental growth on the early earth: Precambrian Res., v. 10, p. 217-247.

Hallberg, J.A., 1972, Geochemistry of Archaean volcanic belts in the Eastern Goldfields region of Western Australia: J. Petrol., v. 13, p. 45-56.

Hamilton, P.J., Evensen, N.M., O'Nions, R.K., Smith, H.S., and Erlank, A.J., 1979, Sm-Nd dating of Onverwacht Group volcanics, southern Africa: Nature, v. 279, p. 298-300.

Hamilton, P.J., Evensen, N.M., O'Nions, R.K., Glikson, A.Y., and Hickman, A.H., 1980, Sm-Nd dating of the Talga-Talga Subgroup, Warrawoona Group, Pilbara Block, Western Australia: Extended Abst., 2nd Int. Archaean Symp., Perth, Geol. Soc. Australia, p. 11-12.

Hargraves, R.B., 1976, Precambrian geologic history: Science, v. 193, p. 363-371.

Heinrichs, T.K., and Reimer, T.O., 1977, A sedimentary barite deposit from the Archaean Fig Tree Group of the Barberton Mountain Land (South Africa): Econ. Geol., v. 72, p. 1426-1441.

Hickman, A.H., 1980, Geology of the Pilbara Block and its environs: Geol. Surv. West. Australia Bull., No. 127, (in press).

Hutchinson, R.W., 1965, Genesis of Canadian massive sulphides reconsidered by comparison to Cyprus deposits: Canadian Mining Metall. Bull., v. 58, p. 972-986.

Hutchinson, R.W., 1973, Volcanogenic sulfide deposits and their metallogenic significance: Econ. Geol., v. 68, p. 1223-1246.

Hutchinson, R.W., 1976, Metallogenic evolution of massive sulfide deposits through geologic time: Abst., Canadian Mining Metall. Bull., v. 69, No. 767, p. 94.

Hutchinson, R.W., 1978a, Ore deposits, their depositional environments and evolution through geologic time, _in_ Geological and geochemical evolution of massive sulphide deposits: Programme of post-graduate courses _in_ economic geology, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 149 p.

Hutchinson, R.W., 1978b, Geological and geochemical evolution of massive sulphide deposits, _in_ Geological and geochemical evolution of massive sulphide deposits: Programme of post-graduate courses in economic geology, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 149 p.

Hutchinson, R.W., and Hodder, R.W., 1972, Possible tectonic and metallogenic relationships between porphyry copper and massive sulphide deposits: Canadian Mining Metall. Bull., v. 65, p. 34-40.

Hutchinson, R.W., Ridler, R.H., and Suffel, G.G., 1971, Metallogenic relationships in the Abitibi belt, Canada : a model for Archean metallogeny: Canadian Mining Metall. Bull., v. 74, p. 48-57.

Hyde, R.S., and Walker, R.G., 1977, Sedimentary environments and the evolution of the Archean greenstone belt in the Kirkland Lake area, Ontario: Geol. Surv. Canada Paper 77-1A, p. 185-190.

Jakeš, P., and Gill., 1970, Rare earth elements and the island arc tholeiitic series: Earth Planet. Sci. Lett., v. 9, p. 17-28.

James, H.L., 1954, Sedimentary facies of iron-formation: Econ. Geol., v. 49, p. 235-293.

Knight, C.L., editor, 1975, Economic geology of Australia and Papua New Guinea, 1. Metals: Australian Mining Metall. Inst. Mono. Ser., No. 5, 1126 p.

Krauskopf, K.B., 1967, Introduction to geochemistry: New York, McGraw-Hill, Inc., 721 p.

Lambert, R. St J., 1980, The thermal history of the earth in the Archean: Precambrian Res., v. 11, p. 199-213.

Lear, P.A., 1977, Metallogeny of the Limpopo Mobile Belt in Botswana: Geol. Surv. Botswana, Bull., v. 12, p. 203-208.

Lear, P.A., 1979, The ore mineralogy of the Pikwe and Selebi nickel-copper deposits, Botswana: Geol. Soc. South Africa Spec. Pub. 5, p. 117-132.

Leelanandam, C., 1967, Occurrence of anorthosites from the charnockitic area of Kondapalli, Andhra Pradesh: Geol. Soc. India Bull., v. 4, p. 5-7.

Levinson, A.A., 1974, Introduction to exploration geochemistry: Wilmette, Illinois, Allied Publishing Ltd., 614 p.

Lowe, D.R., 1980, Archean sedimentation: Ann. Rev. Earth Planet. Sci., v. 8, p. 145-167.

Lowman, P.D., 1972, The geologic evolution of the moon: J. Geol., v. 80, p. 125-166.

Lowman, P.D., 1976, Crustal evolution in silicate planets : implications for the origin of continents: J. Geol., v. 84, p. 1-26.

Macgregor, A.M., 1951a, Some milestones in the Precambrian of Southern Rhodesia: Geol. Soc. South Africa Proc., v. 54, p. xxvii-lxxi.

Macgregor, A.M., 1951b, The primary source of gold: South African J. Sci., v. 47, p. 157-161.

Mason, B., 1966, Principles of geochemistry: New York, John Wiley and Sons, Inc., 329 p.

Mitchell, A.H., and Bell, J.D., 1973, Island-arc evolution and related mineral deposits: J. Geol., v. 81, p. 381-405.

Naidu, P.R.J., 1963, A layered complex in Sittampundi, Madras State, India: Min. Soc. America Spec. Paper No. 1, p. 116-123.

Naldrett, A.J., 1973, Nickel sulphide deposits - their classification and genesis, with special emphasis on deposits of volcanic association: Canadian Inst. Mining Metall. Trans., v. 76, p. 183-201.

Naldrett, A.J., and Cabri, L.J., 1976, Ultramafic and related mafic rocks : their classification and genesis with special reference to the concentration of nickel sulphides and platinum-group elements: Econ. Geol., v. 71, p. 1131-1138.

Naldrett, A.J., and Gasparrini, E.L., 1971, Archean nickel sulphide deposits in Canada : their classification, geological setting and genesis with some suggestions as to exploration: Geol. Soc. Australia Spec. Pub. 3, p. 201-226.

Naqvi, S.M., 1971, The petrochemistry and significance of Jogimardi traps, Chitaldrug Schist Belt, Mysore: Bull. Volcanol., v. 35, p. 1069-1093.

Naqvi, S.M., 1977, Archaean sedimentation of Dharwars in the central part of the Chitradorga schist belt, Karnotaka, India: Geophys. Res. Bull., v. 15, p. 17-30.

Nesbitt, R.W., 1971, Skeletal crystal forms in the ultramafic rocks of the Yilgarn block, W.A. : evidence for an Archean ultramafic liquid: Geol. Soc. Australia Spec. Pub. 3, p. 331-348.

Pereira, J., and Dixon, C.J., 1965, Evolutionary trends in ore deposition: Trans. Inst. Min. Metall., B74, 505-527.

Pettijohn, F.J., 1943, Archean sedimentation: Geol. Soc. America Bull., v. 54, p. 479-506.

Pyke, D.R., 1975, On the relationship of gold mineralization and ultramafic volcanic rocks in the Timmins area: Ontario Div. Mines. Misc. Paper 62, 23 p.

Pyke, D.R., Naldrett, A.J., and Eckstrand, O.R., 1973, Archean ultramafic flows in Munro Township, Ontario: Geol. Soc. America Bull., v. 84, p. 955-978.

Reimer, T.O., 1980, Archean sedimentary baryte deposits of the Swaziland Supergroup (Barberton Mountain Land, South Africa): Precambrian Res., v. 12, p. 393-410.

Reynolds, D.G., Brook, W.A., Marshall, A.E., and Allchurch, P.D., 1975, Volcanogenic copper-zinc deposits in the Pilbara and Yilgarn Archaean Blocks: Australian Mining Metall. Inst. Mono. Ser., No. 5, p. 185-195.

Rivalenti, G., 1976, Geochemistry of meta-volcanic amphibolites from south west Greenland, in Windley, B.F., ed., The early history of the Earth: John Wiley and Sons, London, p. 213-223.

Robb, L.J., and Robb, V.M., 1980, The nature of Archaean pegmatite deposits in the north-eastern Transvaal: Univ. Witwatersrand Econ. Geology Research Unit, Inf. Circ. 136, 15 p.

Roy, S., 1966, Syngenetic manganese formations of India: Jadavpur Univ., Calcutta, 219 p.

Rubey, W.W., 1951, The geologic history of sea water - an attempt to state the problem: Geol. Soc. America Bull., v. 62, p. 1111-1148.

Rubey, W.W., 1955, Development of the hydrosphere and atmosphere, with special reference to probable composition of the early atmosphere: Geol. Soc. America Spec. Paper 62, p. 631-650.

Sangster, D.F., 1972, Precambrian volcanogenic massive sulphide deposits in Canada : a review: Geol. Surv. Canada Paper 72-22, 44 p.

Sawkins, F.J., 1976, Massive sulphide deposits in relation to geotectonics: Geol. Assoc. Canada Spec. Paper 14, p. 221-240.

Schidlowski, M., 1978, Evolution of the earth's atmosphere : current state and exploratory concepts, in Noda, H. ed., Origin of life: Center. Acad. Publ., Tokyo, p. 3-20.

Schwerdtner, W.M., Stone, D., Osadetz, K., Morgan, J., and Stott, G.M., 1979, Granitoid complexes and the Archean tectonic record in the southern part of northwestern Ontario: Canadian J. Earth Sci., v. 16, p. 1965-1977.

Sillitoe, R.H., 1972, Formation of certain massive sulphide deposits at sites of sea-floor spreading: Inst. Mining Metall. Trans., v. 81, sect. B, p. B141-B148.

Sims, P.K., and Morey, G.B., Editors, 1972, Geology of Minnesota : a centennial volume: Geol. Surv. Minnesota, St. Paul Minnesota, 632 p.

Smith, H.S., Erlank, A.J., and Duncan, A.R., 1980, Geochemistry of some ultramafic komatiite lava flows from the Barberton Mountain Land, South Afirca: Precambrian Res., v. 11, p. 399-415.

Söhnge, P.G., Le Roex, H.D., and Nel, H.J., 1948, The geology of the country around Messina: Geol. Surv. South Africa, Explan. Sheet 46 (Messina).

Subramaniam, A.P., 1956, Mineralogy and petrology of the Sittampundi complex, Salem district, Madras State, India: Geol. Soc. America Bull., v. 67, p. 317-390.

Tarney, J., Dalziel, I.W.D., and de Wit, M.J., 1976, Marginal basin "rocas verdes" complex from S. Chile : a model for Archaean greenstone belt formation, in Windley, B.F., ed., The earth history of the earth: John Wiley and Sons, London, p. 131-146.

Taylor, S.R., 1964, Abundance of chemical elements in the continental crust : a new table: Geochim. Cosmochim. Acta, v. 28, p. 1273-1284.

Thayer, T.P., 1976, Metallogenic contrasts in the plutonic and volcanic rocks of the ophiolite assemblage: Geol. Assoc. Canada Spec. Paper 14, p. 211-219.

Tilling, R.I., Gottfried, D., and Rowe, J.J., 1973, Gold abundance in igneous rocks : bearing on gold mineralization: Econ. Geol., v. 68, p. 168-186.

Turekian, K.K., and Wedepohl, K.H., 1961, Distribution of the elements in some major units of the earth's crust: Geol. Soc. America Bull., v. 72, p. 175-192.

Veizer, J., and Jansen, S.L., 1979, Basement and sedimentary recycling and continental evolution: J. Geol., v. 87, p. 341-370.

Viljoen, M.J., and Bernasconi, A., 1979, The geochemistry, regional setting and genesis of the Shangani-Damba nickel deposits, Rhodesia: Geol. Soc. South Africa Spec. Pub. 5, p. 67-98.

Viljoen, M.J., and Viljoen, R.P., 1969a, The geology and geochemistry of the Lower Ultramafic Unit of the Onverwacht Group and a proposed new class of igneous rocks: Geol. Soc. South Africa Spec. Pub. 2, p. 55-86.

Viljoen, R.P. and Viljoen, M.J., 1969b, The geological and geochemical significance of the upper formations of the Onverwacht Group: Geol. Soc. South Africa Spec. Pub. 2, p. 113-151.

Viljoen, M.J., and Viljoen, R.P., 1970, Archaean vulcanicity and continental evolution in the Barberton region, Transvaal, in Clifford, T.N., and Gass, I., eds., African magmatism and tectonics: Oliver and Boyd, Edinburgh, p. 27-39.

Viljoen, R.P., Saager, R., and Viljoen, M.J., 1969, Metallogenesis and ore control in the Steynsdorp Goldfield, Barberton Mountain Land, South Africa: Econ. Geol., v. 64, p. 778-797.

Viljoen, M.J., van Vuuren, C.J.J., Pearton, T.N., Minnitt, R.C.A., Muff, R., and Cilliers, P., 1978, The regional geological setting of mineralization in the Murchison Range with particular reference to antimony: Geol. Soc. South Africa Spec. Pub. 4, p. 55-86.

Visser, D.J.L., Compiler, 1956, The geology of the Barberton area: Geol. Surv. South Africa Spec. Pub. 15, 253 p.

Viswanathan, S., 1975, Rocks of unusual chemistry in the charnockite terrains of India, and their geological significance: Geol. Mag., v. 112, p. 63-69.

Walker, R.G., 1978, A critical appraisal of Archean basin-craton complexes: Canadian J. Earth Sci., v. 15, p. 1213-1218.

Walker, R.G., and Pettijohn, F.J., 1971, Archean sedimentation : analysis of the Minnitaki basin, northwestern Ontario, Canada: Geol. Soc. America Bull., v. 82, p. 2099-2130.

Walker, M.R., Buick, R., and Dunlop, J.S.R., 1980, Stromatolites 3.4-3.5 billion years old from the North Pole area, Pilbara Block, Western Australia : Nature (in press).

Watson, J., 1973, Influence of crustal evolution on ore deposition: Inst. Mining Metall. Trans., v. 82, sect. B, p. B107-B113.

Wilde, S.A., 1980, The Jimperding Belt in the Toodyay area and the Balingup Metamorphic Belt and associated granitic rocks of the southwestern Yilgarn Block: Excursion Guide, 2nd Int. Archaean Symposium, Perth, Geol. Soc. Australia, 41 p.

Williams, D.A.C., 1979, The association of some nickel sulfide deposits with komatiitic volcanism in Rhodesia: Canadian Mineralogist, v. 17, p. 337-349.

Wilson, J.F., 1979, A preliminary reappraisal of the Rhodesian basement complex: Geol. Soc. South Africa Spec. Pub. 5, p. 1-23.

Windley, B.F., 1977, The evolving continents: John Wiley and Sons, London, 385 p.

Worst, B.G., 1962, The geology of the Buhwa iron ore deposits and adjoining country : Belingwe district: Geol. Surv. Rhodesia Bull., No. 53, 114 p.

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