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A SYNOPSIS OF CANADIAN STRATIFORM COPPER DEPOSITS IN SEDIMENTARY SEQUENCES

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ABSTRACT

Stratiform (1) copper deposits in sedimentary sequences have not made significant contributions to Canadian copper production. Nevertheless, sufficient occurrences are known of this very important geological type of deposit to suggest that some potential exists. Occurrences are widely distributed in rocks of many ages but the main ones are found in Carboniferous rocks of the Canadian Appalachians and Proterozoic rocks of the Canadian Shield and Cordillera.

Analogous to similar deposits in other parts of the world, Canadian occurrences characteristically are found in sediments deposited in continental or marginal marine, low latitude, arid or semi-arid areas. A number of the occurrences, such as those in Mississippian rocks of the Canadian Appalachians, and Proterozoic rocks of the Seal Lake area Labrador, Coppermine River and Redstone River areas, Northwest Territories, and in the Gateway Formation of the Clark Range of Alberta and British Columbia, have formed in the basal rocks of a marine transgression following a long period of continental sedimentation.

All deposits and occurrences are found in rocks that postdate oxygenation of the earth's atmosphere (about 2 300 m.yr.). Because no bonafide example of this type of deposit has been found in the extensive, well explored Archean terranes of Canada, a relatively highly evolved atmosphere seems to have been essential for their formation.

The detailed nature, distribution and significance in Canada of this important geological type of deposit will not be known until further exploration and studies have been carried out.

INTRODUCTION

Despite the country's large size and diverse geology, stratiform copper deposits in sedimentary sequences have not accounted for significant amounts of Canada's copper production. Nevertheless, because this type of deposit is very important in other parts of the world and favourable geological indications exist in Canada, an attempt has been made to examine and compile available information on such stratiform deposits and occurrences throughout the country. This paper is a résumé of information and impressions gathered to date. It is based on available published

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(1) In this paper "stratiform" is used informally and includes deposits that more accurately could be termed "concordant" or "penconcordant." It also refers to some concordant deposits in metamorphic rocks with layering of questionable origin.

and unpublished reports and on many personal cursory examinations of these deposits and occurrences as part of a broad geological study of Canadian copper deposits.

There has been only limited exploitation of these deposits and this has been mainly on metamorphosed ones of questionable origin (e.g. Anglo-Rouyn and Harvey Hill Mines). In total, only a few million tons of 2 to 3 percent copper ore have been extracted from such deposits. Even though the immediate future for exploitation of such deposits is not much brighter, it is hoped that over the long term major ore bodies of this type will be found in Canada. For example, the Redstone deposit in the Northwest Territories is large and has good grade sections; however, its highly faulted nature and very remote location limit its economic potential.

In Canada, exploration for stratiform copper deposits in sedimentary sequences has been sporadic and only now are some long term exploration programs being initiated. Some occurrences have been known for decades but many, even in areas where the geology is well documented, have been discovered only within the last fifteen years. This pattern of discovery and the very subtle nature of much of this mineralization suggest that important deposits could have been missed in previous investigations.

REGIONAL DISTRIBUTION

Figure 1 shows the distribution of the main deposits and occurrences in relation to the major geological regions of Canada. It can be noted that deposits and occurrences are widely distributed in rocks of variable age. Even though deposits of this type are located in rocks ranging from lower Aphebian age (about 2 300 m.yr.) to Triassic, most are found in Helikian (about 1 400-1 000 m.yr.) and Carboniferous rocks. The deposits with Helikian host rocks are localities numbers 5, 12(?), 14, 15, 16 and 18 (fig. 1) and the ones with Carboniferous host rocks are localities numbers 1 and 2 (fig. 1).

Most, if not all of the major geological regions shown on figure 1, except those comprised essentially of Archean rocks (older than about 2 500 m.yr.), such as the Slave and Superior Provinces, probably contain at least a few deposits or occurrences of this type. Areas such as the eastern part of the Churchill Province (between the Superior and Nain Provinces on figure 1), which includes the important Labrador Trough, may contain numerous occurrences of this type even though no well documented examples have been reported. An area such as the Labrador Trough contains favourable geological strata that are possibly the same general age as the iron- and copper-bearing beds in the Marquette region of the United States. Similarly the lack of occurrences in Arctic areas of Canada is probably also simply a function of insufficient exploration rather than a real lack of deposits. Both Proterozoic and Phanerozoic sedimentary sequences in the Canadian Arctic include numerous units with environments favourable for the occurrence of stratiform copper deposits.

Nevertheless, the apparent lack of such deposits in Archean areas (older than about 2 500 m.yr.) is probably real rather than apparent. In these areas the rock sequences appear to be too old. The older age limit for this type of deposit is in

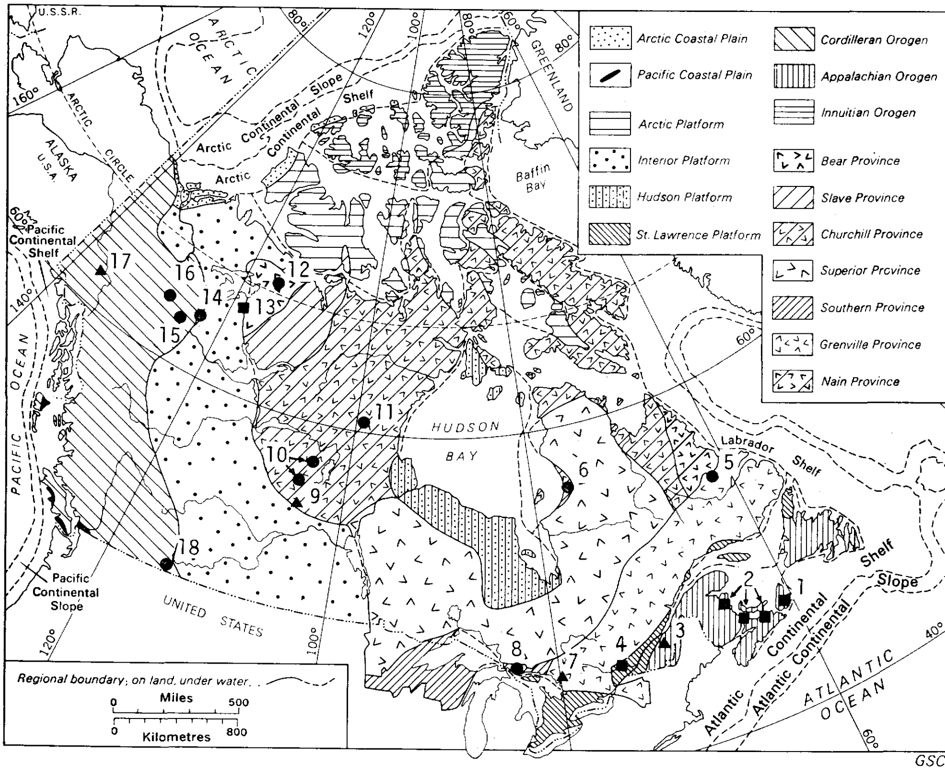

FIG. 1. — *Geological regions of Canada (after Douglas, 1970) and location of stratiform copper deposits and occurrences; circle indicates deposits in Proterozoic rocks; square indicates deposits in Paleozoic rocks; triangle indicates metamorphosed deposits of questionable origin. 1, Windsor-Horton Groups; 2, Canso-Pictou Groups; 3, Harvey Hill Mine; 4, Ottawa Area; 5, Seal Lake Area; 6, Richmond Gulf Area; 7, Parry Sound Area; 8, Sault Ste. Marie-Flack Lake Area; 9, Anglo-Rouyn Mine; 10, Wollaston Lake Fold Belt; 11, Hurwitz Group; 12, Coppermine River Area; 13, Hottah Lake Area; 14, Cap Mountain Area; 15, Redstone Area; 16, Keele River Area; 17, Minto Area; 18, Clark Range.*

rocks about 2 300 m.yr. old, which seems to coincide with oxygenation of the earth's atmosphere or "oxyatmoversion" (Roscoe, 1973).

The other major limitation on the distribution of these deposits is the existence of suitable environments of formation in the host sedimentary sequence. Stratiform copper deposits in sedimentary sequences, in Canada and elsewhere, characteristically have formed in sediments deposited in low latitude, arid or semi-arid, continental or marginal marine areas (e.g. Strakhov, 1962; Lombard and Nicolini, 1962; Kirkham, 1973, Renfro, 1974). Areas that do not contain sediments deposited in such environments seem to be devoid of such deposits.

Many of the major geological regions shown in figure 1 contain large areas of poorly documented metamorphic rocks. At least a few of these areas probably contain significant metamorphosed deposits of this type, but at present it is difficult to anticipate where these deposits might be located.

CANADIAN APPALACHIANS

Stratiform copper deposits in sedimentary sequences occur in two main areas in the Canadian Appalachians—Cambrian and/or possibly uppermost Precambrian rocks of southeastern Quebec and Carboniferous basins of Nova Scotia, New Brunswick and possibly Newfoundland.

The Harvey Hill Mine (No. 3, figure 1) which produced minor amounts of copper and silver in the past and is presently being reopened on a small scale, is perhaps the best example of this type of mineralization in south-eastern Quebec. The intensely deformed, recumbently folded, schistose nature of the host rocks make it very difficult to unravel the geology of this deposit. The main mineralized zones consist of disseminated chalcopyrite, bornite, chalcocite [2] and minor amounts of pyrite and molybdenite, conformable with the schistosity, in chloritoid-muscovite schists. These zones are cut by metamorphic gash veins some of which contain copper sulphides for as much as 80 feet from the conformable zones. Similar occurrences are present in a narrow belt that extends more than 150 miles to the southwest (G. Harron, personal communication).

The numerous occurrences in Carboniferous rocks of Nova Scotia and New Brunswick (fig. 2) can be divided into two main groups: those which occur in

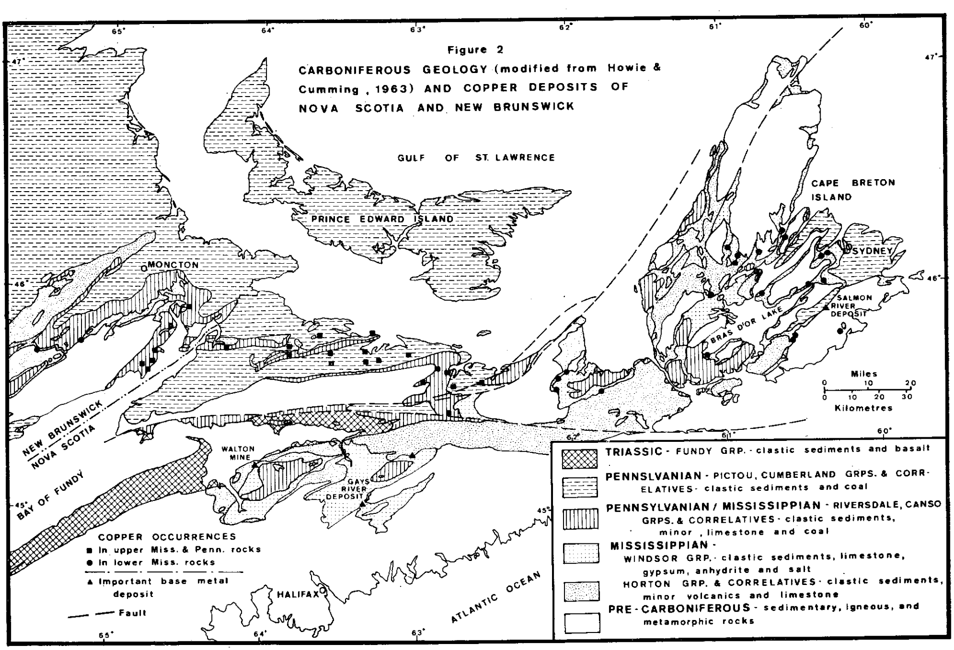

FIG. 2

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[2] "Chalcocite" is used in this paper as a field term.

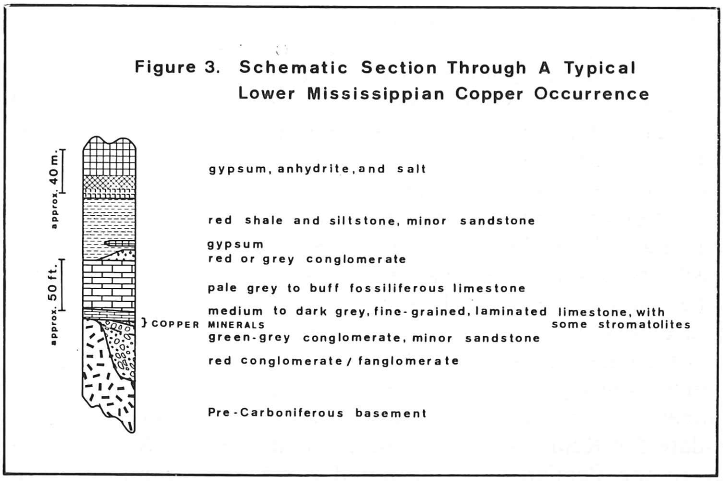

FIG. 3

lower Mississippian rocks, especially at the contact between the Windsor and Horton Groups or their stratigraphic correlatives (Binney and Kirkham, 1974), and those which occur in upper Mississippian and Pennsylvanian rocks (Papenfus, 1931 and Brummer, 1958). The latter group may include deposits in lower Permian rocks, since the age of the host rocks has not been well established at some localities. The deposits found at the Windsor-Horton contact are typical of ones formed in sediments deposited in paralic or marginal environments (i.e. the

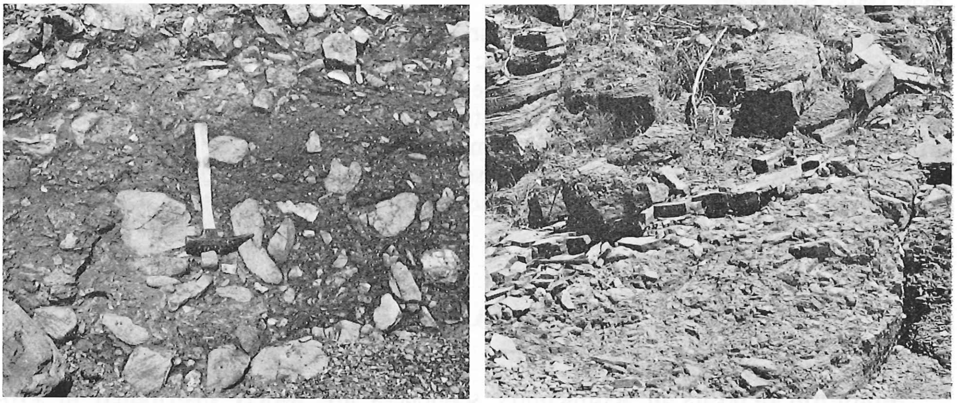

FIG. 4. — *(4a) (left) Typical red conglomerate that occurs about 80 feet stratigraphically below the lower Mississippian copper beds at East Bay on Cape Breton Island, Nova Scotia (GSC, Photo 9-3-73). (4b) (right) Typical dark grey, fine-grained, stromatolitic, laminated basal Windsor limestone overlying green-grey conglomerate at East Bay, Nova Scotia. Copper minerals occur in the conglomerate and lowest limestone beds (GSC, Photo 202516-B).*

"Kupferschiefer-type" deposits of Kirkham, 1973); whereas, most of those formed in the upper Mississippian and Pennsylvanian rocks are typical "Red-Bed" copper deposits that occur in sediments deposited in continental environments.

Figure 3 is a typical schematic section through one of the lower Mississippian copper occurrences. The stratigraphic sequence at most of these copper occurrences is remarkably similar from one locality to another and consists of a variable thickness of red conglomerate or fanglomerate (fig. 4*a*) overlain by a few inches to a few feet of green conglomerate, in turn overlain by a few inches to a few feet of dark, fine-grained, laminated, sandy limestone (fig. 4*b*) which grades upwards to paler fossiliferous limestone. Evaporites, other clastic rocks and limestones occur higher in the sequence. Pyrite, chalcopyrite, and, at a few localities, bornite and chalcocite, are disseminated in the upper part of the green conglomerate and lower part of the dark, laminated limestone (Binney and Kirkham, 1974). Malachite is a common weathering product in the upper part of the green conglomerate.

This mineralization has many similarities to the Kupferschiefer and is an ideal candidate for Renfro's coastal sabkha model (1974). Schenk (1967), drawing an analogy to the Persian Gulf, proposed a sabkha, strandline model for these copper-bearing beds. The base metal mineralization, although characteristically very sparse, has wide areal extent similar to that of the Kupferschiefer and Marl Slate. The main differences between this and Kupferschiefer mineralization are age (Mississippian versus Permian) and the fact that the Carboniferous basins of eastern Canada were far more irregular and had much more local, paleogeographic relief than did the Zechstein basin of Europe.

The Walton, Gays River, Smithfield and Salmon River deposits (fig. 2) are the largest base metal deposits found to date in the Carboniferous basins. The Walton deposit is a fault-controlled, base metal-barite-silver deposit near the Horton-Windsor contact (Boyle and Jambor, 1966 and Boyle, 1972). The Gays River and Smithfield deposits are "Mississippi Valley-type" or carbonate hosted zinc-lead deposits in the Windsor Group and the Salmon River deposit is a disseminated galena and pyrite deposit in Pennsylvanian sandstones adjacent to a Devonian sialic basement.

Most of the "Red-Bed" copper occurrences in upper Mississippian and Pennsylvanian rocks (fig. 2) tend to be erratic and have proved to be of minor importance. They have been described by Papenfus (1931), Brummer (1958) and others. As in many "Red-Bed" copper deposits chalcocite occurs as a replacement of woody material, pyrite or carbonate cement in green-grey patches or beds within a red bed sequence. In only a few of these deposits, such as the Dorchester deposit in New Brunswick, has the mineralization been demonstrated to have significant lateral continuity.

CANADIAN SHIELD

Stratiform deposits in sedimentary sequences are widely distributed in Proterozoic rocks of the Canadian Shield (fig. 1). Disseminated pyrite and chalcopyrite occur in pink and grey quartzites in the Lorrain Formation of the Huronian Supergroup in the Sault Ste. Marie and Flack Lake areas of Ontario (No. 8, fig. 1). In the Flack Lake area some gypsum and anhydrite nodules have been noted in the overlying Gordon Lake Formation. The Lorrain Formation, which contains the oldest red beds (about 2 300 m.yr. or Paleoaphebian age) known in Canada, is also the oldest host rock known to contain this type of copper mineralization.

The occurrences at Parry Sound (No. 7, fig. 1) in the Grenville Province consist of conformable zones of disseminated chalcocite and bornite in amphibolitic gneisses of uncertain origin. Conceivably these occurrences could have been early stratiform deposits in highly metamorphosed Huronian or other Proterozoic strata.

Other deposits in rocks of younger Aphebian age (about 1 800-1 900 m.yr.) occur along Richmond Gulf on the east side of Hudson Bay (No. 6, fig. 1) and in highly metamorphosed sediments in the central part of the Churchill Province (Nos. 9, 10 and 11, fig. 1). The deposits in the Richmond Gulf area are reported to comprise disseminated chalcopyrite and pyrite in arkosic sandstones near the base of Proterozoic strata that unconformably overlie Archean rocks of the Superior Province.

Numerous occurrences of disseminated copper, lead and zinc minerals have been found in the highly deformed and metamorphosed Aphebian rocks of the Wollaston Lake fold belt in Saskatchewan (Pyke and Partridge, 1967; Rath and Morton, 1969, Sangster and Kirkham, 1974). Similar mineralization has also been reported to occur in correlative rocks of Manitoba and in rocks of the Hurwitz Group of the Northwest Territories (No. 11, fig. 1). Host rocks for the disseminated base metal mineralization are typically highly metamorphosed arkosic sandstones and conglomerates. Pyrite, sphalerite, galena, chalcopyrite, bornite, chalcocite and native copper have all been found but in most areas the copper minerals occur separately from the lead and zinc minerals, though at one locality galena and chalcopyrite are present together in large boulders. At a number of localities the sulphide mineralization appears to occur near older basement areas.

The Anglo-Rouyn Mine (No. 9, fig. 1) also occurs in highly metamorphosed rocks of the central Churchill Province (fig. 1). The preproduction reserves were 2 million tons of ore grading 2.4 percent copper (Forsythe, 1972) and about 0.03 to 0.05 ounces per ton gold (J. Randall, personal communication). The deposit consists primarily of boudinaged, concordant zones of disseminated chalcopyrite, pyrite and pyrrhotite in calc-silicate gneisses and meta-arkoses. Forsythe (1972) suggested that it is an epigenetic, fault-controlled deposit; however, the writer suggests that it was initially a disseminated stratiform deposit that has been subjected to intense deformation and metamorphism resulting in significant local redistribution and recrystallization of sulphides. Even if a pre-metamorphic origin can be demonstrated the genetic affinities are still much in doubt. The significant gold content is not typical of stratiform copper deposits in sedimentary sequences and the deposit could conceivably have had volcanic rather than sedimentary affiliations.

The deposits in the Seal Lake area of Labrador (No. 5, fig. 1) are Helikian in age (about 1 250 m.yr.) and those in the Coppermine River area (No. 12, fig. 1) are either Helikian or Hadrynian in age (1 200-600 m.yr.). In both areas the deposits are remarkably similar to the important White Pine deposit in the Keweenaw Peninsula (Ensign *et al.*, 1968; White, 1971; Brown, 1971).

The deposits in the Seal Lake area have been described by Brummer and Mann (1961) and Gandhi and Brown (1974); some of the comparable occurrences in the Coppermine River area have been described briefly by Kirkham (1970). In both areas the copper occurs in the first green-grey marine beds that overlie a thick sequence of flood basalts and red beds (figs. 5, 6 and 7). The underlying flood basalts are noted for their numerous minor copper occurrences. Although

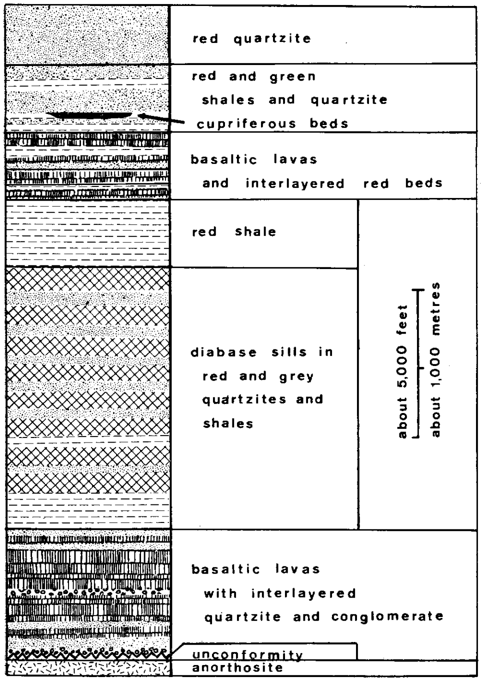

FIG. 5. — *Generalized section through the Seal Lake Group in Labrador showing position of cupriferous beds (adapted from Gandhi and Brown, 1974).*

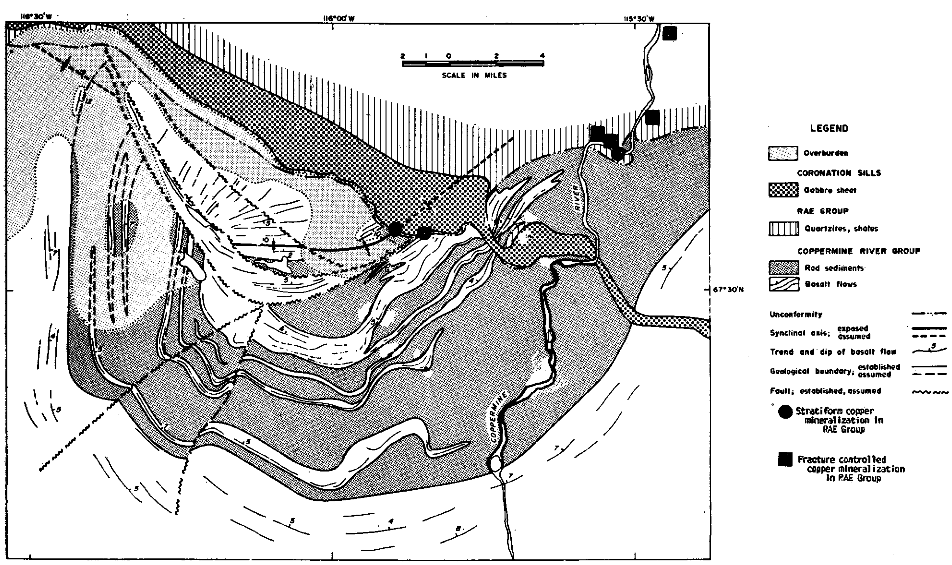

FIG. 6. — *Generalized geological map of the Coppermine River area, Northwest Territories (adapted from Baragar and Donaldson, 1973), showing the location of copper occurrences in the Rae Group.*

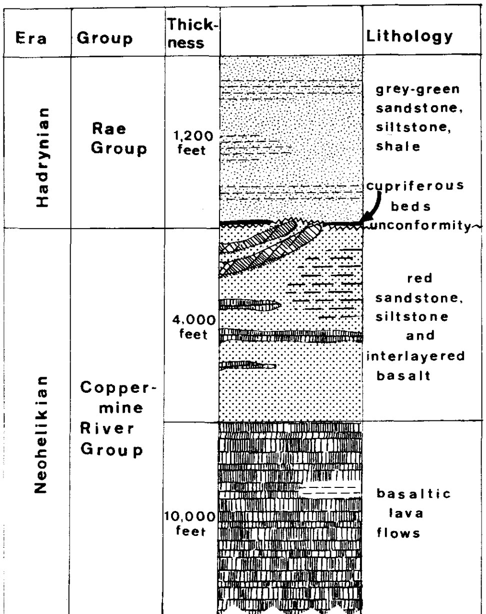

Figure 7. Columnar Section Showing Position of Cupriferous Beds in Coppermine River Area

FIG. 7

only subeconomic concentrations of chalcopyrite, bornite, and chalcocite have been found in the sedimentary rocks at both localities, the regional geology, tectonic setting, stratigraphy, age and the position of the cupriferous sediments are all remarkably similar to those of the Keweenaw Peninsula.

INTERIOR AND ARCTIC PLATFORMS AND INNUITIAN BELT

Only minor amounts of copper mineralization have been discovered to date in the Interior and Arctic Platforms and the Innuitian belt (fig. 1). At Hottah Lake (No. 13, fig. 1) disseminated chalcocite occurs in lower Paleozoic grey shale interlayered with red and green shales, bituminous dolomite with minor chalcopyrite, and sandstone (Thorpe, 1971). Minor occurrences of copper mineralization have also been reported in Proterozoic, Silurian, Devonian and Permo-Carboniferous strata at remote localities in Arctic Platform and Innuitian belt, but few data are available on these occurrences.

The interior Paleozoic basins of Canada were probably not major sites for copper deposition, although on first inspection they seem to contain many sedimentary units favourable for stratiform copper deposits. The carbonate units and multicycle, clean quartz sands that characterize these basins were, for the most part, deposited far from any immature terrigenous area that might have provided suitable geochemical sources for copper. The Hottah Lake and Ottawa localities occur along the margins of the basins where copper could have been derived, directly or indirectly, from adjacent basement areas. On the other hand the diverse geology and tectonic history of Arctic areas with more varied possible sources and depositional sites for copper indicate a significantly higher potential.

CANADIAN CORDILLERA

Although there is some indication of stratiform copper mineralization in Paleozoic and Mesozoic strata of the Canadian Cordilleran region, most of the known mineralization occurs in Proterozoic rocks of Helikian age (about 1 000 to 1 400 m.yr.).

In the northern Cordillera stratiform copper mineralization occurs at Cap Mountain (Aitken *et al.*, 1973) and in the Redstone River (Coates, 1964; Watson and Mustard, 1973), Keele River and Minto areas (fig. 1). At present little is known about the mineralization at Cap Mountain or the Keele River area but important deposits are known in the Redstone River and Minto areas.

In the Minto area, chalcopyrite, bornite, secondary copper minerals, minor pyrite and magnetite with significant amounts of precious metals occur in layered biotitic gneisses of a migmatite complex. The origin of these deposits is *very much*

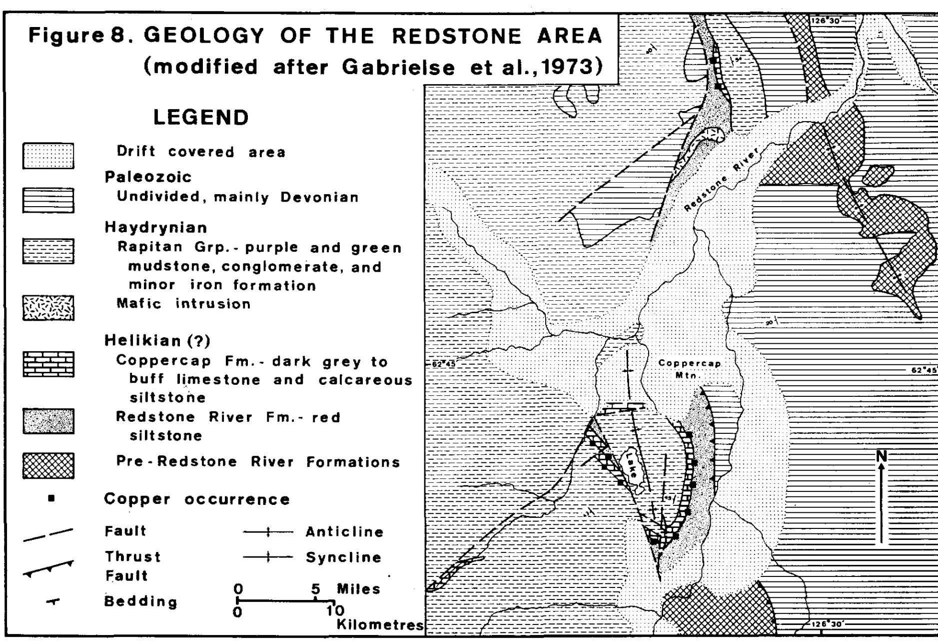

FIG. 8

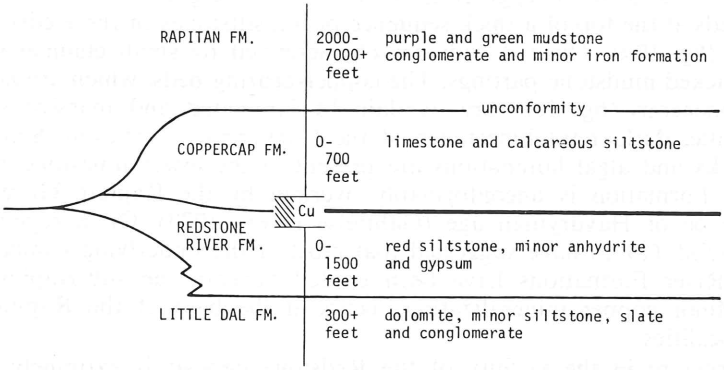

FIG. 9. — *Schematic section through copper-bearing strata in the Redstone River area, Northwest Territories (adapted from Gabrielse* et al., *1973).*

in doubt but, despite the very potassic nature of the host rocks and the relatively high gold content, there is a possibility that these are highly metamorphosed, remobilized stratiform deposits in metasedimentary rocks. Clarification of the origin and nature of these deposits must await further studies.

Figures 8 and 9 show the general geology and stratigraphy in the vicinity of the Redstone deposit. Copper mineralization of variable grade and thickness has been traced continuously for more than four miles along the face of Coppercap Mountain (fig. 10*a*) and has been found 20 miles to the north where the copper

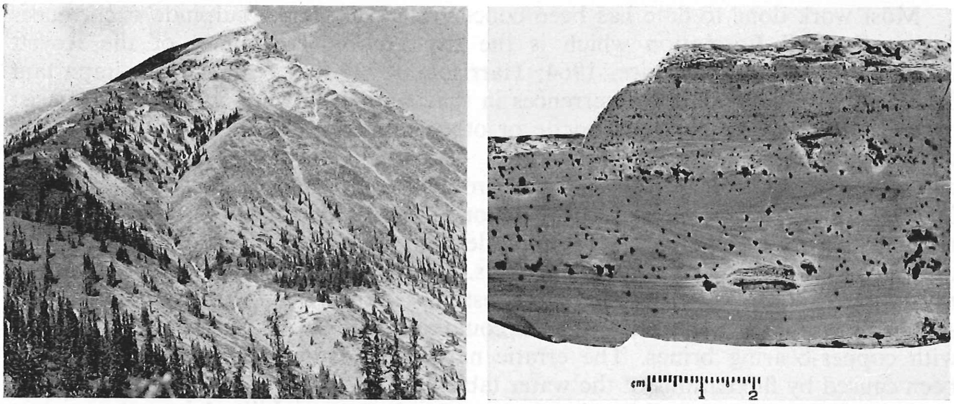

FIG. 10. — *(10a) (left) View from the south of the Coppercap Formation (light) overlying the Redstone River Formation (dark) on the south end of Coppercap Mountain, Northwest Territories. The copper-bearing beds occur at the top of the Redstone River Formation (GSC, Photo 202516-A). (10b) (right) Typical specimen of pale, fine-grained, silty, carbonate grainstone copper bed showing delicate climbing ripples and a calcite concretion, Redstone River area, Northwest Territories. The dark spots are disseminated chalcopyrite. Note that the bed is not carbonaceous (GSC, Photo 201963-B).*

beds are exposed again. Pyrite, chalcopyrite, bornite and chalcocite occur disseminated in four to six pale, green-grey, silty carbonate grainstones and calcareous siltstone beds at the top of a thick sequence of red siltstones of the Redstone River Formation (fig. 10*a*). The red beds are characterized by small channel structures with suncracked mudstone partings. The copper-bearing beds, which are *not* noticeably carbonaceous (fig. 10*b*) are overlain by laminated and massive shaly and sandy, pyritic, dark, fetid limestones of the Coppercap Formation. Some dessiccation cracks and algal laminations are present in the lower limestone beds. The Coppercap Formation is unconformably overlain by the Rapitan Group that is thought to be of Haydrynian age (Gabrielse *et al.*, 1973). On a regional scale, Gabrielse *et al.* (1973) have suggested that most of the underlying Coppercap and Redstone River Formations have been eroded beneath the sub-Rapitan unconformity. Minor copper mineralization occurs at the base of the Rapitan Group at many localities.

The structure in the vicinity of the Redstone deposit is extremely complex. Numerous minor and major low-angle and high-angle faults of late Mesozoic age cut the copper-bearing strata; and Proterozoic faulting probably also took place in the district between the times of deposition of the Coppercap Formation and the overlying Rapitan Group.

Copper deposition evidently occurred in basal marine sediments that transgressed a very broad alluvial plain. Although the actual copper-bearing beds are not carbonaceous, the fetid conditions in the overlying carbonates probably provided suitable anoxic, sulphurous conditions necessary for copper deposition.

The last main area to be discussed is the Clark Range in southern Alberta and British Columbia (figs. 11 and 12). Analogous to equivalent Belt rocks in the United States (Harrison, 1972; Clark, 1971), numerous stratiform copper occurrences are known in various units of the Purcell sequence (Morton *et al.*, 1973).

Most work done to date has been concentrated on copper sulphide occurrences in the Grinnell Formation which is the stratigraphic equivalent of the Revett Formation in Montana (Price, 1964; Harrison, 1972) that contains the important Spar Lake deposit. Copper occurrences in the Grinnell Formation typically consist of erratically disseminated chalcocite or other copper sulphides in the pure white quartzite members of an otherwise red clastic sequence. The copper shows a marked preference for beds that were probably the most permeable ones in the formation. Sand-filled mudcracks, analogous to those described by Garlick (1967) at Mufulira and by Glennie (1970) in modern inland sabkhas, are common features associated with the white quartzite beds. Quite possibly these were aeolian or reworked aeolian sands that came to rest in sabkhas. At some time soon after sedimentation these permeable sands could conceivably have become saturated with copper-bearing brines. The erratic nature of the mineralization could have been caused by fluxuations of the water table and the resulting variations in Eh-pH conditions. At a few localities copper has also been remobilized into the contact zones of diabase dykes.

In the Gateway Formation copper sulphide mineralization, more characteristic of paralic marine sediments, occurs in thin but extensive green-grey and buff siltstone beds with mudcracks and salt casts that occur near the top of a red bed sequence. Unlike the mineralization in the Grinnell Formation this mineralization is persistent over large areas.

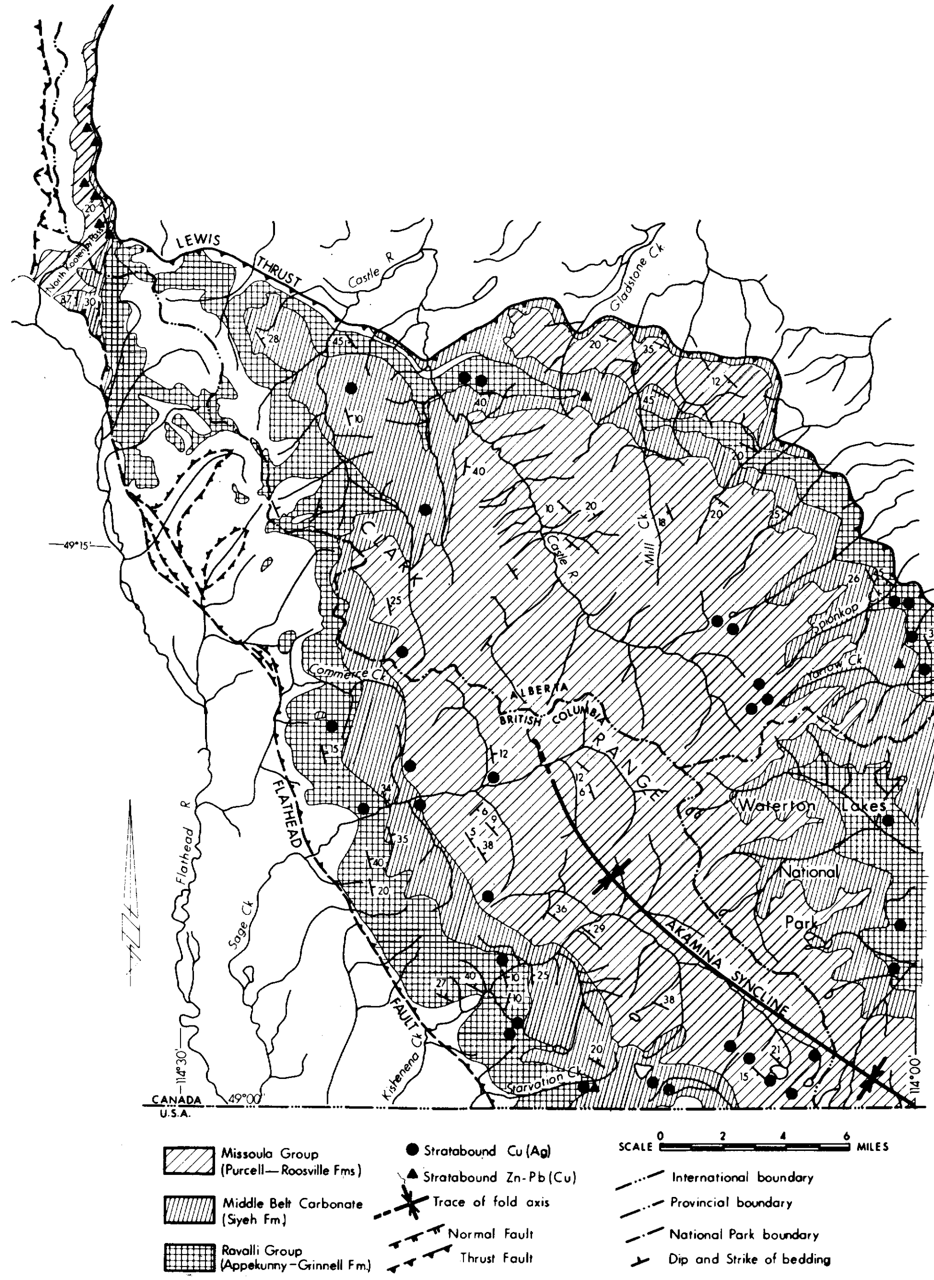

FIG. 11. — *Geological sketch map of the Clark Range, southern Alberta and British Columbia, showing locations of principal stratabound* Cu (Ag) *and* Zn/Pb (Cu) *occurrences (after Morton* et al., *1973).*

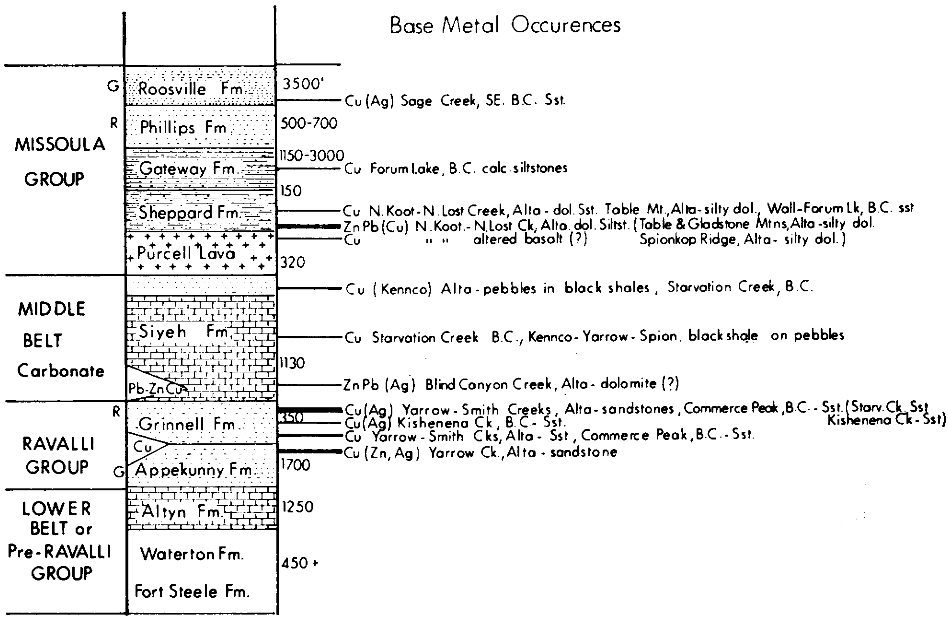

FIG. 12. — *Generalized stratigraphic section of Precambrian rocks and stratabound base metal occurrences in the Clark Range (after Morton* et al., *1973).*

CONCLUSIONS

Stratiform copper mineralization in sedimentary sequences is widely distributed in Canada but it has not yet been of major economic importance. It occurs in rocks of diverse nature ranging in age from Paleoaphebian to Triassic. The most significant mineralization discovered to date, as in other parts of the world, occurs in the basal rocks of a marine transgression following a long period of continental sedimentation. These and other paralic marine sediments, as well as some continental sediments, seem to offer the most immediate potential for major copper deposits of this type. Exploration and studies of these deposits in Canada are still in their infancy and it is apparent that much further work is necessary before a reasonable idea of their distribution and importance can be ascertained.

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