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COPPER MINERALIZATION IN MIOGEOSYNCLINAL CLASTICS OF THE BELT SUPERGROUP, NORTHWESTERN UNITED STATES

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ABSTRACT

The Belt Supergroup is a stack of fine-grained clastic and minor carbonate rocks at least 20 km thick, deposited in an epicontinental basin on the western margin of the Canadian shield in the period about 1 450 to 850 m.yr. (million years) ago. Most of the stack is of shallow-water marine origin, though the lowest exposed rocks include extensive turbidites and the uppermost may contain some fluvial sandstones and conglomerates. The lower third of the stack consists of graywackes and graphitic shales, and the upper two-thirds of red-bed sequences, black shales, and carbonates. The entire stack has been metamorphosed to greenschist or higher facies.

Anomalous copper occurs in almost every Belt formation except the lowest one (Prichard) and in localities scattered throughout the 130 000 km^2 of exposed Belt. The copper is principally in chalcocite, bornite, and chalcopyrite that have replaced groundmass and clasts of the host rocks. Highly anomalous copper is found only in green and white beds within the red-bed sequences; no anomalous copper has been found in purple or red (oxidized) beds. Though copper concentrations tend to follow more permeable (coarser) layers, they also cut across the bedding, indicating that the copper has been mobilized and reconcentrated.

Copper of ore grade and quantity has as yet been found only in what are now impermeable white quartzites and siltites of the Revett Formation, in a zone about 30 km wide and 100 km long in northwestern Montana. The structural position of the zone on a post-Revett dome suggests that copper was reconcentrated epigenetically in permeable strata of a structural-stratigraphic trap prior to or during regional metamorphism of the formation.

INTRODUCTION

The Belt basin, an area of about 130 000 km^2 in northwestern United States and adjacent parts of Canada (fig. 1), is one of several epicratonic reentrants onto the North American craton formed in Precambrian Y [1] time. During a period spanning about 600 m.yr. (1 450 to 850 m.yr.) the basin was filled largely by fine-grained

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[1] This letter refers to an interim time scale for the Precambrian adopted for use by the U.S. Geological Survey (James, 1972). Precambrian Y time is 1 600 to 800 m.yr. ago.

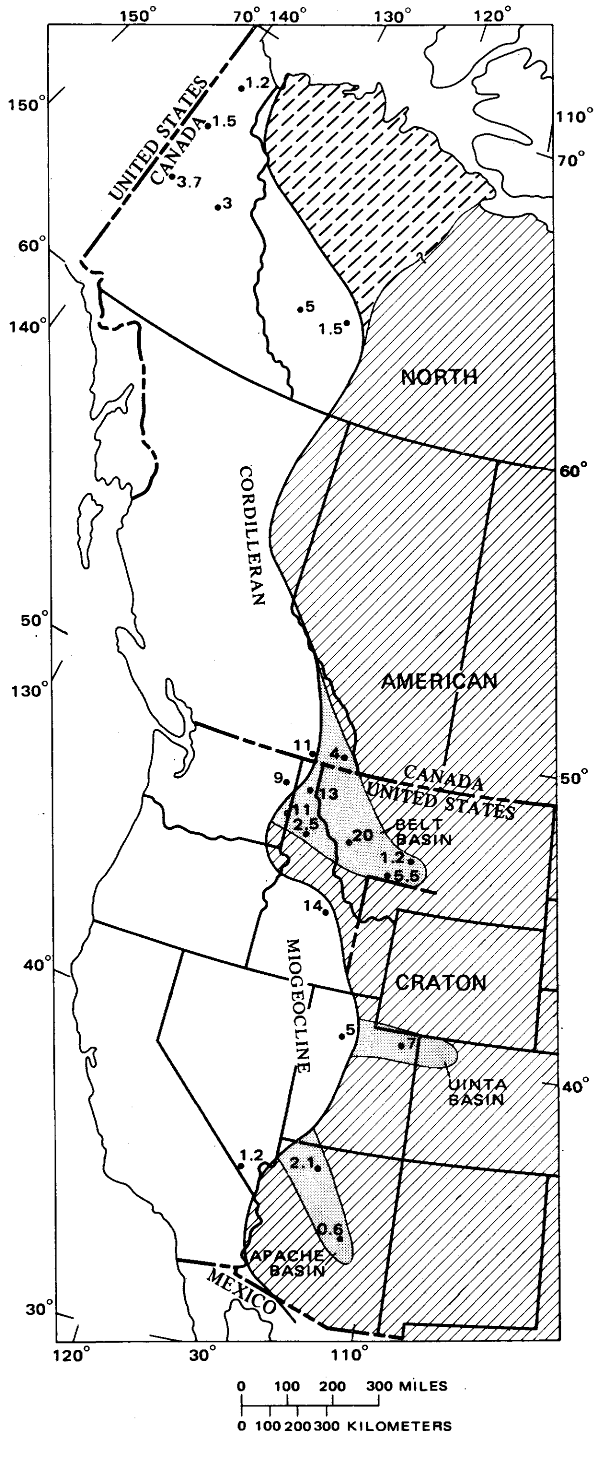

FIG. 1. — *Principal basins of sedimentation along the U.S.-Canadian Cordillera during Precambrian Y time (1 600-800 m.yr. ago). Compiled largely from Gabrielse (1972), King (1969), and Harrison (1972). Numbers show approximate thickness in thousands of meters of remnant Precambrian Y sedimentary rocks. Pattern in northwest part of craton indicates possible extension.*

clastic rocks and some carbonate that accumulated at least in one area to a minimum thickness of about 20 km.

Striking characteristics of the Belt Supergroup include: (1) its general fineness of grain-size over thousands of square kilometers and through thousands of meters of section, wherein only about 10 percent of the rocks are as coarse as medium sand; (2) a repetition of remarkably similar rock types in many formations; (3) subtle facies changes that may extend for tens of kilometers before being clearly identifiable; (4) general conformity between all formations and groups; (5) shallow water indicators—such as salt casts, mud crack casts, and stromatolites—that, in general, decrease in abundance with depth in the section; and (6) a pervasive regional metamorphism in the greenschist facies that ranges from almost unmetamorphosed rocks high in the section in the eastern part of the basin to biotite zone rocks everywhere at depth in the section and throughout the lower half of the section in the western part of the basin.

A surge of new interest in the Belt Supergroup began in 1961 with the discovery of strata-bound copper occurrences. Much of the new geologic data gathered in the following decade has been summarized recently (Harrison, 1972), and space limitations do not permit extensive repetition of that summary. This paper will review the stratigraphic record only briefly and will concentrate on the distribution and types of copper occurrences. Parts of the Belt basin still do not have adequate geologic maps, and sedimentologic studies are few and cover only small parts of the basin. Many mining companies are actively exploring for ore, but they have not yet released much information on tonnage, grade, and type of occurrence. Thus most of the data on copper in this report has been gathered personally by me and my colleagues of the U.S. Geological Survey. I am particularly grateful to J. D. Wells, M. R. Mudge, R. L. Earhart, A. B. Griggs, G. B. Gott, and F. K. Miller for their generous permission to use unpublished data that they have collected. D. J. Grimes, J. A. Domenico, and J. G. Frisken, all of the U.S. Geological Survey, provided the analytical data that are summarized in this report.

GENERAL GEOLOGY

All the events with which this paper is concerned are related to the rocks of the Belt Supergroup and occur within the time span of their formation and metamorphism in late Precambrian time. Even though Belt terrane as seen today has been subject to major episodes of Phanerozoic sedimentation, intrusion, volcanism, and tectonism—largely extensive thrust faulting, high-angle tear faults, and basin-and-range block faults—none of this post-Precambrian activity bears on the origin of the strata-bound copper occurrences, and it is relevant only as it disrupts the previously formed mineralization.

The time of Belt sedimentation was one of very minor intrusion, a single limited episode of volcanism, high-angle faulting of very limited extent primarily at some basin edges, and only gentle warping at continental hinge lines or out within the basin. Low-grade regional metamorphism (greenschist facies) of Belt rocks was accomplished prior to deposition of Middle Cambrian quartzites. The original distribution and any major redistributions of disseminated strata-bound copper sulfide minerals in regionally metamorphosed rocks must have occurred prior to the regional metamorphism, as rocks in the biotite zone and lower parts

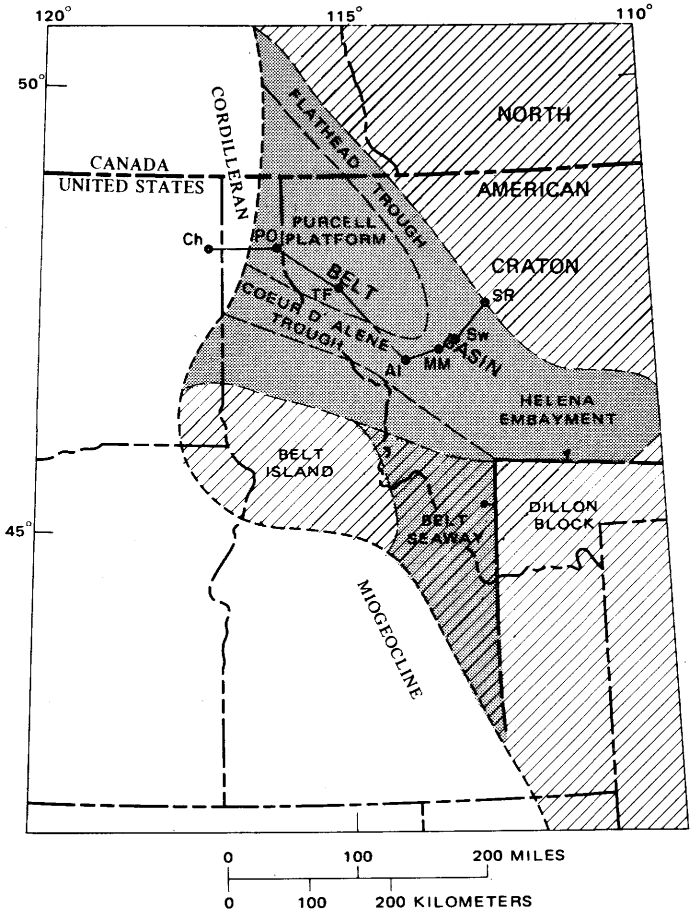

FIG. 2. — *Principal paleotectonic elements of the Precambrian Belt basin (from Harrison and others, in press). Dashed-and-dotted line shows line of section used in figures 3 and 4; SR, Sun River Canyon area (Mudge, 1972); Sw, Swan Range (M. R. Mudge and R. L. Earhart, unpublished data); MM, Mission Mountains (J. E. Harrison, unpublished data); Al, Alberton area (Wells, in press); TF, Thompson Falls area (A. B. Griggs, unpublished data); PO, Pend Oreille area (Harrison and Jobin, 1963); Ch, Chewelah area (F. K. Miller, unpublished data). Stippled areas contained Belt rocks; Belt island may have connected at times to the Dillon block. Bar and ball on downthrown sides of faults.*

of the chlorite-sericite zone now have highly sutured and interlocked textures that cause a very low to zero permeability. Local redistributions of copper and lead related to contact metamorphism and hydrothermal activity adjacent to a few Precambrian basic sills have been identified in one area on the eastern side of the basin (Morton and others, 1973) but no major redistributions have as yet been recognized in the contact metamorphic and tectonically disturbed zones around Mesozoic-Cenozoic plutons. The remainder of this report will be concerned solely with the late Precambrian history and will make use of paleotectonic reconstructions of the

Precambrian Belt basin; the data and interpretations upon which those reconstructions depend are presented elsewhere (Harrison, 1972; Harrison, Griggs, and Wells, in press; Ruppel, in press).

The Belt basin contained several paleotectonic elements (fig. 2), one or more of which dominated the basin's development at different times over a 600 m.yr. time span. The general pattern, however, is one of a slowly sinking epicratonic basin in almost perfect balance with a craton of low relief. Conglomerates of limited extent formed along the fault on the north side of the Dillon block during the first third of Belt time (McMannis, 1963), and some are presumed related to a fault on the west side that was active in late Belt time (Winston, 1973). The subsiding basin was controlled primarily by repeated gentle downflexing along the hinge lines where it joined the craton, and by steepening into the Cordilleran miogeocline. How far Belt sediments extended to the west in the miogeocline is unknown because they are now overlain unconformably by the younger Precambrian Windermere Group as well as covered by Phanerozoic sediments and thousands of meters of Cenozoic basalts. At least 12 000 m of Belt sediments occur in the westernmost exposures, which suggests that Belt sedimentation extended many kilometers out into the old miogeocline. Within the basin, the major tectonic elements (figs. 2 and 3) were the persistent Cœur d'Alene trough and a gentle dome in the general area of the Purcell platform; the dome formed, probably by differential subsidence, toward the end of mid-Belt carbonate deposition and persisted until the end of Belt sedimentation.

A diagrammatic section through the basin (fig. 3) serves to illustrate not only the present stratigraphic terminology and correlations, but also some of the subtle facies changes and paleotectonic elements. The Belt Supergroup consists of rocks that can be subdivided into four major packages. The oldest package, as represented on figure 3, is the Prichard Formation whose base is nowhere exposed in the central part of the basin. The Prichard Formation consists of a lower unit dominated by turbidites (Edmunds, 1973) and an upper unit of black pyritic or pyrrhotite argillite, and is everywhere in the biotite zone of regional metamorphism. No anomalous amounts of copper have been found in the Prichard. In contrast, all rocks above the Prichard Formation are red-bed sequences or carbonates, most of which contain anomalous amounts of copper in places. Directly overlying the Prichard Formation is the Ravalli Group, which consists of gray, red, purple, and green pelitic rocks and one psammitic unit—the Revett Formation. The uppermost unit of this group, the Empire Formation, is a green laminated argillite and siltite that commonly contains thin lenses and small concretionary pods of limestone. Most of the Ravalli Group is in the biotite zone of regional metamorphism, and where metamorphism has proceeded to the greatest degree the rocks tend to be gray and contain tiny euhedral crystals of magnetite that formed at the expense of the hematite which formerly colored the rocks red. Overlying the Ravalli Group is the middle Belt carbonate whose highly calcareous and dolomitic eastern facies is called the Helena Formation and whose more clastic western facies is called the Wallace Formation. The strata consist of black limestone and dolomite containing stromatolites and oolites, black laminated shales that at places contain pyrite, green dolomitic pelites, and minor amounts of calcareous or dolomitic quartzite. Although these rocks are predominantly in the chlorite-sericite zone, secondary biotite, defining the biotite zone of regional metamorphism, at places reaches as high as mid-Wallace. The upper Belt package is the Missoula Group, which consists of bright red and green clastic rocks and carbonate; glauconitic sands are common

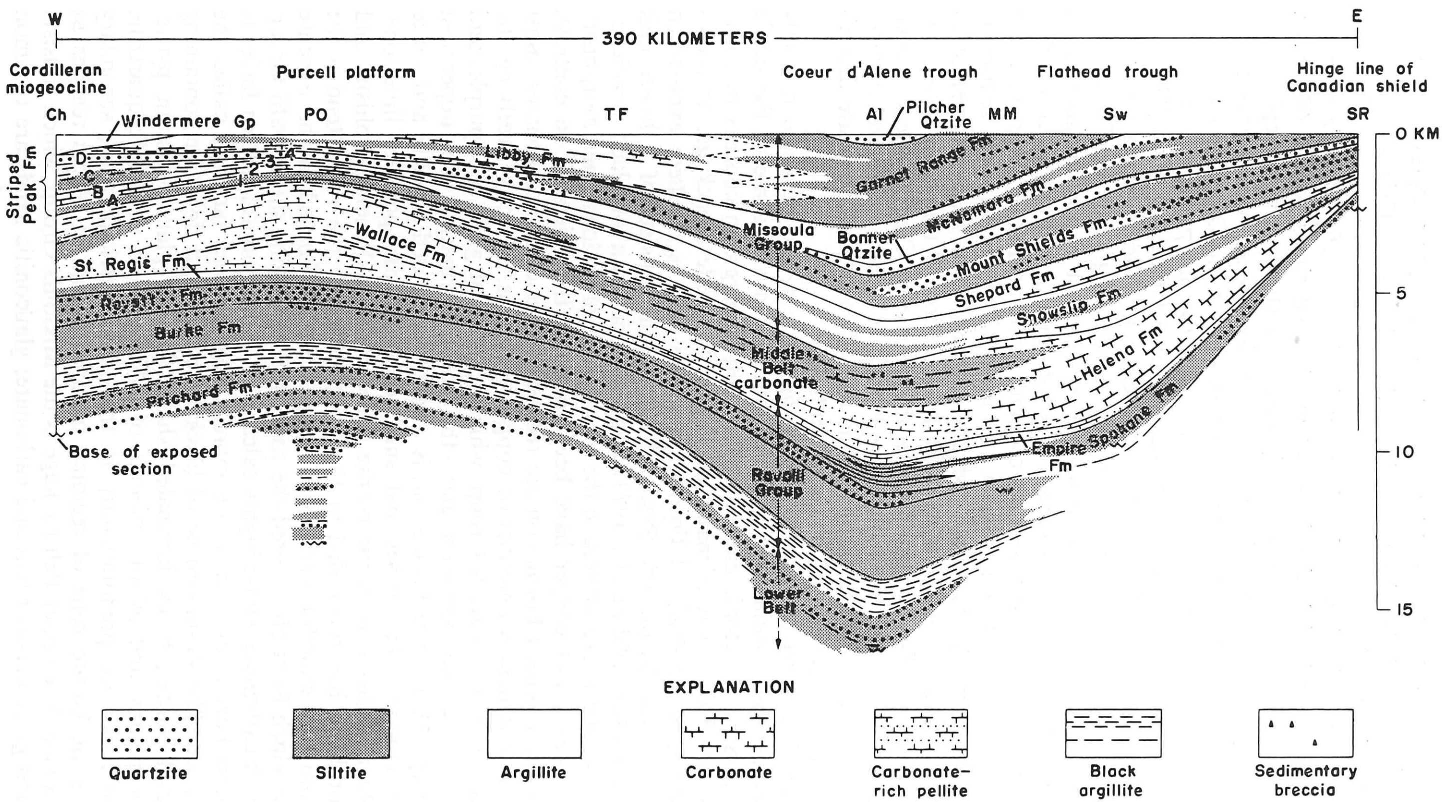

FIG. 3. — *Diagrammatic section through the Belt basin. Top of section is unconformity with Flathead Quartzite (Middle Cambrian) or its equivalent. Letters indicating control points are explained on figure 2. Most formations are of mixed lithology, but only dominant lithologies are shown. Vertical exaggeration about 40 ×. A, B, C, and D and 1, 2, 3, 4 identify informal members of the Striped Peak Formation.*

in the eastern parts (Mudge, 1972) as are salt casts, and black shales are common in the west. The Purcell Lava occurs in the Missoula Group near the U.S.-Canadian border where it rests unconformably on the Snowslip Formation and the upper part of the Helena (Price, 1964). Most rocks of the Missoula Group are in the chlorite-sericite zone, although the highest units in the east retain some relict clay minerals.

All rocks above the turbidites of the lower part of the Prichard Formation appear to be shallow-water marine and sea-marginal sediments, although recent work (Winston, 1973) suggests that some formations may have been deposited as continental terrace wedges prograded across low terrain by braided streams. No beds of evaporites have been found in the Belt Supergroup even though salt casts are common. One excellent example of a delta is represented by the Revett-St. Regis rocks (Hrabar, 1971) built northward into the basin from Belt island (fig. 2) (Harrison and others, in press).

Some of the subtle facies changes and activity of paleotectonic elements are illustrated on figure 3. The vertical exaggeration is about 40 times, so what appear to be pronounced troughs and domes are actually very gentle warps. The coarsening and thinning of formations toward the eastern margin of the basin are readily apparent, as is the great Helena carbonate bank and its seaward correlatives represented by the middle Belt carbonate. Note also that facies changes tend to take place gradually across tens or even hundreds of kilometers. Some units, such as the upper part of the Prichard Formation or the Empire Formation, appear to be lithologically identical over thousands of square kilometers of Belt terrane. Continued subsidence of the Cœur d'Alene trough is obvious from the persistent accumulation of thick sediments in it. The Flathead trough received thicker accumulations of sediment when the Missoula Group was being deposited. The dome of the Purcell platform appears to have begun forming late during Wallace sedimentation, and was a significant factor during Missoula Group sedimentation.

In summary, the Belt Supergroup appears to represent a slow filling of a shallow epicratonic reentrant that persisted as a depression for about 600 m.yr. Early basin fill was dominated by turbidites and black shale that have no known anomalous copper with them. Subsequent deposits were largely red-bed sequences, stromatolitic carbonates, and some black shale. Although salt casts are abundant in the red beds, geologic conditions required to form beds of evaporites apparently were never reached. Anomalous amounts of copper have been found largely in the red-bed sequences and only sparsely in the carbonates.

STRATA-BOUND COPPER DISTRIBUTION

Anomalous amounts of copper (100 or more parts per million) have been found in parts of all but three Belt formations (Prichard, Bonner, and Pilcher). The copper occurs primarily in chalcopyrite, chalcocite, and bornite, and to a lesser degree in digenite (?), covellite, tetrahedrite (?), malachite, azurite, and brochantite. Copper sulfides have been found in all rock types except red (oxidized) beds, and they replace both groundmass and clasts in all occurrences. They tend to be concentrated along sedimentary features such as bedding, minor cut-and-fill structures, mud-crack casts, sandstone dikes, and various water escape structures; some are concentrated along minor fractures in the rocks. In all strata-bound occurrences, the

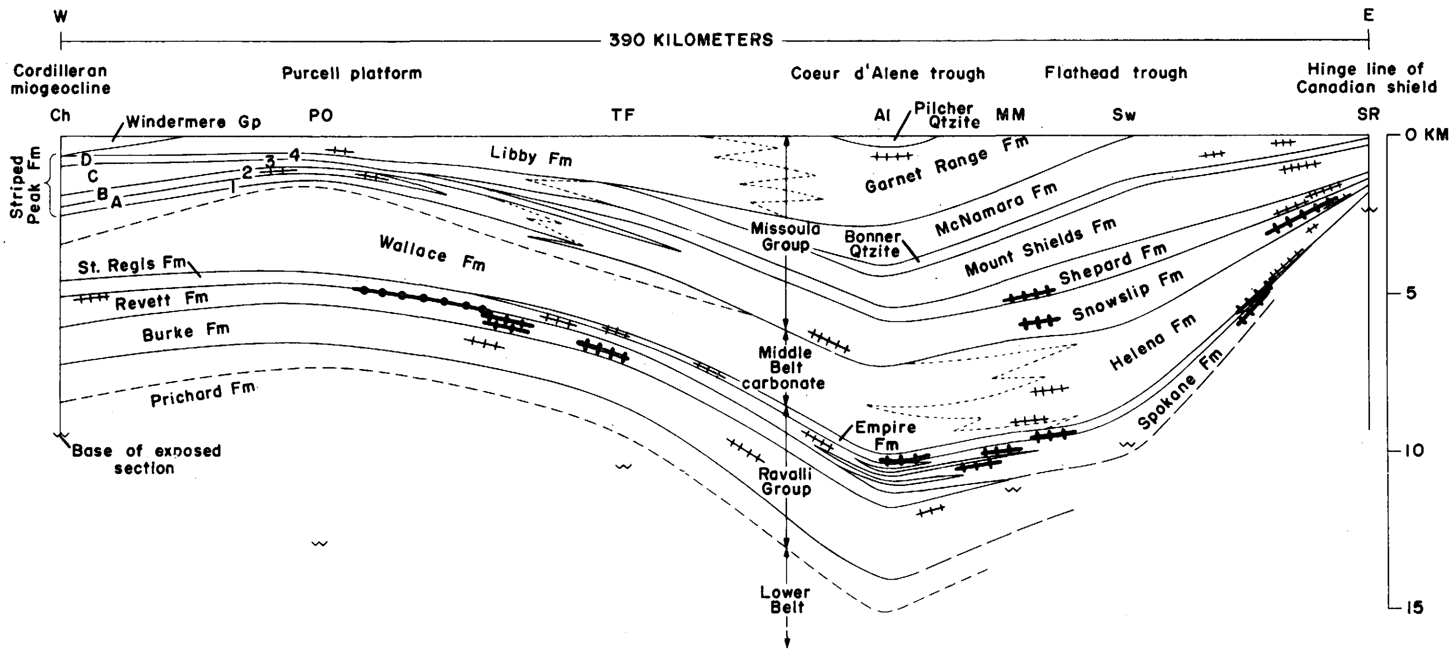

FIG. 4. — *Distribution and amount of anomalous copper in Belt rocks. Heavy line with dots-ore grade (about 1 percent); heavy line with bars-several thousand ppm; light line with bars-several hundred ppm. Information should be considered minimal. Letters indicating control points are explained on figure 2. Vertical exaggeration about 40 ×.*

copper sulfides tend to be in the coarser parts of the rock, such as quartzite and siltier laminae in shaly rocks, or with carbonate lenses and pods. Associations of copper minerals with black argillites, black pyritic argillites, and stromatolites are known but are rare, even though these rock types are common in the Belt Supergroup. The great bulk of the anomalous copper is in green (chloritic and reduced) beds of any lithology or in light gray to white siltites and quartzites. The copper is always accompanied by small but anomalous amounts of Ag and Hg; is commonly accompanied by small but anomalous amounts of V, Cr, and Pb; and at a few places is accompanied by slightly anomalous amounts of Ba, Sc, Bi, Mo, or Sn. Ag, usually as native silver, is the only element in sufficient quantity to increase the value of the copper ore.

Copper concentrations have been found throughout the Belt basin. Figure 4 shows the stratigraphic location of many occurrences, although the diagram contains minimal information because I have eliminated many data that are still considered confidential by many mining companies. The lower grade concentrations tend to contain a single sulfide, usually chalcopyrite or chalcocite; the higher grade concentrations tend to contain bornite in addition to one or both of the other principal sulfides. Although some stratigraphic zones, such as the base of the Shepard Formation or the Empire Formation, are more favorable for occurrences of copper than other zones, the diagram also shows that the copper is discontinuous.

TYPES OF COPPER OCCURRENCES

Although the most widespread and numerically abundant strata-bound copper sulfide occurrences are in green beds in the red-bed sequences, the only known deposits of ore grade are in the white to buff quartzites and siltites of the Revett Formation. Other occurrences in black shale, dark-gray dolomite, or dolomitic stromatolites are minor, consist of scattered grains of chalcopyrite, and will not be considered further in this paper. The secondary copper minerals—malachite, azurite, and brochantite—are widespread in some areas filling fractures, coating weathered surfaces, and disseminated through less metamorphosed porous rocks. None of the occurrences appears significant in terms of ore, and because most appear to be relatively recent redistribution in the zone of weathering, they too will not be considered further in this paper. For simplicity in discussion, I will treat the copper sulfide occurrences in green beds separately from those in the Revett quartzite.

Copper sulfide content in green beds ranges from background amounts of copper (about 15 ppm) to one known occurrence of ore grade (about 1 percent). Rocks containing several hundred ppm Cu tend to have a single copper sulfide, most commonly chalcopyrite in carbonates or carbonate-bearing rocks, and chalcocite or bornite in clastic rocks. Chalcopyrite tends to be in grains somewhat larger than the average grain size of the host rocks, and at places as pseudomorphs after pyrite. A typical occurrence of chalcopyrite in the Empire Formation is shown in plate 1, B. Chalcocite and bornite tend to be finely disseminated, or in thin films, or in tiny clots. A typical occurrence of chalcocite in a green argillite bed of the Spokane Formation is shown in plate 1, A. Note that although the chalcocite tends to be concentrated along bedding, the upper zone of concentration in detail cuts

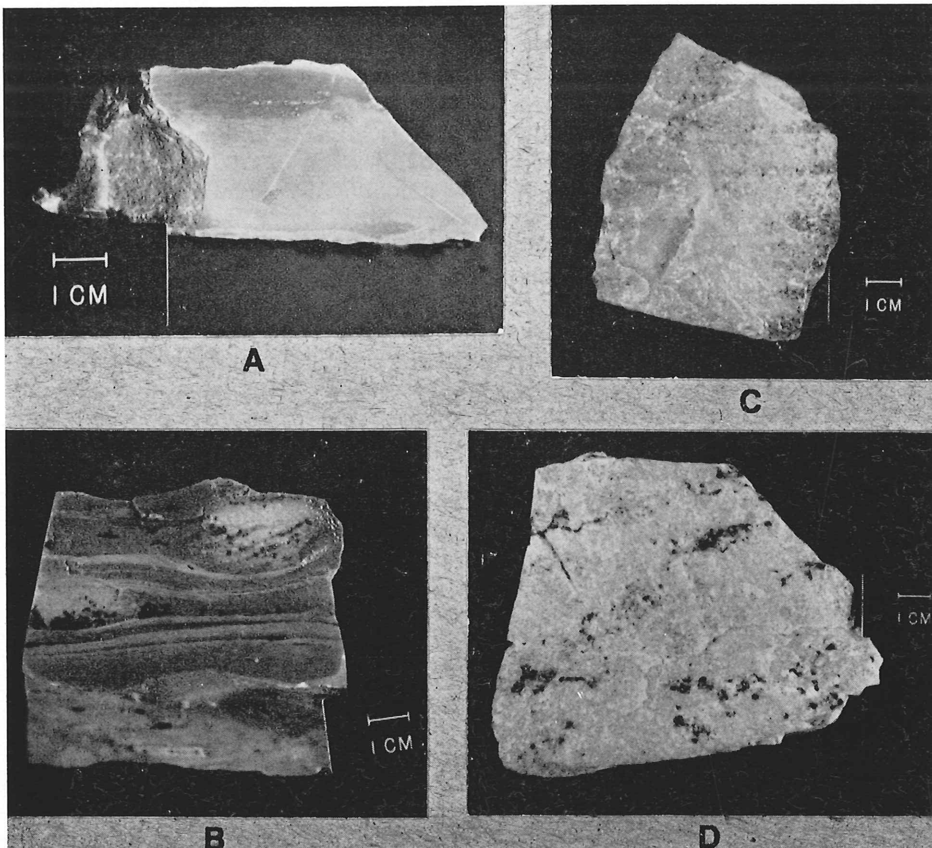

PLATE 1. — *Typical concentrations of copper sulfides in Belt rocks. — A. Green argillite of the Spokane Formation. Darker zones near top and bottom of specimen contain chalcocite; light spots in upper zone are highly concentrated clots of the mineral. — B. Laminated green argillite (light gray) and green silty argillite (dark gray) containing limestone pods (white) of the Empire Formation. Large chalcopyrite grains and clots have replaced host rock along bedding planes and within limestone pods. — C. White fine-grained quartzite of the Revett Formation. Bornite-chalcocite-chalcopyrite has replaced host rock along beds. Left side of specimen is typical of some weathered rinds from which all traces of anomalous copper have been removed. — D. White medium-grained quartzite of the Revett Formation. Bedding dips gently from right to left. Bornite-chalcocite-chalcopyrite disseminations and clots have replaced host rock primarily along bedding. Photographs by R. B. Taylor, U.S. Geological Survey.*

across bedding. Rocks containing several thousand ppm Cu tend to have two or more copper sulfides that form clots, irregular patches, and even thin layers.

Distribution of copper within the green beds varies both laterally and vertically. Some of the characteristics of the distribution are summarized on figure 5 which illustrates the relation of lithology to copper and silver analyses from 30 cm (1 ft) chip samples taken across 4 roadcut exposures of copper-bearing green beds. The diagrams show the following important points regarding the green-bed coppers: (1) the zones of anomalous copper can be at the top or bottom, or within a green bed; (2) the copper zones tend to pinch out along or cut across bedding; and (3) copper content of beds adjacent to the enriched zones tends to be less than the normal background of about 15 ppm. These observations strongly suggest that the copper sulfides as seen today have been mobilized and redistributed, at least on a local scale. Furthermore, they may have been redistributed at least twice, because a simple diagenetic oxidation and leaching of copper from the red beds into the green beds would have concentrated copper at the red-green (oxidation-reduction) interface. Association of copper sulfides with the coarser parts of the rocks suggests that the redistributions were related to permeability and were, therefore, accomplished post-deposition but prior to or during Precambrian regional metamorphism which reduced or destroyed permeability. Distinctions among syngenetic, diagenetic, paleohydrologic, and metamorphic distributions are not yet decipherable, but are under study because of their import in guiding exploration in areas where other concentrations of ore-grade copper may have been deposited in favorable geologic environments.

Zoning of the sulfides in green beds is suggested even though the supporting data are limited. In the general area of the Flathead and Cœur d'Alene troughs (fig. 4) a vertical change has been documented in one formation. Basal parts of the Empire Formation contain localized polymineralic assemblages of copper sulfides. A zone about 100 m above the base contains chalcopyrite and pyrite at some

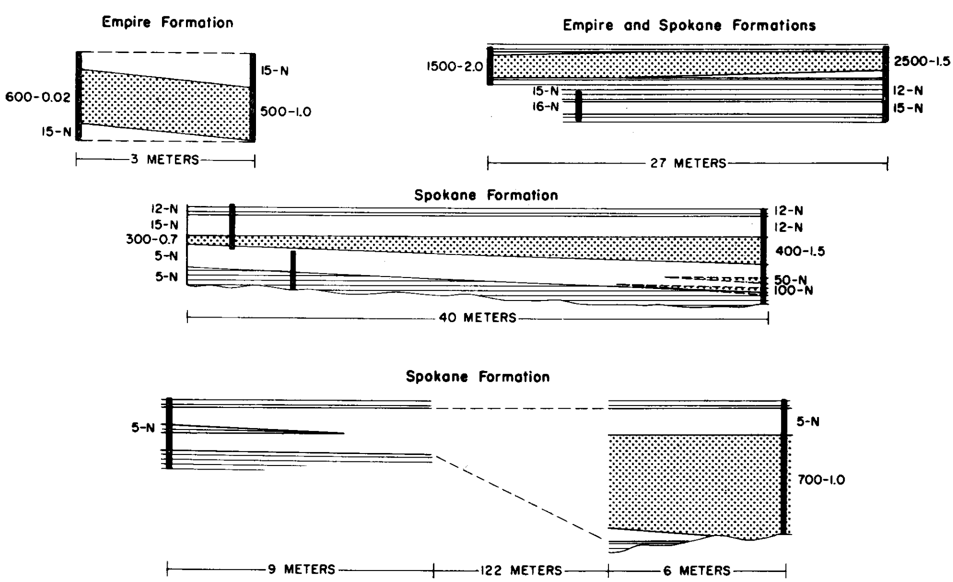

FIG. 5. — *Zones of anomalous copper in green beds of the Empire and Spokane Formations. Vertical bars indicate where chip samples were taken along 30 cm (1 ft) intervals. Purple beds shown by horizontal line pattern; green beds are unpatterned; zones of anomalous copper are stippled. First number is average* Cu *content in ppm; second number is average* Ag *content in ppm; N indicates none detected at spectrographic sensitivity limit for* Ag *(0.05 ppm).*

places; other sulfide-bearing zones higher in the formation contain only pyrite. The sulfide concentrations within these zones appear to be discontinuous both laterally and vertically, but no continuous exposure shows all three zones. Lateral variation (zoning?) appears also in green beds of the Ravalli and Missoula Groups wherein copper-bearing rocks in the western and middle parts of the basin (fig. 4) tend to contain mostly chalcopyrite and chalcocite whereas those in the east contain largely chalcocite and bornite. Rocks in the east also contain more malachite than those to the west and may represent another example of lateral zoning of syngenetic or diagenetic copper minerals. The fact that the eastern rocks are less metamorphosed and thus subject to more intense weathering and more pervasive groundwater circulation could explain the relative increase of copper carbonate and perhaps the increase of secondary sulfides. On the other hand, as pointed out to me by Felix Mendelsohn (oral commun., 1973), facies changes in Belt rocks are so subtle and spread out that any zoning of syngenetic copper sulfides may also be subtle and spread out. Data adequate to test either hypothesis are not yet available.

Copper ores are known to date only in the Revett Formation and only in the western Montana copper-sulfide belt (Clark, 1971), an area of about 3 000 km^2 in the western part of the Belt basin (figs. 4 and 6). The Revett Formation represents a deltaic environment, and the delta was built northward into the basin from Belt island. The south and central parts of the sedimentary prism contain about 50 percent medium-grained, blocky, purple-striped, purplish-gray, or white crossbedded slightly calcareous, feldspathic quartzite, interlayered with about equal amounts of pale-purple or green siltite and argillite. The outer edges of the sedimentary prism contain about equal amounts of purple or purple-striped very fine grained slightly calcareous, feldspathic quartzite and siltite, and purple or green argillite. Anomalous copper and ore occur only in white or green rocks in the western Montana copper-sulfide belt.

Revett ores of the Spar Lake deposit (west-central part of the copper-sulfide belt, fig. 6) were described from surface and drill-core data by Clark (1971), and more recently in a paper presented by Norman Lutz (Pacific Northwest Metals and Minerals Conference, April, 1973) based on data obtained from tunneling exploration. Typical ores are shown in Plate 1, C and D. The ore is polymineralic sulfides, crudely zoned vertically, and in a sheetlike deposit about 2 500 m long by 540 m wide by 15 m thick. The deposit is estimated to contain 58 million tons of ore averaging 0.8 percent Cu and containing about 1.7 ounces of Ag per ton. The ore minerals tend to be along bedding or crossbedding planes and at places are in clots as large as walnuts. Some ore is in "rod shaped structures" perpendicular to bedding (perhaps along water release structures formed during diagenesis). Where the ore terminates against a fault, the mineralization is intensified suggesting a post-ore remobilization and reprecipitation of copper adjacent to the fault. The ore has replaced groundmass and clasts of white carbonate-bearing feldspathic quartzites and siltites whose grains are highly sutured and interlocked. Purple-gray and purple-striped clastic rocks that are above and below the ore-bearing zone at the Spar Lake deposit and that bound ore zones in other parts of the copper belt are remarkably similar in mineralogy and texture to the white clastic rocks of the ore zones, except for the hematite dust that colors the purple rocks. More significantly, the purple rocks contain no anomalous copper.

The geometry of the copper-sulfide belt relative to the Revett sedimentary prism and the post-Revett dome (fig. 6) led to the suggestion (Harrison, 1972) that

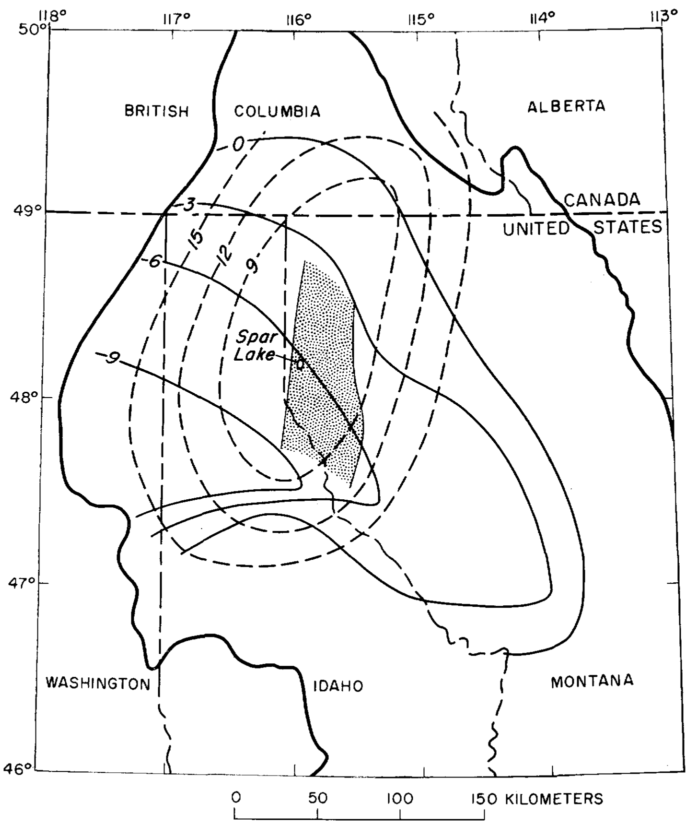

FIG. 6. — *Western Montana copper-sulfide belt (stippled) as related to the Revett sedimentary prism (outlined by solid-line isopachs in hundreds of meters) and the post-Revett dome (outlined by dashed-line isopachs in hundreds of meters for the lower part of the Missoula Group). Figure modified from Harrison (1972, fig. 14).*

the Revett ores were deposited in a structural-stratigraphic trap formed by Precambrian doming of what were then highly permeable quartzites in the Revett Formation. Such an hypothesis would require considerable remobilization of copper by paleohydrologic or metamorphic processes. We are attempting to test the feasibility of that hypothesis, but as yet we have insufficient data to either confirm or deny it. Possible sources for remobilized copper may have been in the Revett sediments or in the rather abundant anomalous copper in green beds of the Burke and St. Regis Formations where they lie downdip from the dome in the Belt basin (fig. 4).

CONCLUSIONS

Strata-bound copper sulfides in the Belt Supergroup are primarily in red-bed sequences and may, therefore, be similar in genesis to the Katangan deposits in

Africa and the Adelaidean deposits in Australia. Evidence for remobilization of copper sulfides in Belt rocks is convincing for many occurrences, and the remobilization must have been prior to or during late Precambrian regional metamorphism. Criteria to determine whether remobilization was diagenetic, paleohydrologic, metamorphic, or some of each have not yet been found. The probability is high that any original syngenetic distributions have been modified slightly to severely. As a consequence much more geologic data on Belt rock sedimentology, Belt basin paleotectonic and paleohydrologic processes, and regional metamorphism are essential to further exploration for ore.

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