MAR 19740008: SOUTHWESTERN ALBERTA

Received date: Dec 31, 1974

Public release date: Jan 01, 1976

SULPHIDE DEPOSITS ASSOCIATED WITH PRECAMBRIAN

BELT-PURCELL STRATA

IN

ALBERTA AND BRITISH COLUMBIA

CANADA

ROGER MORTON, B.Sc., Ph.D.
P. Geol.

ERIK O. GOBLE, B.Sc.,
P. Eng.

RONALD J. GOBLE, B.Sc.,
P. Geol.

KINTLA EXPLORATIONS LIMITED

ROGER MORTON Dept. of Geology, University of Alberta,
ERIK GOBLE Edmonton, Alberta, Canada

RONALD J. GOBLE Kintla Explorations Limited, Edmonton, Alberta, Canada

Sulfide Deposits Associated with Precambrian Belt - Purcell Strata in Alberta and British Columbia, Canada

Abstract: Recent exploration in the Lewis Range of southwest Alberta and southeast British Columbia has revealed stratabound Cu $\pm$ Pb, Ag mineralization within apparently unmetamorphosed arenites (and rarely argillites and limestones) of the Appekunny, Grinnell, Siyeh, Lower Sheppard, Gateway and Lower Roosville Formations of the Belt - Purcell Supergroup. 'Cu poor' horizons are characterized by finely disseminated, interstitial assemblages of chalcopyrite ($\pm$ pyrrhotite, sphalerite, hematite) whereas 'Cu rich' horizons carry bornite + blaubleibender covellite ($\sim Cu_{1.12}S$ and $Cu_{1.32}S$) $\pm$ anilite ($\sim Cu_{1.76}S$), digenite ($\sim Cu_{1.80}S$), djurleyite ($\sim Cu_{1.95}S$), idaite, wittichenite, tennantite and magnetite. Grades of 0.3 to 2.0% Cu are common in surface samples of the mineralized sediments and local secondary enrichment has resulted in grades of up to 6.4% Cu. A number of 'modified stratabound' occurrences of Cu $\pm$ Ag mineralization, due to localized hydrothermal effects adjacent to and within faults and Precambrian diorite sills cutting Upper Grinnell sediments have been recorded. One such sill contains extensive chalcocite-bornite mineralization grading 1.83 to 3.45% Cu and up to 0.86 oz/ton Ag. Stratabound Zn - Pb, Ag mineralization has been observed in argillaceous dolomites of the Siyeh and Lower Sheppard Formations. Grades of 2.25 to 7.5% Zn and 0.75 to 2.5% Pb have been recorded in dolomites carrying sphalerite - galena $\pm$ hydrozincite. The origin of the metal-bearing parental solutions in the Canadian sector of the Belt basin are, together with the post-depositional behavior of the metalliferous deposits, discussed in the light of the regional tectonic setting.

CONTENTS

INTRODUCTION

This preliminary report constitutes a description of the general geologic settings of certain metalliferous showings within the Lewis and Clark Ranges of the Rocky Mountains in SW Alberta and SE British Columbia; for location see Fig. 1. All of the occurrences described below are situated in rocks of the Belt Supergroup within the Lewis Thrust Plate. The general stratigraphic succession of the SW Canadian Belt Supergroup (after Price, 1962) is presented in Table 1 and a correlative diagram for comparison with equivalent horizons in the United States (after Harrison, 1972) in Fig. 2. An age of approximately 1300 m.y. is assumed for the deposition of the Appekunny and Grinnell Formations on the basis of Obradovich and Peterman's (1967) ages of 1313 $\pm$ 15 m.y. for the lateral equivalents of these horizons in Montana. The upper part of the sequence (the Roosville Formation) probably has an age slightly in excess of 1000 m.y. (Harrison, 1972).

The Lewis Thrust Plate is bounded by Mesozoic to early Tertiary thrust faults of the Lewis system on its eastern side and on its western flank it is truncated by the early Tertiary, lystric, Flathead Fault (Balley, 1966). The Precambrian strata and lavas within the thrust sheet are folded into a broad synclinorium (the Akamina Syncline) whose axial trace trends NW-SE (Fig. 3). Recent observations (N. Badham, 1972 pers. comm.) have revealed that the strata of the Grinnell Formation in the region of Commerce Peak on the SW side of the Thrust Plate are affected by two distinct phases of folding, namely an older phase with tight, eastward plunging fold (Columbian?) and a younger phase characterized by a superimposed set of open, N-S trending (Laramide?) folds which parallel the traces of the major thrust faults and the Akamina synclinorium's axial trace.

Within the region, especially in the SE, around Yarrow and Spionkop Creeks, a series of amygdaloidal, porphyritic quartz diorite sills and dykes cut the Ravalli Group rocks. These instrusions are always strongly altered and primary assemblages of plagioclase ($\sim An_{50}$) + quartz + augite + biotite are extensively replaced by chlorite + sericite + epidote + carbonates. The quartz diorite suite may be comagmatic with the Purcell Lavas dated at ~1100 m.y. by Hunt (1958, 1961). Elsewhere, especially in the SW of the Lewis Thrust Plate, numerous, coarse leucodiorite sills of unknown age cut the argillaceous rocks of the Siyeh Formation. These sills carry abundant pyrite and pyrrhotite with minor chalcopyrite and up to 118 ppm Au.

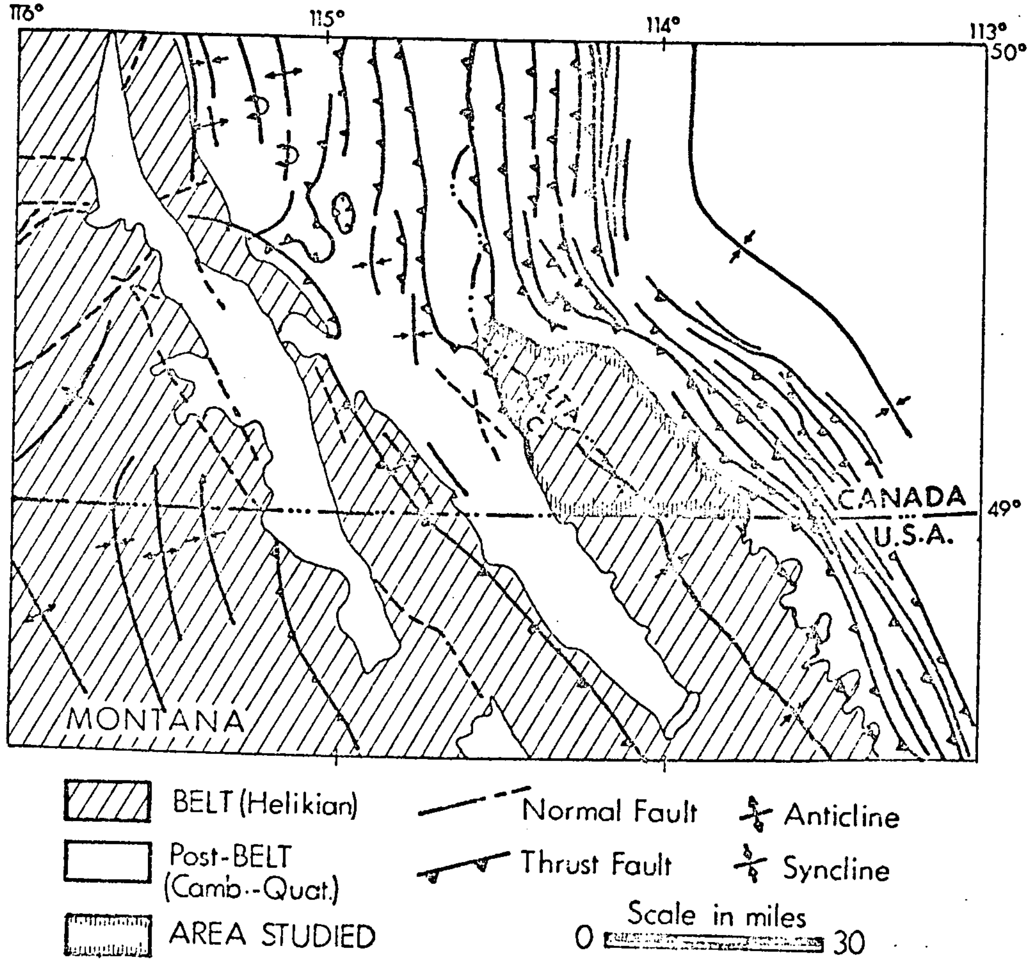

Fig. 1. Tectono-stratigraphic setting of the area discussed in this paper; (after Monger and Preto, 1972)

19740008

METALLIFEROUS DEPOSITS

General Observations

It has long been known (Dawson, 1886) that the Purcell Lava and the Precambrian dioritic sills of the region are commonly characterized by Cu mineralization. During the first decade of the 20th century, small scale mining was actually performed on cupriferous diorite dykes in the Blakiston Brook area of Waterton Lakes National Park. At this time the first staking of the cupriferous arenites of the Ravalli Group took place in the Yarrow Creek district in the SE part of the Lewis Thrust Plate. But, owing to the very low outcrop grades, little further interest was shown in the area until Kennco Explorations (Western) Ltd. carried out an exploration program on the Grinnell Formation strata in 1966. Further exploration and drilling has since been performed by Akamina Minerals Ltd. (now Alcor Minerals Ltd.), Cominco Ltd. and by Kintla Explorations Ltd. during the period 1968-1972. The principal base metal occurrences discovered during these exploration programs are indicated in Fig. 3. It must be noted, however, that the observation of Harrison (1972) that the majority of the Belt lithologies are commonly characterized by anomalous Cu values, is equally true in SW Canada and consequently only those occurrences possessing base-metal mineralization of sufficiently high grade to be noticeable in out-crop are considered herein.

Four distinct associations have been recognized in the rocks of the Lewis Thrust Plate, namely:
(1) Cu $\pm$ Ag in sandstones and argillites.
(2) Zn/Pb $\pm$ Cu(Ag) in carbonates and argillites.
(3) Cu $\pm$ Ag in and adjacent to Precambrian diorites and adjacent to normal faults.
(4) Zn/Pb $\pm$ Cu(Ag) within and adjacent to Precambrian diorites.

Recent investigations have revealed that:
(1) The majority of base metal occurrences are located within the SE half of the Lewis Thrust Plate, with fewer in the NW sector.
(2) The major Cu-bearing horizons are within non-hematitic arenites and argillites of two red-bed sequences, namely, the Grinnell and Appekunny Formations (Ravalli Group) and also in the lavas, arenites and dolomitic strata of the Missoula Group, (with the notable exception of the Phillips Formation). A few minor examples of Cu mineralization have been noted in the strata of the Siyeh Formation (Middle Belt Carbonate). Enrichment of the Cu mineralization has been obviously effected by the younger dioritic intrusions

19740008.

LOCATION	West Montana	Southwest Alberta & Southeast B.C.	North Montana
MISSOULA GROUP	McNamara Fm.	Roosville Fm.	Garnet Range Fm.
	Bonner Qtzite	Phillips Fm.	Bonner Qtzite
	Miller Peak Fm.	Gateway Fm.	Mt.Shields Fm
		Sheppard Fm.	Sheppard Fm.
		Purcell Lava	Purcell Lava
		SS	Snowslip Fm
MIDDLE BELT Carbonate	Wallace Fm.	Siyeh Fm.	Helena Dolomites
RAVALLI GROUP	St. Regis Fm. / Spokane Fm.	Werner Peak Fm.	Empire Fm.
	Revett Fm.	Grinnell Fm.	Spokane Fm.
	Burke Fm.	Appekunny Fm.	Appekunny Fm.
LOWER BELT	Prichard Fm.	Altyn Fm.	Altyn Fm.
		Waterton & Fort Steele Fm.	Waterton Fm.
	Base – not – exposed		
PRE-BELT Crystalline Rocks		Aphebian (?)	

Fig. 2. Correlation chart for Belt Supergroup rocks of SW. Canada and NW. United States; (after Harrison, 1972)

ERA	PERIOD OR EPOCH	GROUP FORMATION		LITHOLOGY	THICKNESS (feet)
		EROSIONAL UNCONFORMITY			
PRECAMBRIAN	PURCELL		MOYIE INTRUSIONS	Diorite sills and dykes	
	PURCELL (LEWIS)	GATEWAY KINTLA	ROOSVILLE FORMATION	Green argillite, siltstone, sandstone, stromatolitic dolomite	3500±
			PHILLIPS FORMATION	Red sandstone, siltstone, argillite	500- 700
			GATEWAY FORMATION (upper member)	Argillite, argillaceous siltstone, dolomite dolomitic sandstone, and argillite	1150-3000
			SHEPPARD FORMATION	Quartzitic & dolomitic sandstone, dolomite, oolitic dolomite, argillite, siltstone, pillowed andesite	150- 900
		EROSIONAL UNCONFORMITY IN PART			
			PURCELL LAVA	Chloritized andesite, & amygdaloidal andesite, pillowed andesite	00- 600
			SIYEH FORMATION	Limestone, dolomite, argillite & sandy limestone & dolomite, argillite, stromatolitic limestone	1130-3000
			GRINNELL FORMATION	Red argillite, sandstone & siltstone; white, green & red quartzite	350-1700
			APPEKUNNY FORMATION	Green argillite; white, grey & green quartzite; sandy argillaceous dolomite & dolomitic argillite; siltstone	1500-2000
			ALTYN FORMATION	Argillaceous limestone & dolomite; sandy dolomite, argillite, & stromatolitic dolomite	500-4000
			WATERTON FORMATION	Limestone & dolomite, argillite, & argillaceous dolomite	1500+

Table 1. Stratigraphic succession of SW Canadian Precambrian (after Price, 1962)

19740008.

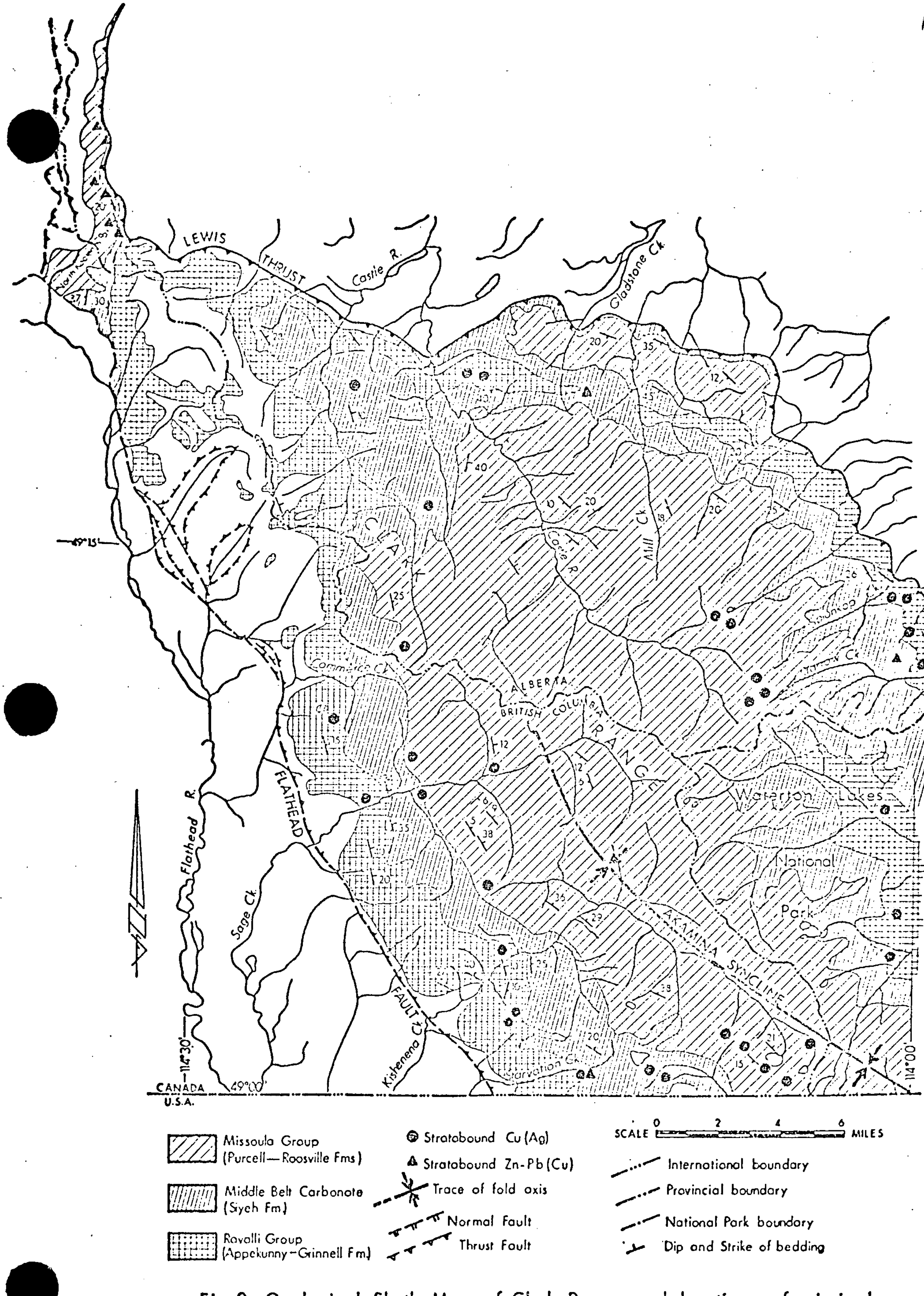

Fig. 3. Geological Sketh Map of Clark Range and locations of principal stratabound Cu (Ag) and Zn/Pb (Cu) occurences discussed.

and by local hydrothermal activity associated with some normal faults.

(3) Zn/Pb $\pm$ Cu mineralization is characteristically limited to the colomitic strata of the Lower Siyeh Formation (Lower, Middle Belt Carbonate) and to the Lower Sheppard Formation (Lower Missoula Group) on the NW strike outcrops of the Lewis Thrust complex. Zn/Pb $\pm$ Cu mineralization appears to be absent from the Belt strata of the SW sector of the Clark Range. Such mineralization is also found in dioritic sills which cut the Lower Siyeh Formation at Blind Canyon, N of Yarrow Creek.

DETAILS OF OCCURRENCES

Copper Deposits in Sedimentary rocks

(a) Yarrow Creek-Spionkop Creek Area

Centered upon Lat. 49°12'N and Long. 114°W in SW Alberta, to the NE of Mount Glendowan, this area has undergone the most intensive study of the whole region. Details of the local geology were given by Stevenson (1968), Goble (1970) and Morton et al. (1973). The principal Cu showings are located in the Upper Grinnell, Lower Grinnell and Upper Appekunny Formations and rarely in the Lower Siyeh Formation; the former horizon being the most mineralized. Considerable enrichment of the mineralization has been noted in the arenites adjacent to certain normal faults in the district. The principal occurrences occur along a 3 mile belt in the upper 200 ft. of the Grinnell Formation section and are found in 3 to 8 ft. thick, white or green coarse arenites and occasionally in green or black argillites. The mineralization often appears to be richer at arenite-argillite contacts. Grades of 0.5 to 2.0% Cu are common; an average of 5 analyses from the Spionkop Creek sector revealed 0.6% Cu and 0.1 oz Ag/ton (3 ppm). The same horizon at Spionkop Creek, when sampled in close proximity to a Precambrian quartz diorite sill, showed a range of 1.08 to 5.71% Cu (average 3 analyses: 2.64% Cu). Similar Upper Grinnell quartzites near Yarrow Creek have an average of 2.52% Cu and 0.59 oz Ag/ton (18 ppm) (average of 20 grab samples).

Similar mineralization has also been detected in arenites of the Upper Appekunny Formation near Yarrow Creek. This horizon has an average of 0.61% Cu and 0.06 oz/ton (2 ppm) Ag with traces of Zn, but has shown grades of up to a maximum of 2.86% Cu when drilled in depth.

Morton et al. (1973) and Goble (1970) have shown that the higher grade Cu occurrences of the Upper Grinnell are characterized by an interstitial and epigenetic assemblage of bornite + blaubleibender covellite ± digenite, djurleyite, idaiite, chalcopyrite, galena, tennantite, wittichenite and magnetite. In contrast, the arenites with low-grade Cu showings have a typical interstitial, epigenetic assemblage of chalcopyrite ± sphalerite, pyrrhotite and hematite.

One occurrence of black shale, bearing small, apparently detrital bornite pebbles has been reported from the Upper Siyeh Formation of this district.

(b) The North Kootenay Pass-North Lost Creek Area

Centered around Lat. 49°25'N and Long. 114°34'W, at the northern extension of the Lewis Thrust Plate in SW Alberta, between the North Kootenay Pass and the Carbondale River, this is an area recently studied by Abraham (1973). In this sector chalcopyrite is common as amygdule fillings in the upper part of the Purcell lava flows. Abraham (op. cit.) showed that in this district the Purcell lavas are enriched in Cu, carrying 154 to 366 ppm Cu (c.f. average basalt: 87 ppm).

Anomalous Cu values (136 to 466 ppm) were also found in finely laminated, dark grey, dolomitic siltstones and siltstone of the Middle Sheppard Formation (Lower Missoula Group); c.f. average sandstone value of 10 to 40 ppm. These sediments carry minor chalcopyrite with pyrite and traces of galena and sphalerite.

(c) The Commerce Creek-Sage Creek Area

This sector lies within SE British Columbia, centered around Lat. 49°8'N and Long. 114°8'W on the western flank of the Lewis Thrust Plate. In this sector the mineralization occurs as interstitial bornite and covellite in 2" to 20 ft. in thick arenites of the Upper and Lower Grinnell Formation and in arenites of the Roosville Formation (Uppermost Missoula Group). The mineralization in the Grinnell Formation appears to be identical in every way with that found to the east in the Yarrow-Spionkop Creek sector. Grades generally vary from 0.2 to 1.6% Cu (average 14 analyses = 1.6% Cu), but recently extensive 1 to 2 ft. thick beds in the Lower Grinnell Formation have been found to carry 2.5 to 5.0% Cu. Only traces of Ag (i.e. $<$ 0.3 ppm) can be detected in these cupriferous horizons.

The mineralized arenites of the basal Roosville

Formation occur near the trough of the Akamina Syncline, N of Sage Creek. The arenites are up to 10 ft. thick and have been found to carry 0.27 to 1.57% Cu and between 0.01 oz/ton (0.3 ppm) and 0.15 oz/ton (5 ppm) Ag (av. 3 = 1.9 ppm Ag) where mineralized.

(d) The Kishenena Creek Area

Situated in SE British Columbia, at the headwaters of Kishenena Creek, centered upon Lat. 49°2'N and Long. 114°13'N, are numerous showings of cupriferous Middle and Upper Grinnell Formation arenites. These are similar to those seen in the Yarrow Creek area, carry interstitial, epigenetic bornite ± chalcopyrite and grade at around 0.3% Cu and 0.47 oz/ton (14 ppm) Ag. It is noteworthy that here too, considerable enrichment of the Cu mineralization has been effected adjacent to normal faults.

(e) The Starvation Creek Area

This area lies within SE British Columbia, just north of the United States-Canada border, centered upon Lat. 49°1'N and Long. 114°13'W at the headwaters of Starvation Creek. There, 4 to 7 ft. thick Upper Grinnell Formation white arenites carry up to 0.41% Cu (av. 3 grab assays).

Within this sector, similar to the Yarrow Creek area, Middle and Upper Siyeh Formation, dolomitic sediments occasionally carry low Cu values (average 0.01 to 0.08% Cu).

(f) The Wall Lake Area

In this area, which is located in the extreme SE corner of British Columbia, adjacent to the Alberta-United States border, centered upon Lat. 49°1'N and Long. 114°5'W, cupriferous horizons occur in the Lower and Middle Sheppard Formation and the Middle Gateway Formation (Lower-Middle Missoula Group).

The occurrences in the Sheppard Formation are of very low grade (~0.07% Cu) whilst those occurring in 5-7 ft. thick calcareous siltstones of the Middle Gateway Formation, grade between 0.32 and 0.54% Cu; the principal Cu mineral being chalcopyrite.

Zn/Pb-(Cu) Deposits in Sedimentary rocks

(a) The Yarrow Creek-Spionkop Creek Area

Lower Siyeh Formation dolomitic sediments, just north of Yarrow Creek have been found to contain up to 4.17% Pb and 0.18 oz/ton (6 ppm) Ag; the principal sulfide being galena. Higher up in the succession, just north of Spionkop Creek, 0.5 ft. thick beds of silty dolomite in the Sheppard Formation carry finely disseminated sphalerite and secondary hydrozincite; grades of ~7% Zn being recorded.

(b) The Mill Creek Area

Centered around Table Mountain and Gladstone Mountain, at the headwaters of Gladstone Creek, on the north flank of the Lewis Thrust Plate, are two occurrences of base metal mineralization within the basal Sheppard Formation. In the northernmost occurrence at Table Mountain, two buff-weathering, blue-grey, silty dolomite beds, adjacent to the lowest algal horizon of the formation, carry Pb-Zn±Cu mineralization. The uppermost dolomite, separated from the lower by 9 ft. of silty dolomite with a 2 ft. thick bed of <u>Colenia algens</u>, is only 2" thick and contains 2 to 5 mm distorted blebs and streaks of galena and chalcopyrite and minor sphalerite. The opaque minerals are very fine-grained, the galena being concentrated at the edges of blebs and streaks, the sphalerite being exsolved from the chalcopyrite. This bed assays at a maximum of 0.25% Cu. The lower silty dolomite horizon contains streaks and blebs of galena, sphalerite and pyrite aligned parallel to the bedding laminations. No chalcopyrite is present in this horizon. Again galena is concentrated at the peripheries of the blebs.

On Gladstone Mountain, the southernmost occurrence, near the source of Gladstone Creek, a 1 to 5 ft. thick bed of buff weathering, blue-grey, silty dolomite occurs 15 ft. above the base of the Sheppard Formation. This horizon contains finely disseminated galena and sphalerite and assays at ~3% combined Pb-Zn.

(c) The North Kootenay Pass-North Lost Creek Area

Within this area a thin, well-laminated, dolomitic horizon, carrying Zn-Pb mineralization extends over a strike length of some 8 miles. This horizon occurs approximately 10 ft. above the base of the Sheppard Formation, near its contact with the Purcell Lava. The rock varies from a blue-grey silty dolomite to a black dolomitic siltstone and contains fine-grained, disseminated sphalerite (0.15 to 0.9% Fe), chalcopyrite,

pyrite and galena. The galena also occurs in secondary fractures at 45° to the bedding planes. Abraham (1973) found 760 ppm Pb and 505 ppm Zn in a poorly mineralized specimen of this horizon. This mineralized horizon apparently correlates well with those observed in the Mill Creek area.

Cu Deposits Associated with Precambrian Dioritic Intrusions

Altered quartz diorite sills cutting strata of the Upper Grinnell Formation near Yarrow Creek and Spionkop Creek carry abundant, interstitial chalcopyrite, bornite, chalcocite, blaubleibender covellite, digenite, pyrite and arsenopyrite $\pm$ galena and sphalerite. One such intrusion near Spionkop Creek carries 0.02 to 5.28% Cu and up to a maximum of 8.72 oz/ton (267 ppm) Ag and 0.2% Zn. (An average of 32 grab analyses showed 1.1% Cu and 0.38 oz/ton $\equiv$ 12 ppm Ag). A similar 6 to 8 ft. thick sill, near Yarrow Creek, containing chalcopyrite, bornite, chalcocite and covellite, carries up to a maximum of 1.25% Cu and up to 2.22 oz/ton (68 ppm) Ag; (the average of 12 grab analyses being 0.23% Cu and 0.63 oz/ton $\equiv$ 19 ppm Ag).

Similar occurrences to these have been noted in dioritic sills of the Kishenena Creek region in SE British Columbia.

Zn/Pb-Cu Deposits Associated with Precambrian Diorite Intrusions

(a) The Yarrow Creek-Spionkop Creek Area

A number of quartz diorite sills and dykes cutting dolomitic strata of the Siyeh Formation in the Spionkop Creek-Blind Canyon sector carry disseminated Zn-Pb-Cu mineralization in the form of sphalerite, galena, bornite, chalcocite and covellite. These intrusions carry up to 6.26% Zn (average 12 analyses = 0.73% Zn), up to 4.3% Pb (average 12 analyses = 0.04% Pb), up to 1.3% Cu (average 12 analyses = 0.44% Cu) and up to a maximum of 0.86 oz/ton (26 ppm) Ag (average 11 analyses = 0.24 oz/ton $\equiv$ 7 ppm Ag).

(b) The Starvation Creek Area

In 1972 a diorite sill cutting strata of the Grinnell Formation in this sector was discovered carrying rich Pb-Cu mineralization. The sill exhibits extreme shattering from its contact to 15 ft. within the intrusion and minor jointing to a depth of 30 ft. and is mineralized by epigenetic veins of galena +

chalcopyrite + tetrahedrite. Grades of 4.5 to 16.2% Pb, 0.57 to 1.33% Cu and 11.7 oz/ton (358 ppm) to 17.8 oz/ton (545 ppm) Ag were recorded over some 5 ft. near the margin of the intrusive.

CORRELATIVE STRATIGRAPHY OF THE MINERALIZED HORIZONS AND COMPARISONS WITH OTHER AREAS

A diagrammatic summary of the principal base-metal occurrences listed herein is presented in Figure 4 and for correlative comparison with those base-metal occurrences described by Harrison (1972), Figures 5 and 6 are presented. It is clear that good correlation exists between the stratabound, epigenetic cupriferous horizons of the Belt Supergroup in Idaho and Montana and those of the Belt Supergroup in SW Canada. Not only can direct stratigraphic correlations be made, inferring an extensive metallogenetic environment, but also correlations of relative 'grades' can be made (i.e. the most cupriferous horizons of the Upper Grinnell Formation and Upper Appekunny Formation in Canada appear to correspond well to the unique productive horizons within the Revelt Formation in the U.S.A.). A further noteworthy feature is the fact that the only horizon totally lacking any base-metal mineralization in the SW Canadian sequence is the Phillips Formation, which is correlated with the Bonner Quartzite of Idaho and Montana. Harrison (1972) observed that the latter horizon was consistently barren of any metalliferous anomalies.

The lithological associations too, are remarkably similar to those described by Clark (1971) and by Harrison (1972) in the NW United States. They also exhibit many features in common with the deposits of the Dzezkhazgan district of the U.S.S.R. described by Bogdanov (1971). In all cases these cited authors have noted the constant association of higher-grade base-metal mineralization with the green, more porous arenites and siltites, especially where they are somewhat calcareous or dolomitic.

The epigenetic redistribution and enrichment of the 'stratabound' Cu concentrations adjacent to the Precambrian diorites and normal faults in the district have been discussed in some detail by Goble (1970) and by Morton et al. (1973). It was concluded, on the basis of fluid inclusion studies, geochemical data and sulfur-isotope data, that the dioritic intrusions had induced a local 'cyclic' hydrothermal concentration of base metals where they had intruded such cupriferous, wet sediment as the Grinnell Formation arenites soon after the deposition of these strata and possibly during

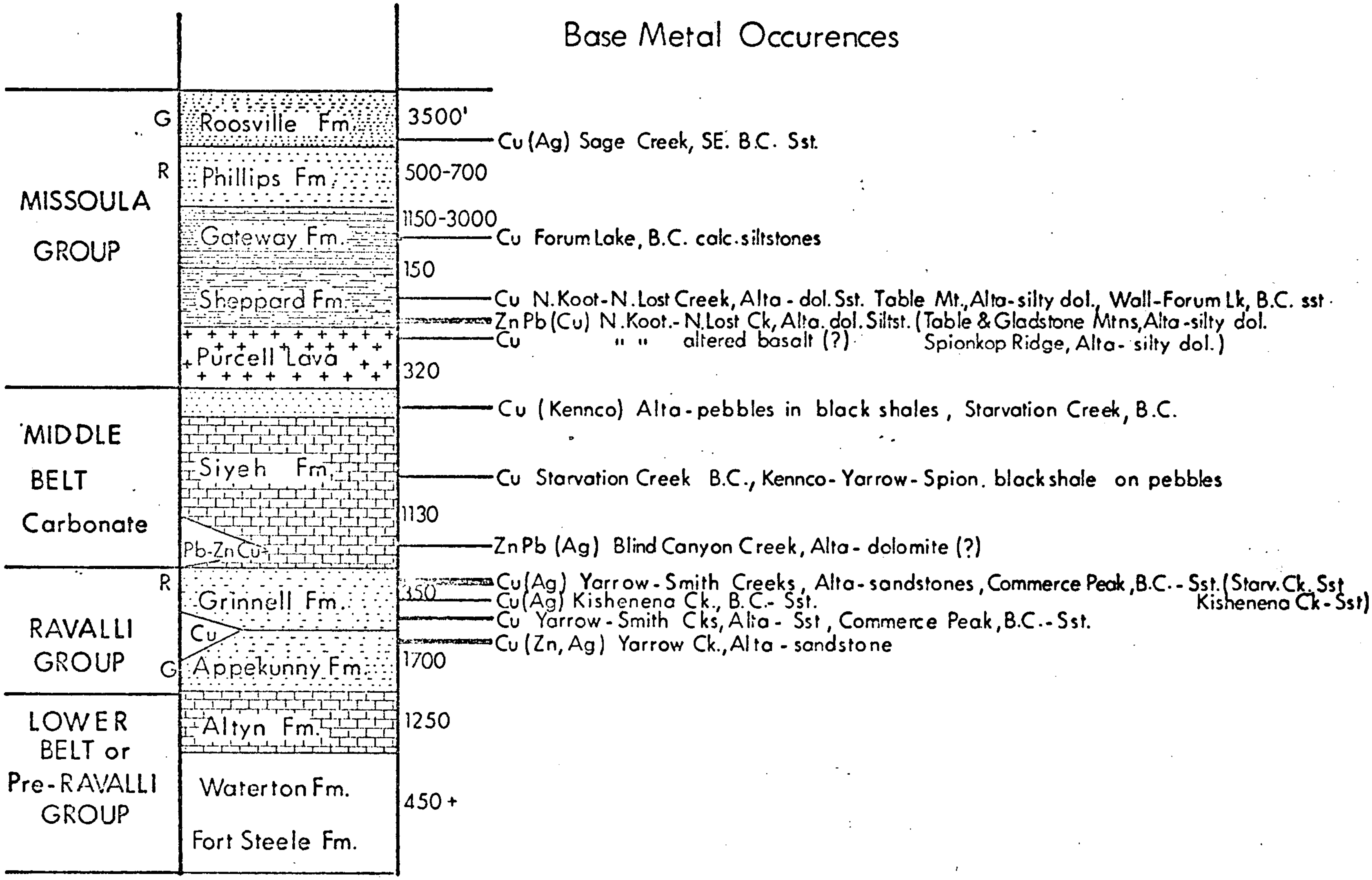

Fig. 4.

1974008

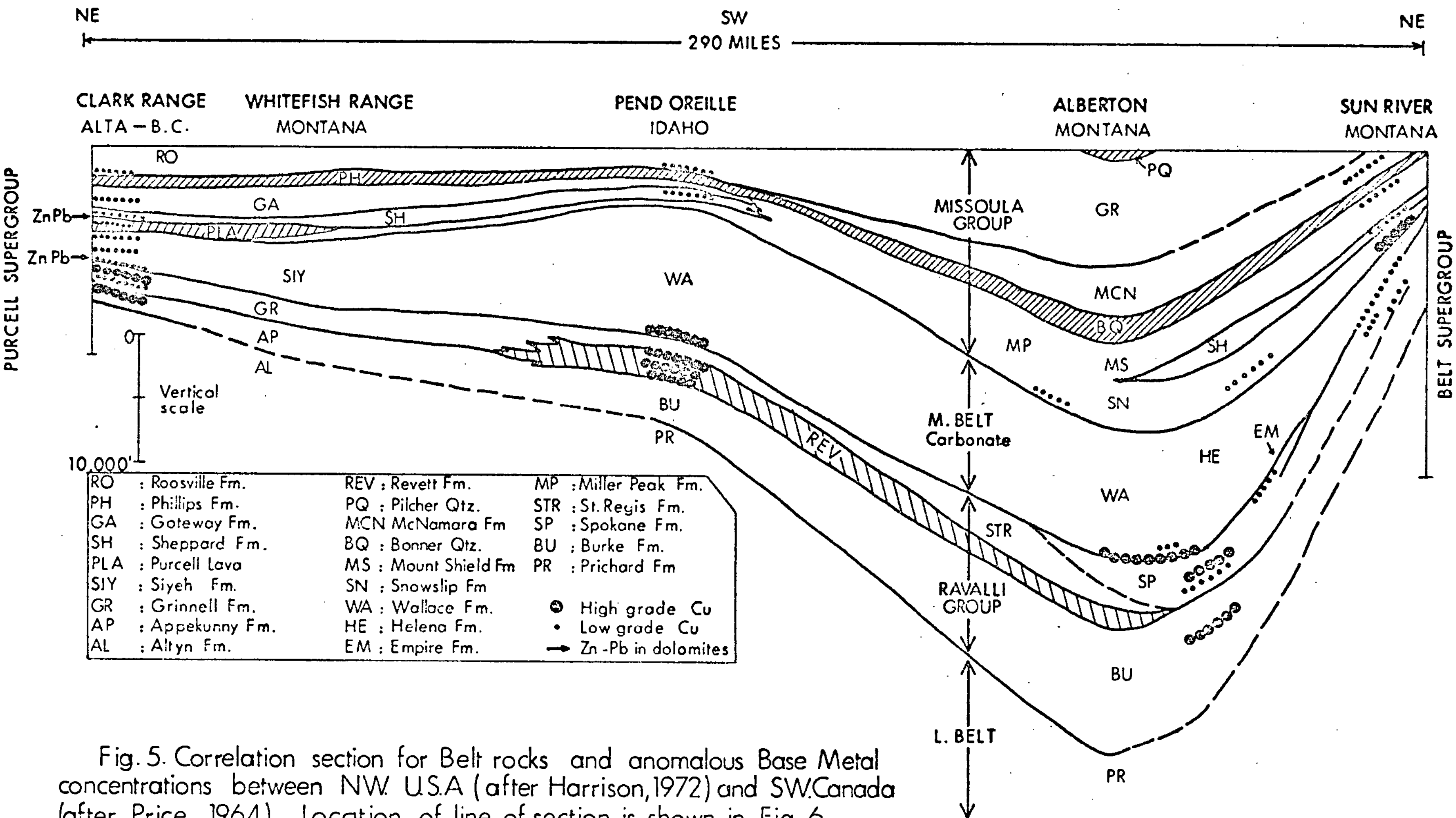

Fig. 5. Correlation section for Belt rocks and anomalous Base Metal concentrations between NW. U.S.A (after Harrison, 1972) and SW. Canada (after Price, 1964). Location of line of section is shown in Fig. 6.

1974008

19740008.

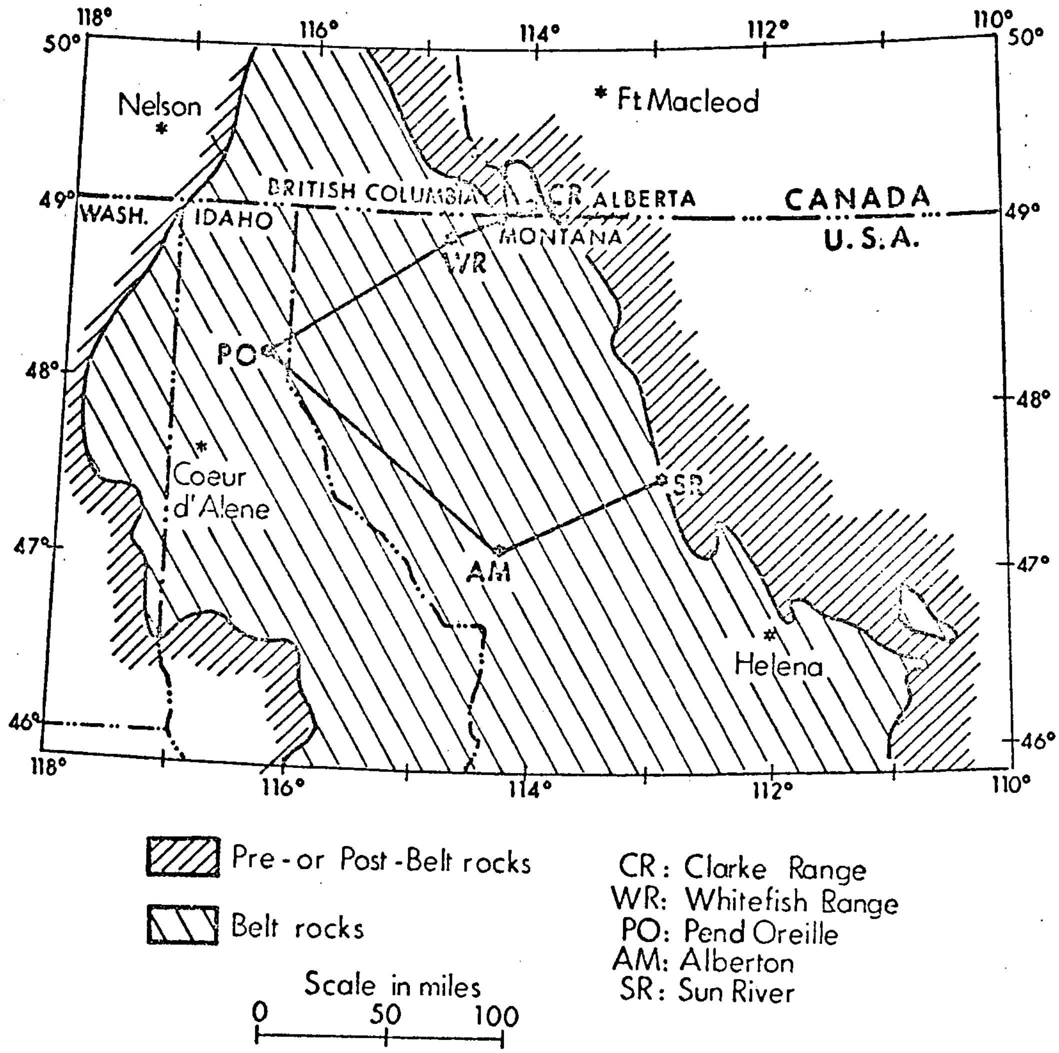

Fig. 6. Approximate distribution of Belt rocks in NW. U.S.A. and Canada with line of section of Fig. 5.

their diagenesis. It is evident from recent work that minor intrusions also have probably effected mobilization of stratabound Zn-Pb-Cu deposits where they intrude the strata of the Grinnell and Siyeh Formations. Such cases would be contact metamorphic analogies of the regional metamorphic mobilization which effected local concentrations of Cu + Pb minerals in the Revelt Quartzites of the NW Montana 'Cu Belt' (Harrison, 1972) and direct analogies with the mobilization effected by dioritic intrusions cutting the cupriferous arenites of Udokkan in the U.S.S.R. (Samama, 1972; Bakun et al. 1966).

METALLOGENESIS IN THE BELT BASIN

Any attempt at a metallogenetic hypothesis for the base-metal deposits of the Belt Supergroup must take into account their widespread and apparently constant stratigraphic controls, together with the distinct chemo-lithologic controls of the Cu versus Zn-Pb deposits described above. The correlation of metalliferous horizons and relative grades over such great distances strongly suggests regional syn-sedimentary controls operative over a large sector of the Belt miogeosyncline at different times during its history.

In view of the almost total absence of evidence for detrital transport of the component sulfides, initial deposition of the metals may have been effected either by direct precipitation from the basinal waters or by some diagenetic process involving either metal-bearing formation waters or metalliferous sediments. Thus, on the one hand it is necessary to seek an origin for metal-bearing fluids and on the other a source of metalliferous detritus. With so little evidence at hand concerning the details of facies variations within the metalliferous horizons relative to basin configuration and tectonics, the question of detrital origin is difficult to resolve at this early date. In contrast to this, the question of metalliferous-fluid sources might be discussed in the light of evidence for the existence of a graben structure of Belt age in SW Alberta and SE British Columbia, presented by Kanasewich (1968). This graben, revealed by seismic reflection studies, was traced some 450 km from SW Alberta and apparently extends towards the site of the Sullivan Mine at Kimberley, British Columbia. In the opinion of Kanasewich (op. cit.) this structure is probably filled with approximately 35,750 ft. of Belt Supergroup sediments and he postulates that the Sullivan deposits might owe their origin to solutions emanating from the mantle through this graben. Morton et al. (1973) have discussed this concept and suggested that this structure, if truly filled by Belt Supergroup sediments, would be of aulacogenic character. Such an aulacogen would be analogous to those described by Hoffman (1972) as representing 'stranded' intracontinental remnants of ancient ridge-ridge-ridge triple junctions, where mantle plumes rise beneath a continental mass. In such a case the Belt miogeosyncline could represent the complimentary 'active arms' of such a triple junction. If this palaeo-tectonic setting did exist in the Alberta-British Columbia sector of the Belt terrain, it would be natural to consider the possibility that exhalative hydrothermal activity played an important role in the supply of metallic ions and sulfur-bearing ionic species to the depositional basin. However, Harrison (pers. comm. 1973), during a study of the tectonics and sedimentation of the Belt region, has encountered no evidence of any influence from this postulated graben in the NW United States and consequently favours a pre-Belt age for the structure. Such findings, whilst precluding the sedimentational influences of this graben, would not directly deny the possibility of prolonged exhalative activity within its bounds.

Finally as Harrison (1972) points out, any future attempts at metallogenetic investigations of base-metal occurrences in the Belt region must be carefully qualified by a realization of the possible range of metasomatic, redistributional processes which have affected the sequence after sedimentation and diagenesis. Not only has small-scale mobilization of the metalliferous fractions taken place adjacent to many intrusions, but there is a distinct probability that the majority of the Belt deposits have experienced at least the physical conditions of the chlorite-sericite zone of the greenschist facies of regional metamorphism (Harrison, 1972). The fluids of such low-grade 'wet' metamorphism are notoriously powerful agents of redistribution, dispersion and local concentration of sulfides. Consequently, the final answers will only begin to emerge after data from sedimentological and stratigraphic studies are augmented by the results of detailed investigations of the petrology and isotopic constitution of the deposits and their host lithologies.

ACKNOWLEDGMENTS

This work was made possible by a grant from the National Research Council of Canada (No. A4242) to R.D.M. Sincere thanks are expressed to Dr. D.G.W. Smith for placing the facilities of the electron microprobe laboratory at the University of Alberta at the authors' disposal during their studies.

REFERENCES CITED

Abraham, A., 1973, Mineralization in the Purcell Supergroup, Southwestern Alberta, Southeastern British Columbia: Unpub. M. Sc. thesis, University of Alberta.

Bakun, N.N., Volodin, R.N. and Krendelev, F.P., 1966, Genesis of Udokansk cupriferous sandstone deposit (Chitinsk Oblast): Intern. Geol. Rev., Washington, v. 8, 4, pp. 455-466.

Bally, A.W., Gordy, P.L. and Stewart, G.A., 1966, Structure, seismic data and orogenic evolution of southern Canadian Rocky Mountains: Bull, Can. Petrol. Geol., 14, pp. 337-381.

Bogdanov, Yu.V. and Golubchina, M.N., 1971, Sulphide sulphur isotope composition is an important criterion of the genesis of stratified copper deposits: Soc. Mining Geol. Soc. Japan, Spec. Issue 3, pp. 304-308.

Clark, A.L., 1971, Stratabound copper sulfides in the Precambrian Belt Supergroup, Northern Idaho and Northwestern Montana: Soc. Mining. Geol. Soc. Japan, Spec. Issue 3, pp. 261-267.

Dawson, G.M., 1886, Preliminary report on the physical and geological features of that portion of the Rocky Mountains between latitudes 49° and 51°30': Geol. Survey of Canada, Ann. Report 1, pt. B.

Goble, R.J., 1970, The Yarrow Creek-Spionkop Creek Copper deposit, Southwestern Alberta: Unpublished M. Sc. thesis, Univ. of Alberta.

Harrison, J. E., 1972, The Precambrian Belt Basin of Northwestern United States - Its geometry, sedimentation and copper occurrences: Geol. Soc. America Bull. 83, pp. 1215-1240.

Hoffman, P., 1972, Aulacogens and the evolution of Continental Margins: Preprint of lecture presented at Gordon Conference.

Hunt, G.H., 1958, Petrology of the Purcell sills in the St. Mary Lake area, B.C.: Unpublished M. Sc. thesis, Univ. of Alberta.

Hunt, G.H., 1961, The Purcell eruptive rocks: Unpublished Ph. D. thesis, Univ. of Alberta.

Kanasewich, E.R., 1968, Precambrian rift; genesis of stratiform ore deposits: Science, 161, pp. 1002-1005.

Morton, R.D., Goble, R.J. and Fritz, P., 1973, The mineralogy, sulfur-isotope composition and origin of some Copper deposits in the Belt Supergroup, Southwest Alberta, Canada: Submitted to Mineralium Deposita.

Obradovich, J.D. and Peterman, Z.E., 1967, Geochronology of the Belt Series, Montana: Proc. conference on Geochronology of Precambrian Stratified rocks, Univ. of Alberta, p. 75 (abstract).

Price, R.A., 1962, Fernie map-area, east half, Alberta and British Columbia: Geol. Survey of Canada, paper 61-24.

Samama, J.C., 1972, Les types classiques des gisements lies aux strates: Kupferschiefer, Red Beds, Haute Silesie. Conferences et seminaires de recyclage. Metallogenie. Ecole Nat. Sup. de Geol. Appliquee et de Prosp. Min. Nancy.

Stevenson, R.W., 1968, Final Report - 1967. Waterton Copper Project. Waterton Area, Alberta, Kennco Explorations (Western) Ltd. Report.