he June Issue . . .

---

tion of The Geological Society of America *Bulletin* is supported in part by the bequest of Richard Alexander
rton Penrose, Jr.

---

ed monthly by The Geological Society of America, Inc., P.O. Box 1719, Boulder, Colorado 80302. Second-
postage paid at Boulder, Colorado, and at additional mailing offices.
iptions: Sold by the volume (January–December). Late orders are filled retroactive to January. Only orders
aid in U.S. dollars accepted. Payments received by March 31 for a current volume earn the subscription rate;
nents received later are accepted only at the volume price (12 times the single-copy rate). For volume 83,
, the subscription rate is $50.00 if paid before March 31; $60.00 after March 31, at the single copy rate of
. Postage: United States, none; Canada and member countries of the Postal Union of American States and
, $1.00; all other countries, $2.00. Society membership, restricted to individuals, includes the privilege of
ving the *Bulletin*. Address sales and subscription inquiries to Fred Uhlman, Business Manager. A Catalog of
ks in Print may be obtained by writing to Fred Handy, Advertising and Promotion Manager.
s changes: North American subscribers should report changes 6 weeks in advance; all others, 3 months in
nce. Claims for non-receipt of copies in North America should be made within 2 months of the date of the
; claims from elsewhere, within 5 months.

JACK E. HARRISON *U.S. Geological Survey, Denver, Colorado 80225*

DAVID BLOOM

Precambrian Belt Basin of Northwestern United States: Its Geometry, Sedimentation, and Copper Occurrences

ABSTRACT

Geometry and provenances of the Belt basin at various stages of its 600-m.y. time span (between about 1,450 to 850 m.y. ago) are decipherable for the middle and upper parts of the Ravalli Group, the Helena-Wallace Formations, and the lower part of the Missoula Group. The Revett and overlying St. Regis Formations (middle and upper parts of the Ravalli Group) had a cratonic source in the south and southwest and were deposited in troughs that reflect the west-northwest trend of the Osburn fault zone (or the Lewis and Clark line whose west-central part includes the Osburn fault zone). The Spokane Formation, correlative of St. Regis, had a source in the Canadian Shield and was deposited in a north- to northwest–trending trough in northwestern Montana, west of, but approximately parallel to, the north-northwest trend of the much younger Montana disturbed belt. The Helena and Wallace Formations were deposited in a broad simple northwest-trending basin between the previous troughs, which received clastic sediments from both the east and southwest; and in which extensive carbonate deposits formed on the eastern shelf. Tectonic adjustment in early Missoula time resulted in a long low dome in the Idaho Panhandle area and in the rejuvenation of the north-northwest–trending trough in the east. Clastic sediments containing abundant hematite were deposited on Helena-Wallace carbonate rocks, and Purcell Lava was poured out in the northeast.

Anomalously high amounts of copper (100 or more ppm) are scattered throughout thousands of square miles of Belt terrane. The copper occurs in almost all formations, but it is most common in green strata. This mode of occurrence suggests a syngenetic or diagenetic origin. Stratabound copper ores, however, are known only as disseminations, discrete blebs, and veinlets in white quartzites and siltites of the Revett Formation in a "copper sulfide belt" along the northwestern Montana border. This belt is perpendicular to the Revett trough but parallel to the dome formed in early Missoula time, suggesting post-Revett epigenetic reconcentration of copper.

Geochronologic data as interpreted by several authors are in apparent conflict with geologic history of the basin as read from the sedimentation record. Many of the conflicts can be resolved by reinterpretation of existing geochronologic and geologic data. It is obvious, however, that the dating of many events, including those that may have caused migration of copper, is in need of refinement.

INTRODUCTION

Continuing accumulation of geologic, geochemical, and geophysical data on Belt rocks has been stimulated by the search for copper deposits. Our knowledge of these rocks has increased at such a rapid rate during the past decade that a summary published only a few years ago by Ross (1963) is now largely out of date. A more recent analysis of stratigraphic data (Smith and Barnes, 1966) has been most useful to workers in the Belt Supergroup, but even that synthesis can now be updated.

This report presents (1) a summary of ideas about the Belt basin in the United States and its geochronology as presented by Zell Peterman and the writer at the Penrose Conference on the Precambrian organized by P. E. Cloud and held in September 1970, and (2) some thoughts concerning the distribution and occurrence of copper in Belt rocks. Much remains to be learned about all phases of geologic history recorded in Belt strata. The summary

---

Geological Society of America Bulletin, v. 83, p. 1215–1240, 15 figs., May 1972

presented here is intended to be only another step of integrating and analyzing available information.

BELT TERRANE

Sedimentary rocks of Belt age (about 850 to 1,450 m.y. old) are exposed locally from northeastern Alaska through Canada to southern Arizona and California (King, 1969a). In Canada, these rocks are called the Purcell Supergroup or System. The most extensive, continuous, and least disturbed exposures, however, are those of the northwestern United States and adjacent parts of Canada (Fig. 1). Even though it is convenient to refer to this area as the "Belt basin," it is apparent that the basin is only an epicratonic re-entrant of a sea that extended along the western edge of the North American Precambrian craton during Belt time (*compare* King, 1969b, Fig. 10).

Limits of the Belt basin are not clearly defined inasmuch as parts of it are covered by younger rocks, and other parts are virtually unknown. Belt rocks rest on Precambrian crystalline rocks east of Helena (Fig. 1) and are bounded by a fault that was active in Belt time (McMannis, 1963) in the area south of Helena. Geologic evidence (Price, 1964; Mudge, 1970) and geophysical interpretations (Kleinkopf and others, 1968) indicated that the eastern edge of the Montana Disturbed Belt, which extends northwest from Helena, is along the approximate eastern edge of the Belt depositional basin. The Belt Supergroup is overlapped by the younger Precambrian Windermere System in the northwest (Fig. 1), and it is buried under Columbia River Basalt in the west. The western and southwestern parts of the basin contain complexly deformed high-grade metamorphic Belt or pre-Belt rocks adjacent to, and as isolated patches within, the major batholiths. Correlation of these rocks with the Belt is largely by chemical similarity rather than stratigraphy.

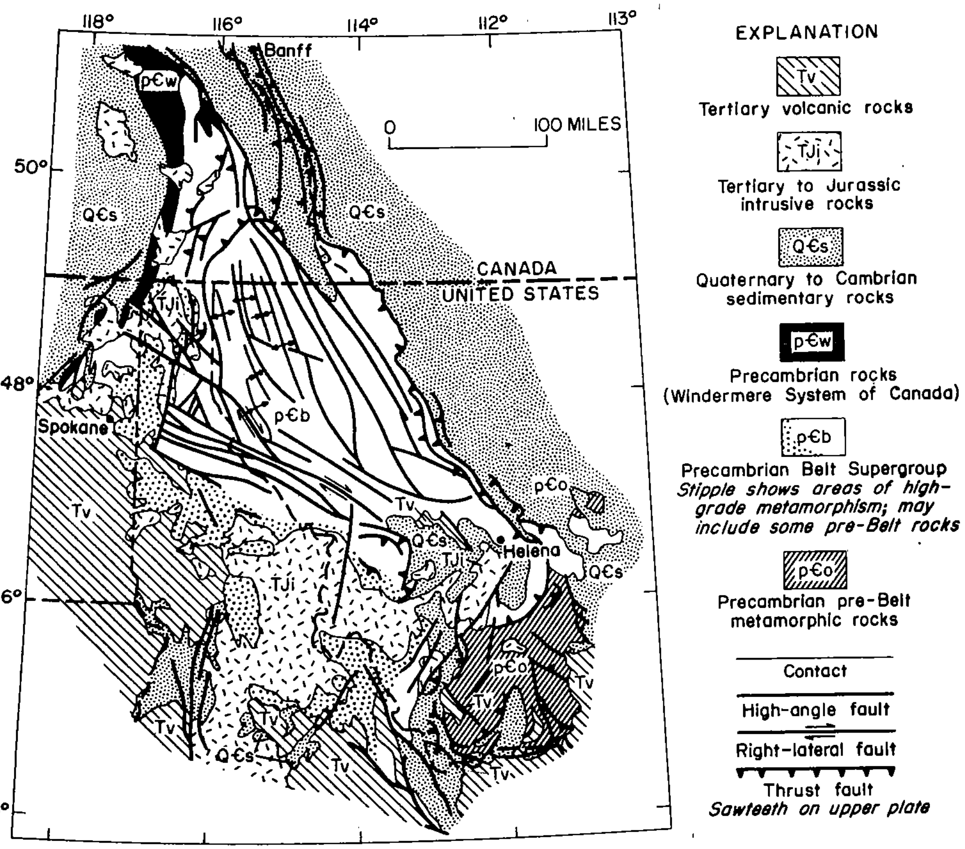


Figure 1. Generalized geologic map of the area of Belt terrane. Modified from Tectonic Map of North America (King, 1969a).

The degree of metamorphism of Belt rocks increases across the basin from northeast to southwest and with depth in the stratigraphic section, as demonstrated by illite transformations to the 2M polymorph (Maxwell and Hower, 1967) and by an obvious increase in biotite content. Most rocks are greenschist facies, although those in the upper part of the section in the eastern part of the basin are almost unmetamorphosed, whereas those in the west and southwest may reach amphibolite facies, particularly near major plutons.

Belt rocks have been described in detail by many workers; only a general description of them as given by Harrison and Grimes (1970, p. 3) will be repeated here:

> Belt rocks are generally monotonous in appearance because of fine grain size and drab color. The bulk of the supergroup has a grain size of silt or clay, and medium sand is the coarsest grain size observed in thousands of feet of rock over large areas. Quartzites and relatively pure to impure dolomites and minor amounts of limestones are scattered through the supergroup, although the carbonate rocks are uncommon in the lower part. Some carbonate rocks contain fossil algal forms, which are the only megascopic evidence of Precambrian life in the rocks. All rocks are dense and hard, reflecting the widespread low-grade metamorphism of most of the supergroup. Because of the metamorphism in most rocks, . . . we use terms such as argillite, siltite, and quartzite rather than claystone, shale, siltstone, and sandstone to describe the rocks. . . . Most rocks contain shallow-water structures, although the abundance of such structures decreases noticeably in the lower parts of the section. Disconformities in the supergroup are difficult to identify, and angular unconformities are rare.

Attention should also be called to data presented in that report (Harrison and Grimes, 1970) showing that Belt rocks from two widely separated areas are all graywacke or similar to graywacke and that the ratio among quartz, potassium feldspar, and plagioclase in siltite is almost identical in rocks from both areas. New information confirms that the two stacks of rocks compared in that report had nonhomogeneous and different source areas, thus indicating a remarkable uniformity in weathering, transportation, and sedimentation processes affecting the two cratonic source areas during Belt time.

Facies changes in the Belt are very noticeable near the edge of the Belt basin in the Montana Disturbed Belt (Price, 1964; M. R. Mudge, 1970, oral commun.) or even spectacular where the one major conglomerate in the supergroup was deposited (McMannis, 1963). But in most of Belt terrane, the changes are subtle and require careful study across tens or even hundreds of kilometers to be defined. Even then, a facies change may involve only an increase in an abundance of argillitic siltite over silty argillite or in an abundance of medium- to coarse-grained siltite over very fine to fine-grained quartzite. The general monotony of the section and cyclical sedimentation, on scales ranging from millimeters to kilometers, reflect the cyclical recurrence of a few depositional environments and the consequent reappearance of remarkably similar rocks in many formations. Most attempts to study basin-wide sedimentation have understandably focused on the more unusual rock types, primarily the carbonate rocks (Smith and Barnes, 1966; McKelvey, 1968).

Belt terrane has been invaded by a variety of igneous rock types during Precambrian and Mesozoic-Cenozoic times. In general, the size and abundance of intrusive rocks of both groups increase from east to west and south. Principal Precambrian intrusive rocks are dioritic to gabbroic sheets known generally in the west as Moyie or Purcell sills, and simply called sills of late Precambrian age in the east. Small granitic plutons are known in southern British Columbia near the western edge of Belt terrane (Rice, 1941; Leech, 1962; Gabrielse and Reesor, 1964; Ryan and Blenkinsop, 1971). The only known Precambrian extrusive rocks are the Purcell Lava (Price, 1964) of southeastern British Columbia and adjacent parts of the United States. The Mesozoic and Cenozoic intrusive rocks range from trachyandesite sills in the eastern part of Belt terrane to granitic plutons in the south and west. Tertiary volcanic rocks cover extensive areas near the batholiths (Fig. 1).

Major geologic and tectonic provinces involving Belt terrane are shown on Figure 2. Although it is not the purpose of this report to discuss at length the tectonic history affecting the basin, a few observations are pertinent. Most tectonic and geologic provinces and features reflect Cretaceous-Tertiary events, but a few are clearly remnants of Precambrian events. Precambrian movement along the

Osburn strike-slip fault zone in the western part of the Lewis and Clark line has been documented by Hobbs and others (1965); Precambrian movement along the Hope strike-slip fault seems reasonably clear (Harrison and others, 1972); and Precambrian movement along the basin-boundary Central Park (Willow Creek) normal fault has been documented by McMannis (1963). The Purcell anticlinorium probably reflects the late Precambrian East Kootenay orogeny of White (1959). Some faults within the Lewis and Clark line, along and branching from the Hope fault zone, and out in the block fault terrane, are also known to be Precambrian, as dated by lead isotopes from galena found along the faults (Zartman and Stacey, 1971). It also seems clear that the northeastern edge of the Montana Disturbed Belt reflects the approximate edge of the old Precambrian craton (Price, 1964; Mudge, 1970).

Superposed on the Precambrian features, and rejuvenating them at some places, are Cretaceous-Tertiary structural features that include three grabens—the Purcell trench, the Libby trough, and the Rocky Mountain trench—and a block fault terrane of basin and range type (Fig. 2). Related to these in time and perhaps genesis are the Montana Disturbed Belt on the east and the Kootenay arc mobile belt on the west. The Cretaceous-Tertiary tectonic events will not be further discussed; because, as important as they appear to be, they have had little effect on the size, shape, and discernible sedimentation patterns of the Belt basin.

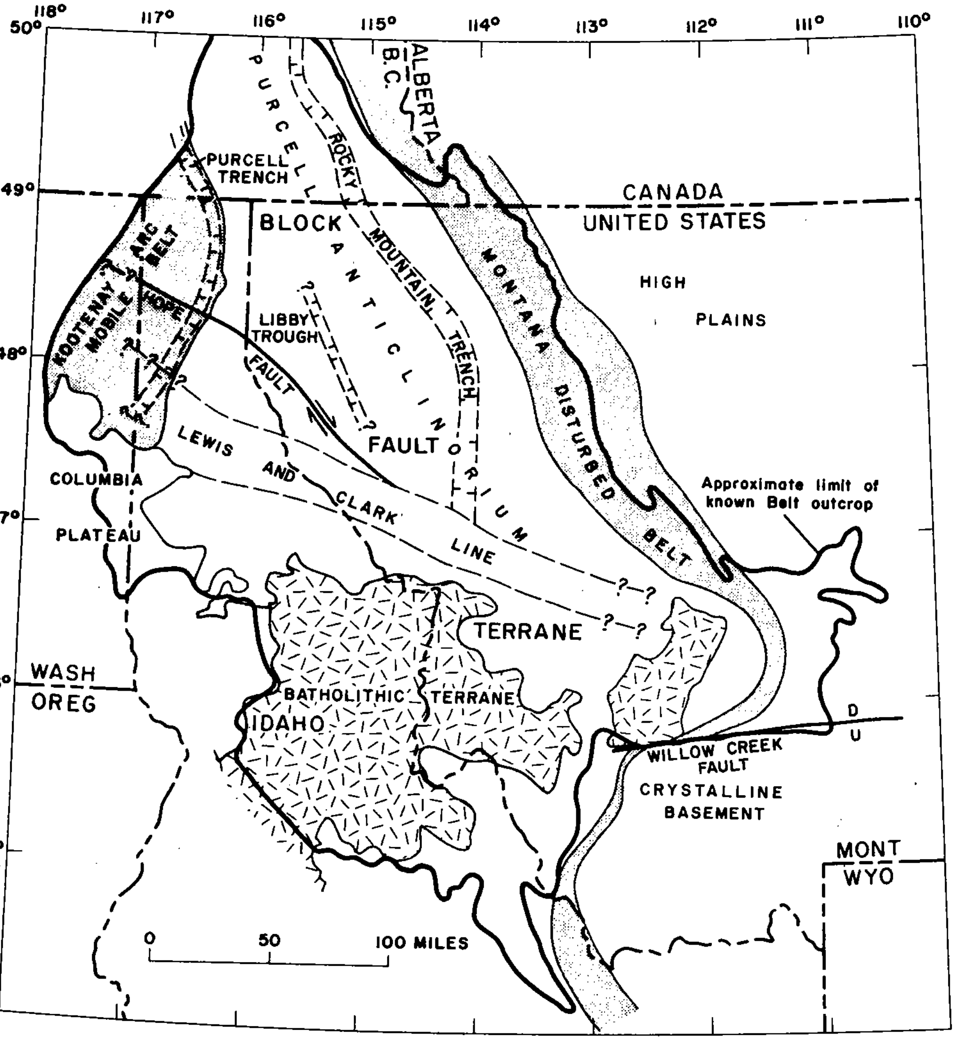


Figure 2. Principal geologic and tectonic provinces eastern Washington, northern Idaho, western Montana, and southern British Columbia. U, upthrown side of fault; D, downthrown side.

Thicknesses of the exposed Belt section in the basin as reported by various authors are shown on Figure 3. The thickest continuous section is near Alberton, Montana, where about 52,000 ft of Belt strata is exposed (J. D. Wells, 1971, oral commun.). An additional 15,000 ft of the lowest unit is exposed a few miles to the west (Wallace and Hosterman, 1956). Thus, the total exposed Belt section in one area, where neither the top nor base of the section is exposed, is 67,000 ft. The fortuitous culmination of the Purcell anticlinorium, which brings up the lower strata, combined with extensive grabens within the culmination, which drop down the higher strata, allows the thick section to be measured in low-dipping to horizontal strata in an area having a diameter of only about 50 mi.

CORRELATION

Progress in knowledge of Belt stratigraphy and a vast increase in geologic map coverage of Belt terrane in the past few years have clarified many previously obscure relations. Johns recently (1970) has summarized the reconnaissance geologic mapping and field studies in Lincoln and Flathead Counties, Montana, which involved about one-fifth of the known Belt basin. Smith and Barnes (1966) have presented a very good summary of basinwide nomenclature and lithologic problems. Harrison and Campbell (1968) voiced a major objection to their correlation. Figure 4 is a composite correlation chart prepared from the sources shown on Figure 3. This chart is similar to that published by Smith and Barnes (1966, Fig. 4), except that the Shepard Formation is here placed in the Missoula Group, the Ravalli Group is subdivided, and more data are presented for the westernmost part of the basin. Informal usages for major lithostratigraphic zones shown on the chart include "lower Belt" for all rocks below the Ravalli Group and "middle Belt carbonate" for rocks between the Ravalli Group and the Missoula Group.

Present nomenclature is shown on Figure 4 and is used on Figures 6, 7, and 8, but it seems appropriate at this time to minimize the confusion of names. The proposed simplifications can be identified by comparing Figures 4 and 5 at appropriate times when reading the following discussion. Three general sets of stratigraphic names were established for Belt rocks of the United States from: (1) the Belt Mountains east of Helena (Walcott, 1899), (2) Glacier Park (Willis, 1902), and (3) the Coeur d'Alene district (Ransome, 1905). As a result of regional studies in recent years, it seems clear that stratigraphic usage should be restricted largely to the names established for the Belt Mountains and the Coeur d'Alene area. Specifically, because of nomenclatural priority, the name Grinnell Argillite is here abandoned in favor of its stratigraphic and lithologic equivalent, the Spokane Formation; and the name Siyeh Limestone is likewise abandoned in favor of Helena Dolomite or Helena Formation. Within the Missoula Group, the name Miller Peak Argillite is changed to Miller Peak Formation and should be limited in use to the general area of Missoula, Montana. The name Kintla, which has been used for one or more units of the lower part of the Missoula Group in Glacier Park and vicinity, is abandoned. The name Marsh Formation is also here abandoned as it consists, according to McGill (1970) and confirmed by G. D. Robinson and M. R. Mudge (1970, oral commun.), of three widespread mappable formations, the Snowslip, Shepard, and Mount Shields. The name Greenhorn Mountain Quartzite is abandoned in favor of Bonner Quartzite. And lastly, the names Spruce, Lupine, Sloway, and Bouchard Formations (Campbell, 1960) are abandoned in favor of their nearby stratigraphic equivalents that bear the older and more widely used names of Miller Peak, Bonner, McNamara, and Garnet Range Formations.

No changes in correlation of the lower part of the Belt are proposed. Those shown on Figure 4 are similar to those suggested by McMannis (1963), Price (1964), Smith and Barnes (1966), and Johns (1970).

Within the Ravalli Group, new information points up some problems and needed changes. In the lower part, the Greyson Shale is separated from the Appekunny and Burke Formations by large areas containing no exposure of (or drill holes into) rocks of the lower part of the Ravalli Group. Thus absolute cor-

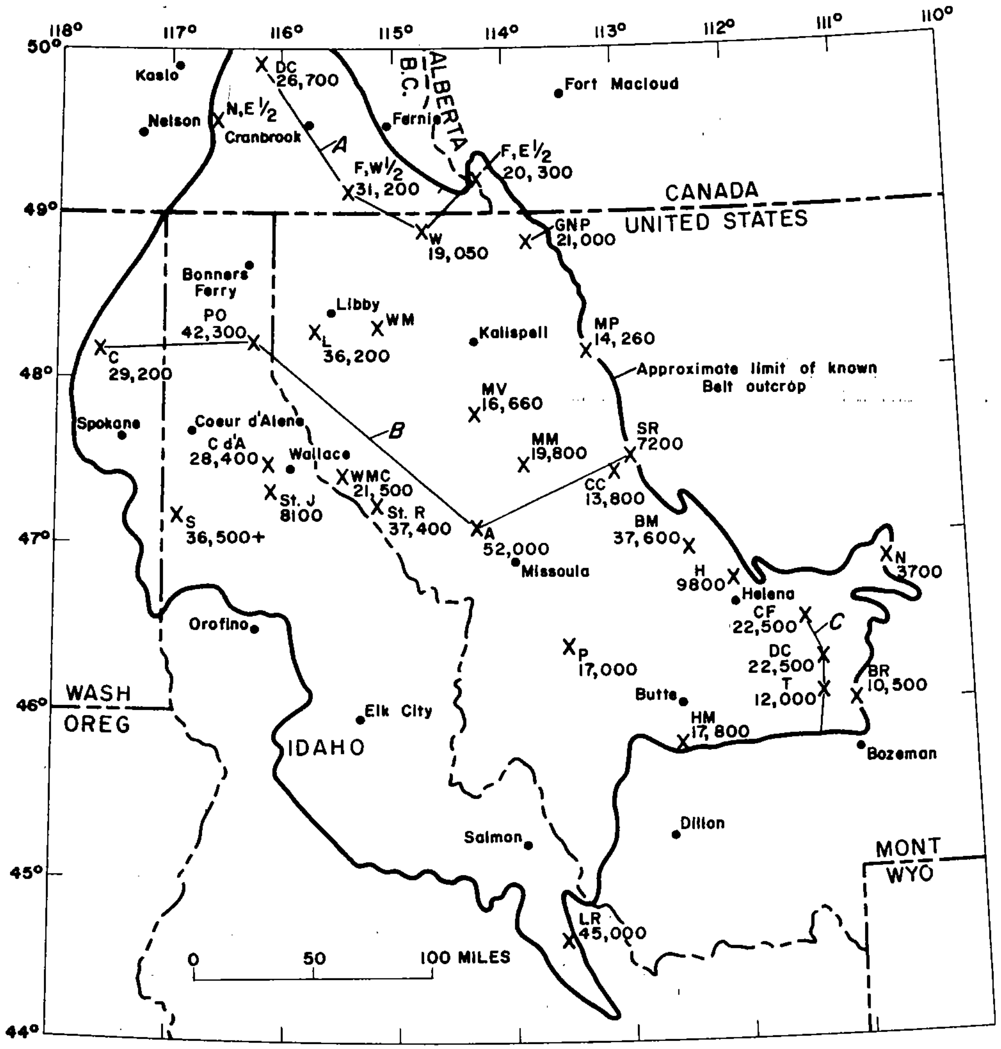


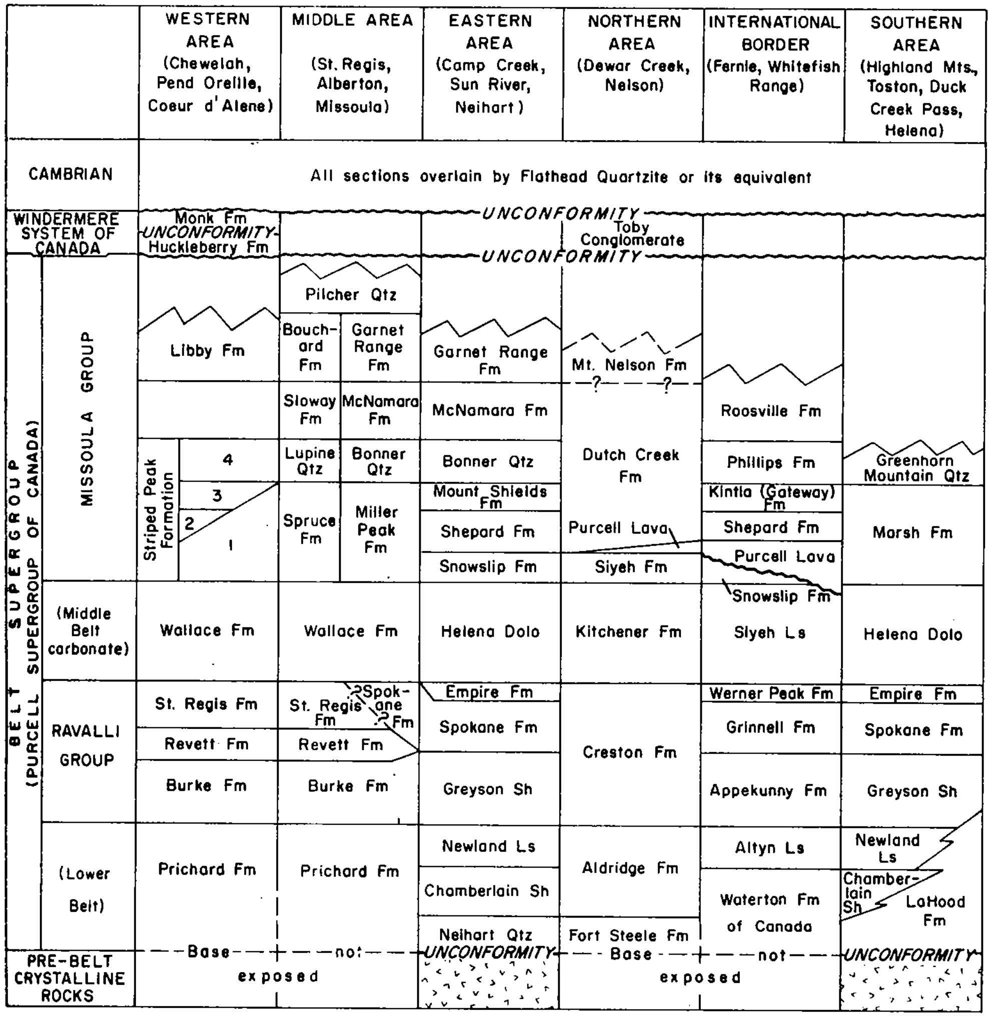
Figure 3. Thickness (feet) of Belt rocks exposed in various areas, and lines of section shown in Figures 6, 7, and 8.

Sources of Data Shown on Figure 3

A–Alberton area (J. D. Wells, unpub. data)
BM–Black Mountain (Bierwagen, 1964)
BR–Bridger Range (McMannis, 1963)
C–Chewelah-Loon Lake area (F. K. Miller and L. D. Clark, unpub. data)
CC–Camp Creek (McGill and Sommers, 1967)
CF–Canyon Ferry quadrangle (Mertie and others, 1951)
Cd'A–Coeur d'Alene area (Hobbs and others, 1965)
DC–Dewar Creek (Reesor, 1956)
DCP–Duck Creek Pass (Nelson, 1963)
F, E½–Fernie, east half (Price, 1962)
F, W½–Fernie, west half (Leech, 1958)
GNP–Glacier National Park (Ross, 1959)
H–Helena area (Knopf, 1963)
L–Libby quadrangle (Gibson, 1948)
LR–Lemhi Range (E. T. Ruppel, unpub. data)
MM–Mission Mountains (Harrison and others, 1969)
MP–Marias Pass (Childers, 1963)
MV–Mission Valley (J. E. Harrison, unpub. data)
N–Neihart (Keefer, 1972)
N, E½–Nelson, east half (Rice, 1941)
P–Phillipsburg quadrangle (Calkins and Emmons, 1915)
PO–Pend Oreille area (Harrison and Jobin, 1963 and 1965)
S–Spokane 1° × 2° sheet (A. B. Griggs, unpub. data)
SR–Sun River Canyon area (Mudge, 1972)
St. J.–St. Joe area (Wagner, 1949)
St. R–St. Regis-Superior area (Campbell, 1960)
T–Toston quadrangle (Robinson, 1967)
W–Whitefish Range (Smith and Barnes, 1966)
WM–Wolf Mountain area (J. W. Trammell, unpub. data)
WMC–Western Mineral County (Wallace and Hosterman, 1956)

relation of the Greyson Shale with the Appekunny and Burke Formations is not possible at this time. The Burke Formation has now been identified in the entire area west of the Rocky Mountain trench; more mapping and study are required east of the trench to determine whether Appekunny and Burke Formations are lithologic equivalents, facies variants, or different sedimentary prisms. In the middle of the Ravalli Group, the Revett Formation now appears to be limited to the western part of the basin and to include finer grained beds on the northeastern edge of its sedimentary prism. These beds have been described by Johns (1970) as part of the Ravalli Group, and they have now been mapped as the middle Ravalli unit (Harrison, unpub. data) in the southern part of the Rocky Mountain trench. Mapping of the upper part of the Ravalli Group in the southern part of the Rocky Mountain trench shows that the Spokane Formation is lithologically distinct from the St. Regis Formation, although the exact relations (interfingering or overlap of the formations) are yet to be worked out.

Another problem is the relation of the rock



		WESTERN AREA (Chewelah, Pend Oreille, Coeur d'Alene)	MIDDLE AREA (St. Regis, Alberton, Missoula)		EASTERN AREA (Camp Creek, Sun River, Neihart)	NORTHERN AREA (Dewar Creek, Nelson)	INTERNATIONAL BORDER (Fernie, Whitefish Range)	SOUTHERN AREA (Highland Mts., Toston, Duck Creek Pass, Helena)
CAMBRIAN		All sections overlain by Flathead Quartzite or its equivalent						
WINDERMERE SYSTEM OF CANADA		Monk Fm UNCONFORMITY Huckleberry Fm			UNCONFORMITY	Toby Conglomerate		
					UNCONFORMITY			
BELT SUPERGROUP (PURCELL SUPERGROUP OF CANADA)	MISSOULA GROUP		Pilcher Qtz					
		Libby Fm	Bouchard Fm	Garnet Range Fm	Garnet Range Fm	Mt. Nelson Fm ? ?		
			Sloway Fm	McNamara Fm	McNamara Fm		Roosville Fm	
		Striped Peak Formation 4	Lupine Qtz	Bonner Qtz	Bonner Qtz	Dutch Creek Fm	Phillips Fm	Greenhorn Mountain Qtz
		3	Spruce Fm	Miller Peak Fm	Mount Shields Fm		Kintla (Gateway) Fm	Marsh Fm
		2			Shepard Fm	Purcell Lava	Shepard Fm	
		1			Snowslip Fm	Siyeh Fm	Purcell Lava Snowslip Fm	
	(Middle Belt carbonate)	Wallace Fm	Wallace Fm		Helena Dolo	Kitchener Fm	Siyeh Ls	Helena Dolo
	RAVALLI GROUP	St. Regis Fm	St. Regis Fm	?Spokane ?Fm	Empire Fm	Creston Fm	Werner Peak Fm	Empire Fm
					Spokane Fm		Grinnell Fm	Spokane Fm
		Revett Fm	Revett Fm					
		Burke Fm	Burke Fm		Greyson Sh		Appekunny Fm	Greyson Sh
	(Lower Belt)	Prichard Fm	Prichard Fm		Newland Ls	Aldridge Fm	Altyn Ls	Newland Ls
					Chamberlain Sh		Waterton Fm of Canada	Chamberlain Sh LaHood Fm
					Neihart Qtz	Fort Steele Fm		
		Base	not		UNCONFORMITY	Base	not	UNCONFORMITY
PRE-BELT CRYSTALLINE ROCKS		exposed				exposed		

Figure 4. Generalized correlation chart for Belt-Purcell Supergroups. Subdivisions of the Striped Peak Formation in the western area are informal members designated by numbers. Names in parentheses are used informally.

units at the boundary between the Ravalli Group and the overlying middle Belt carbonate. The middle Belt carbonate rock unit changes facies from almost pure dolomite in the eastern part of the basin to a dominantly clastic somewhat carbonatic unit containing scattered beds and lenses of carbonate rock of varying thickness in the western part (*see* Fig. 10). At various intervals below the carbonate-bearing strata, there are red to purple clastic beds typical of the St. Regis or Spokane Formation. Sandwiched between the carbonate and the reddish clastics are green strata ranging in thickness from 0 to 2,000 ft, generally argillite or siltite, commonly including slightly carbonatic waxy green argillite or mudstone and at places containing some beds or pods of carbonate rock. At places, the green strata have been called Empire Formation by several authors and Werner Peak Formation by Smith and Barnes (1966). Where the overlying rock is Helena Dolomite (generally along the old shelf now coincident with the Montana Disturbed Belt), the green strata have been included in the Ravalli Group by most geologists because of the ease of identifying the base of the Helena. Where the overlying rock is called Helena Formation (generally in and near the Rocky Mountain Trench), indicating a basinward facies change from pure dolomite to dolomite interlayered with varying amounts of clastics (*see* Fig. 10), the green strata have been included with the Helena Formation because the top of the Ravalli Group as defined by reddish beds is more easily identified. The green strata were called the P_1 unit by Johns (1970), and they were included in the lower part of the lower calcareous member of the Wallace Formation by Harrison and Jobin (1963). In the western part of the basin where the Wallace Formation is mostly carbonate-bearing clastic rocks and where underlying strata (St. Regis Formation) are at places green instead of purple, the problem of mapping and identifying strata equivalent to the Werner Peak or Empire Formation or P_1 is even more difficult. It seems clear that the green beds are not necessarily everywhere equivalent and that this zone may actually contain two or more units that are not necessarily present everywhere in the basin. Detailed study and mapping by M. R. Mudge (1970, oral commun.) along the eastern edge of the basin has allowed him to place a contact in the middle of the green strata and thus place part of the strata at the base of the Helena Dolomite and part at the top of the Ravalli Group. The fact that this thin zone commonly contains anomalous amounts of copper in many parts of the basin suggests that it should be examined more closely in future studies. For this report, the Werner Peak Formation is considered equivalent to the Empire Formation, and both units are considered as the uppermost units of the Ravalli Group as shown by Smith and Barnes (1966, Fig. 4). Strata containing scattered carbonate minerals, pods, and beds in the green-bed zone west of the Rocky Mountain trench are considered as the lowest strata in the middle Belt carbonate unit as mapped by most geologists. Effects of these arbitrary decisions on isopach maps used in this report are minor.

The simplified Belt nomenclature recommended for use in the United States part of the Belt basin is shown in Figure 5.

The middle Belt carbonate has been a key unit in Belt correlation for many years. The general shape of the basin and approximate facies changes from east to west across it were diagrammed by McKelvey (1968, Figs. 2, 3). McKelvey's analysis appears to have been substantially correct. Definition of the top of the middle Belt carbonate was a problem only in the northeastern part of the basin where some workers have included all strata between the Ravalli Group and the Purcell Lava in the middle Belt carbonate. Price (1964) resolved the problem by discovering that the Purcell lava does in fact rest on a surface that cuts down through the Snowslip Formation (upper member of the Canadian Siyeh Formation) into the Helena Dolomite (middle member of the Siyeh Formation). Thus, at places, beds below the Purcell Lava do belong only in the middle Belt carbonate; but at other places, beds below the Purcell Lava belong to the Missoula Group. The contact between the Helena-Wallace Formations and the Missoula Group is one of the sharpest in the entire Belt Supergroup over most of the basin, if the contact is defined as the horizon where hematitic feldspathic red and green clastics characterized by abundant chlorite on bedding planes overlie carbonate or green to black slightly carbonatic pelitic strata of the middle Belt carbonate.

Correlation of units in the Missoula Group has been reasonably well established by a few detailed studies and has been aided significantly by the discovery that the distinctive red feldspathic Bonner Quartzite extends over

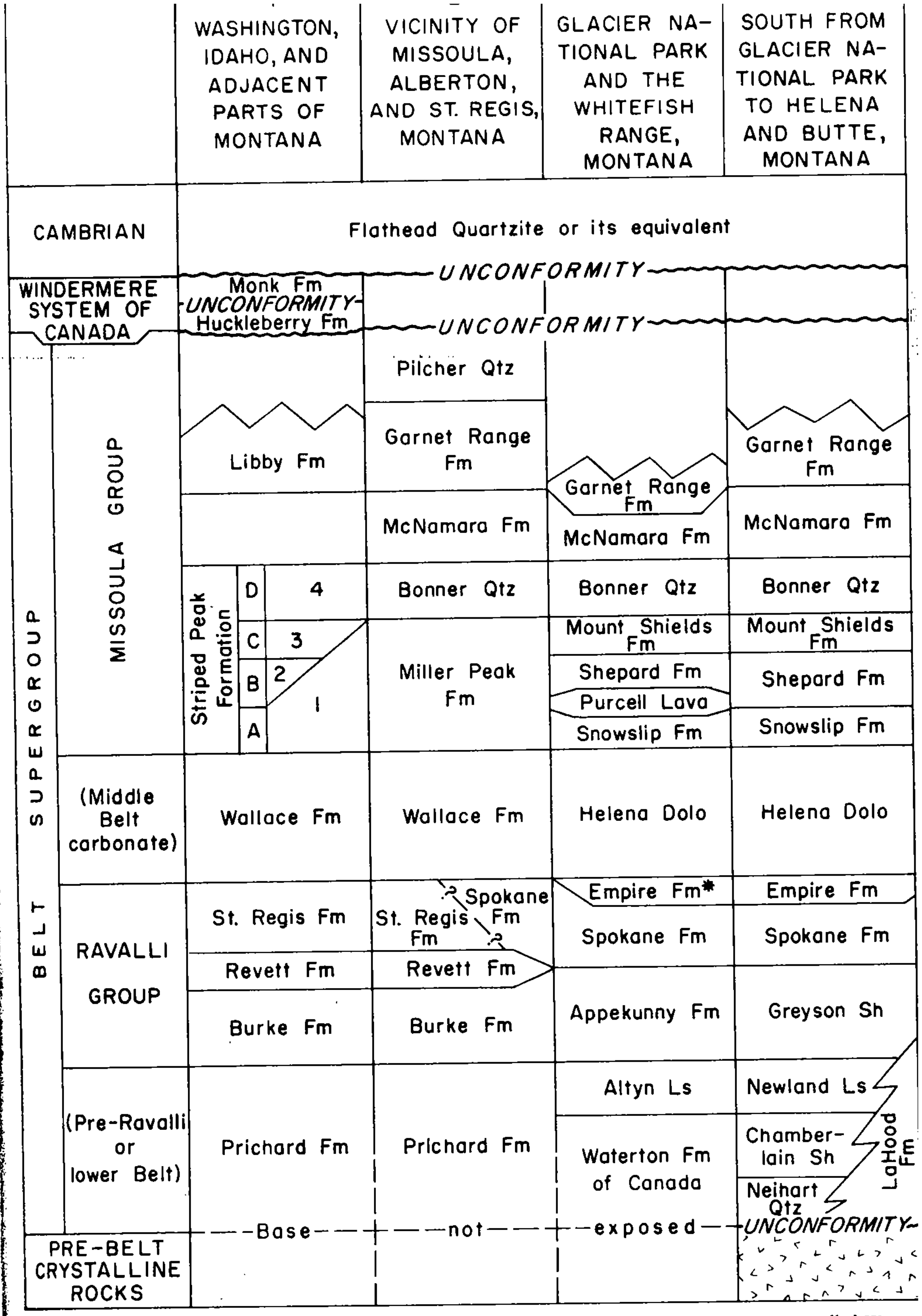


Figure 5. Recommended terminology for the Belt Supergroup. Numbers and letters in column 1 are informal members. Names in parentheses are used informally. * Possibly equivalent strata are called Werne Peak Formation of Smith and Barnes (1966) in th Whitefish Range.

almost the entire basin. However, the relative paucity of detailed data, particularly concerning the upper part of the Missoula Group, limits the kinds of syntheses that can be done at this time. The lower part of the Missoula Group of southern British Columbia and adjacent parts of the United States includes the Purcell Lava, which provides the only time line known in the entire supergroup.

Recent work by E. T. Ruppel (1970, oral commun.) has defined a sequence of strata at least 45,000 ft thick in the Lemhi Range near the southern margin of Belt terrane (Fig. 3). The rocks are largely quartzites, commonly feldspathic, and are tentatively correlated with the Ravalli Group and lower Belt strata (E. T. Ruppel, 1970, oral commun.). Considerable work remains to be done to tie this thick section to the standard Belt section to the north, and so it will not be considered further in this report, although it clearly is important to the total picture of the Belt basin.

GEOMETRY AND SEDIMENTATION IN THE BASIN

The quality and quantity of stratigraphic data vary considerably over the Belt terrane, partly because of lack of study and partly because of complications in stratigraphic analysis caused by high-grade metamorphism and deformation in the Kootenay arc mobile belt and in the batholithic terrane (Fig. 2). In addition, the oldest Belt strata are rarely seen, and the top of the exposed Belt strata is cut by an erosional surface at the base of Middle Cambrian rocks that truncates folded and faulted strata.

Good data are reasonably abundant for the upper part of the Ravalli Group, the middle Belt carbonate, and the lower part of the Missoula Group (Fig. 5). However, these data are inadequate for preparation of isopach maps of every formation, and a less desirable method of grouping some formations must be followed. Nevertheless, the data yield information highly informative about geometry and sedimentation in the Belt basin.

Correlation diagrams, which are also lines of section (Fig. 3) through the basin, are shown in Figures 6, 7, and 8. Figure 6 is based on the excellent summary by Price (1964), who documented in detail the correlations, facies changes, and provenance of Belt rocks in the northernmost part of the Belt basin. Among his many pertinent observations and conclusions are

1. Eastward thinning and convergence in all units is accompanied by a change from a fine clastic facies to a shallow-water carbonate facies in some units, and from a drab green and gray facies to a "red bed" facies (some of which contain coarser feldspathic detritus) in others.
2. It was not necessary that any of the terrigenous sediment originated from some supposed western landmass.
3. The Purcell Lava flowed out on an erosional surface that cuts down through the lower part of the Missoula Group and into middle Belt carbonate rocks. The Shepard Formation lies unconformably on the Purcell Lava.

Figure 7 is a cross section through the middle part of Belt terrane and through the thickest known part of the section. Eastward thinning, convergence, and facies changes in the eastern part of the basin are identical to those described by Price (1964) and have been mapped on the far eastern edge by M. R. Mudge (1970, oral commun.). Facies changes diagrammed by McKelvey (1968, Fig. 3) for the middle Belt carbonate are similar to those shown on Figure 7 and are compatible with the existence of an eastern shelf as proposed by Price (1964). Several new concepts are shown in Figure 7 and will be discussed in subsequent paragraphs. Of particular interest are the trough-dome relation between Alberton and Pend Oreille, and facies changes in rocks of the upper part of the Ravalli Group, the middle Belt carbonate, and the lower part of the Missoula Group.

Figure 8 shows the startling facies changes in the lower Belt documented by McMannis (1963) for the conglomerate formed along the Central Park (Willow Creek) fault (Fig. 2). In the lower part of the Belt, he also recognized shallow-water carbonate (Newland Limestone) replacement of outer basin fine-grained clastics (Prichard Formation), which is identical to the replacement of Aldridge Formation by Altyn Formation as described by Price (1964).

Isopach maps of one or more formations from the upper part of the Ravalli Group through the lower part of the Missoula Group are given in Figures 9, 10, 11, and 12. Most of the data are from the sources listed on Figure 3, but supplementary points also come from information given by Freeman and others (1958), Hietanen (1968), F. K. Miller (1971, written commun.), and M. R. Mudge (1971, oral commun.). Facies changes from north to south (Pend Oreille area to the Idaho batholith) that

---

coarsening in grain size of clastic rocks along with convergence to the southwest (Harrison and Campbell, 1963). This is particularly true for the Wallace Formation where it not only has less carbonate to the southwest but also has a marked increase in mappable thick quartzite units (Hietanen, 1968).

The Revett sedimentary prism is fairly well defined within known Belt terrane (Fig. 9), although it obviously extends an unknown distance to the southwest. The characteristic thick, blocky, cross-bedded quartzites extend almost to the distal end of the prism where the unit thins to about 1000 ft and becomes mostly cross-bedded purple laminated very fine-grained quartzite or medium- to coarse-grained siltite that is interlayered with gray to gre argillite. Toward the southwest, mostly whi blocky, cross-bedded, fine- to medium-grai quartzite becomes increasingly abundant in formation. The prism had a southwest sou area. The thickest part of the prism is para to the Lewis and Clark line (*compare* Figs. 9), which suggests that the prism may be lated to a troughlike depression along an anci line of crustal weakness—the ancestral Le and Clark line.

The basin of deposition for the St. Regis Spokane Formations is defined by the isopa map shown in Figure 10. Recognition that St. Regis and Spokane Formations are differ sedimentary prisms from different sou

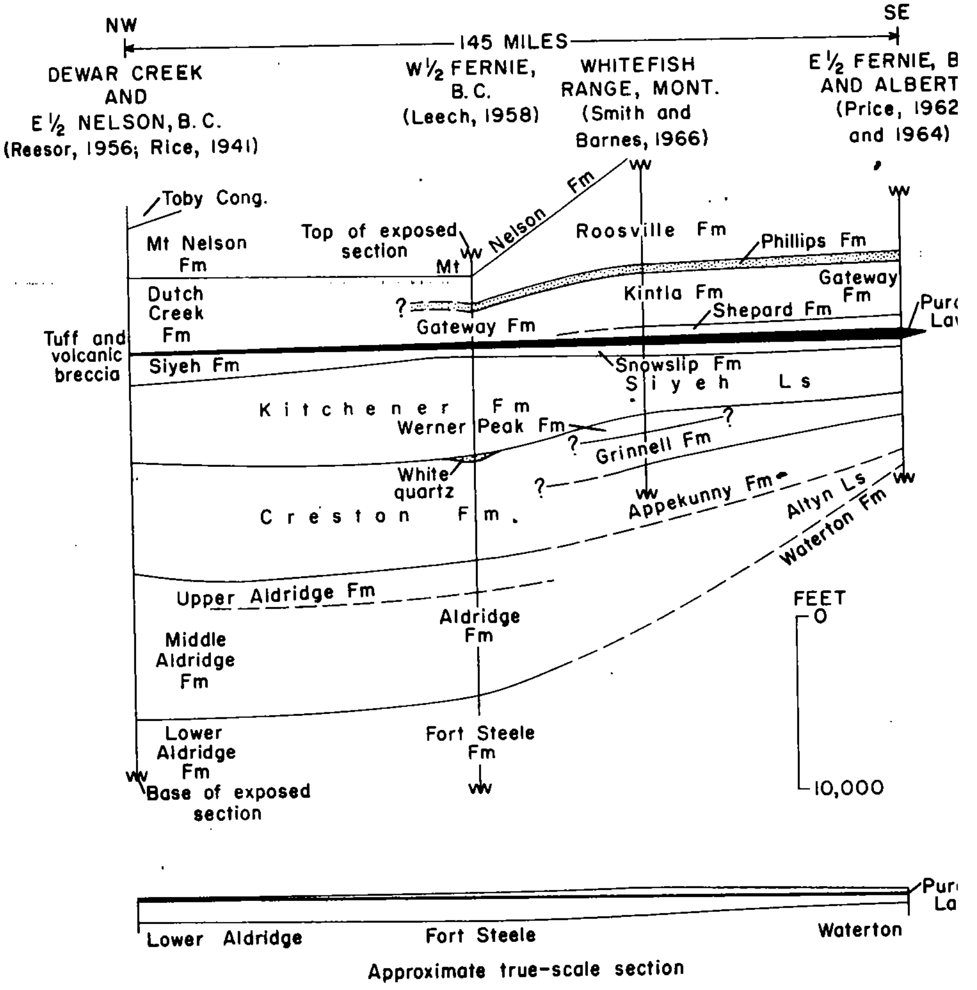


Figure 6. Belt cross section A. Modified from Price (1964):

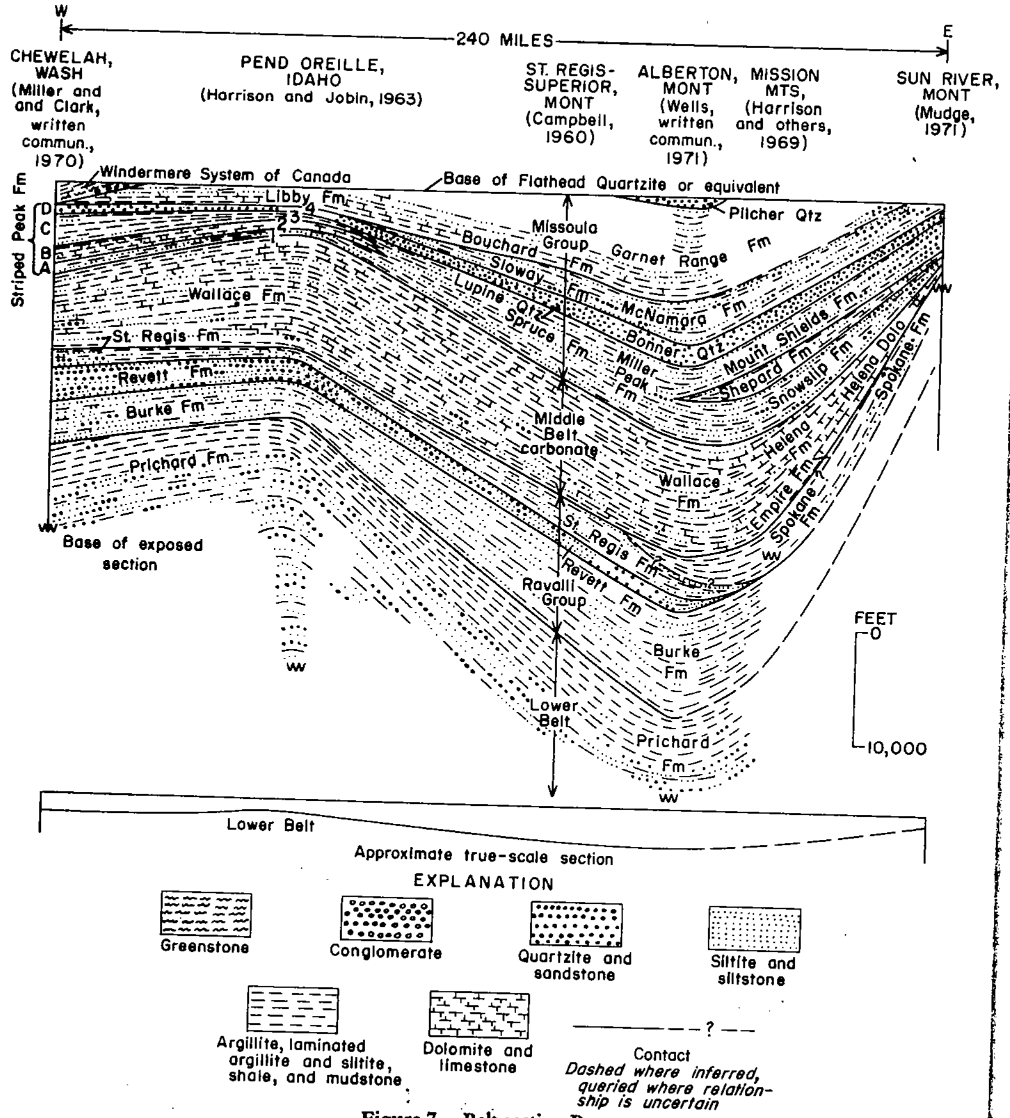


Figure 7. Belt section B.

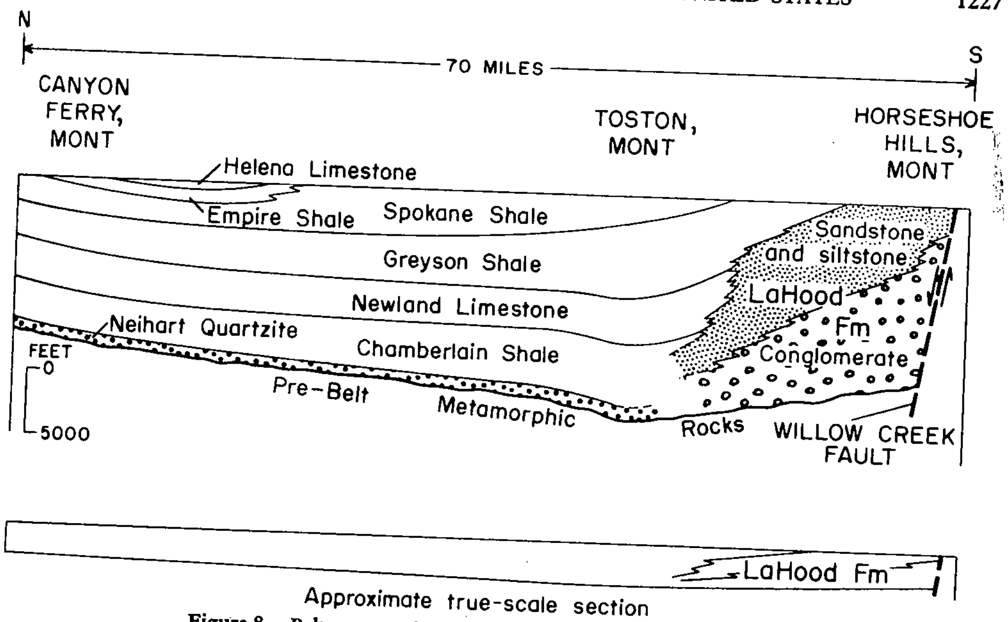


Figure 8. Belt cross section C. Modified from McMannis (1963).

directions results in part from mapping facies changes in each formation and in part from study of the two formations where they are within a few miles of each other near Alberton, Montana. The silty and sandy mainly red-bed facies of the Spokane Formation on the eastern shore (Mudge, 1971) becomes progressively thicker, more argillitic, and less red to the west. In the Mission Valley, the Spokane is almost all pale purple and green argillite. The purple beds disappear northwest of the Mission Valley, and in Canada (Price, 1964, p. 417–418) the Grinnell (Canadian equivalent of the Spokane) has not been distinguished from the Appekunny; equivalents of both are included in the Creston Formation. At the horizon where all reddish tones disappear from the Canadian equivalent of the Ravalli, Figure 10 shows a zero line for the Spokane Formation. It is possible that part of the Creston Formation is part of the Spokane prism, and some of the isopach lines should be open-ended to the north. Facies changes in the St. Regis Formation have been described (Harrison and Campbell, 1963) and are compatible with a southwestern source area. The Lewis and Clark line again appears to nearly coincide with the axis of the St. Regis trough (*compare* Figs. 2, 10). The deepest part of the trough contains a thick sequence of green beds, in contrast to the usual purplish beds, first noticed and discussed by Wallace and Hosterman (1956). Details of the overlap or interfingering of the St. Regis and Spokane sedimentary prisms are yet to be worked out; the questioned overlap shown on Figure 7 is intended to express ignorance rather than fact.

Northward extension and general deepening of the Belt basin following Ravalli time are indicated by the isopach map of the middle Belt carbonate (Fig. 11). Because this unit is important in Belt correlation, it has received more attention than any other unit and, therefore, has more reliable data points to control the map. Clearly the Helena-Wallace sedimentary prism is compound, inasmuch as the basin was receiving sediment from the east, south, and southwest. Extensive carbonate mixed with minor amounts of clastics formed on the eastern shelf (Fig. 7), whereas larger amounts of clastic debris were derived from other source terranes. In many ways, the distribution of facies resembles that of the lower Belt. A working hypothesis for shape and size of the lower Belt basin is that the basin strongly resembled that of the middle Belt carbonate.

Major tectonic adjustment in the basin followed Helena-Wallace time. The new basin configuration is shown by Figure 12, which is an isopach map of the lower part of the Missoula Group (to the top of the Bonner Formation). The floor of what had been the most rapidly subsiding part of the basin became more stable. The trough and dome, so obvious in cross section (Fig. 7), represent the areas of differential subsidence (and perhaps slight upwarp) in the basin during early Missoula time. The trough appears to have been a rejuvenation of the Spokane (Fig. 10) trough, but the dome was new.

Several other lines of evidence also point to the concept that early Missoula time was a period of major tectonic adjustment. Hematitic clastics, representing a deep lateritic weathering of the source area, were deposited on top of stable shelf carbonate rocks; an erosional unconformity locally developed between the Snowslip Formation and the Purcell Lava (Price, 1964); the only lava in the Belt Super-

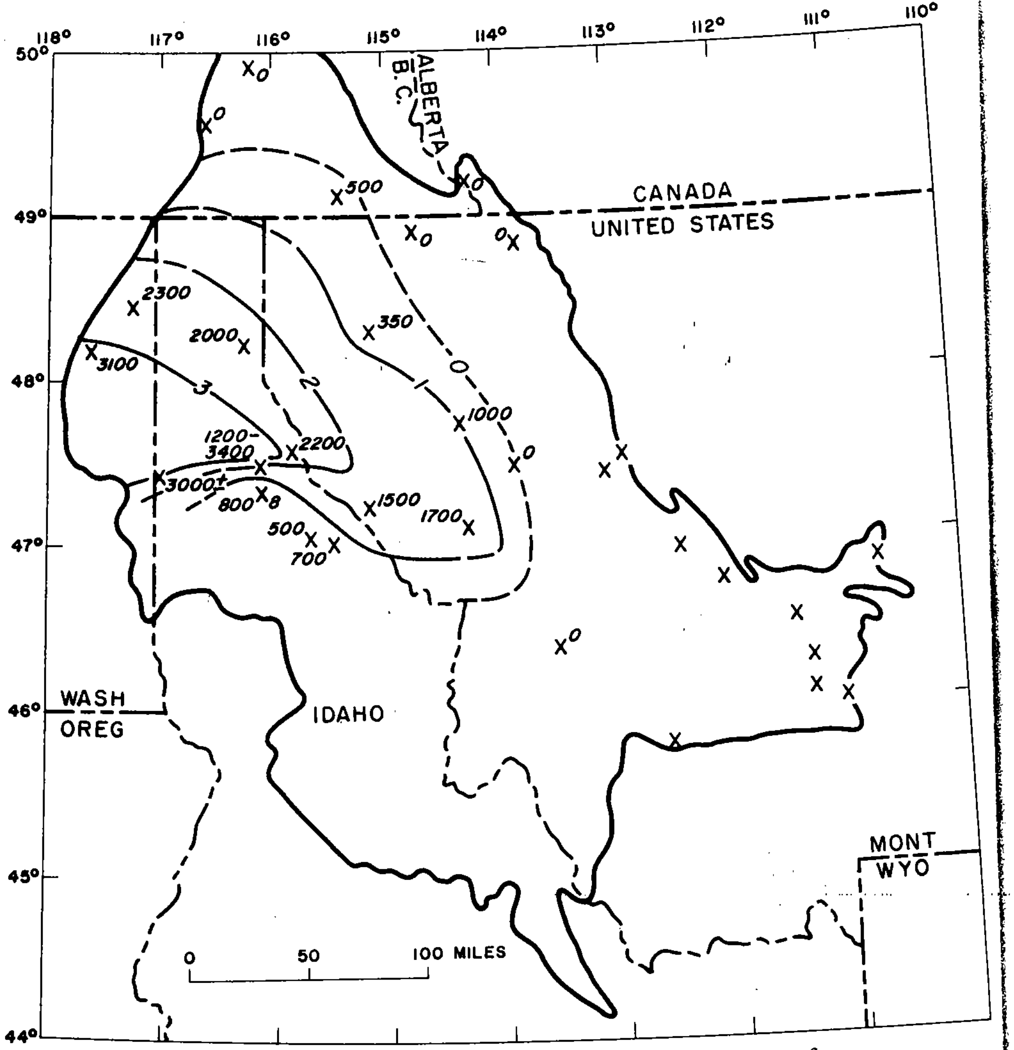


Figure 9. Isopach map of the Revett Formation (middle part of the Ravalli Group). Isopachs dashed where inferred. Interval is 1,000 ft.

group was poured forth; and an angular unconformity formed at the base of the Bonner Formation in one area near the eastern shore (Bierwagen, 1964).

As was true of both the Ravalli Group and the middle carbonate unit, at least two source areas are indicated for the lower sediments of the Missoula Group—one to the northeast and one to the southwest. Thinning and coarsening to the east are shown by the Snowslip and Mount Shields Formations (Fig. 7), whereas the carbonate-bearing Shepard Formation

In the western part of the basin, equivalent strata thin over the dome, and two of them (members 2 and 3 of the Striped Peak Formation) are unique in the Belt in that they commonly contain an astounding 800 to 1,000 ppm of boron (Harrison and Campbell, 1963; Harrison and Grimes, 1970), which is about ten times that commonly present in similar Belt rocks. The underlying upper part of the Wallace Formation in this geographic area also contains more boron than usual, although not nearly so much as the Striped Peak strata. The unusual boron content in all three units extends westward to the Chewelah area (F. K. Miller, 1970, oral commun.). The boron is partly in detrital tourmaline and partly in the clay mineral fraction, and it represents a provenance different from that of equivalent strata in the east. Although a southwestern source area is not unequivocal for the Striped Peak sediments, it seems reasonable to suggest that the boron-rich source terrane of late Wallace time to the southwest also contributed high boron in early Missoula time. The thinning of the Bonner Quartzite over the dome and the absence of McNamara from the dome support a previous suggestion of a local unconformity at the top of the Bonner Quartzite by Harrison and Campbell (1963).

The upper part of the Missoula Group was partly or completely eroded in pre-Flathead (Middle Cambrian) time over much of the Belt basin. The uppermost Belt unit, the Pilcher Quartzite, is known only in a small area near Missoula, Montana. Below the Pilcher is the Garnet Range Formation, which shows a shoreward facies in the east (Fig. 7). It is either truncated or missing completely in most Belt terrane west of the Rocky Mountain trench, which effectively limits synthesis of basin shape for late Missoula time.

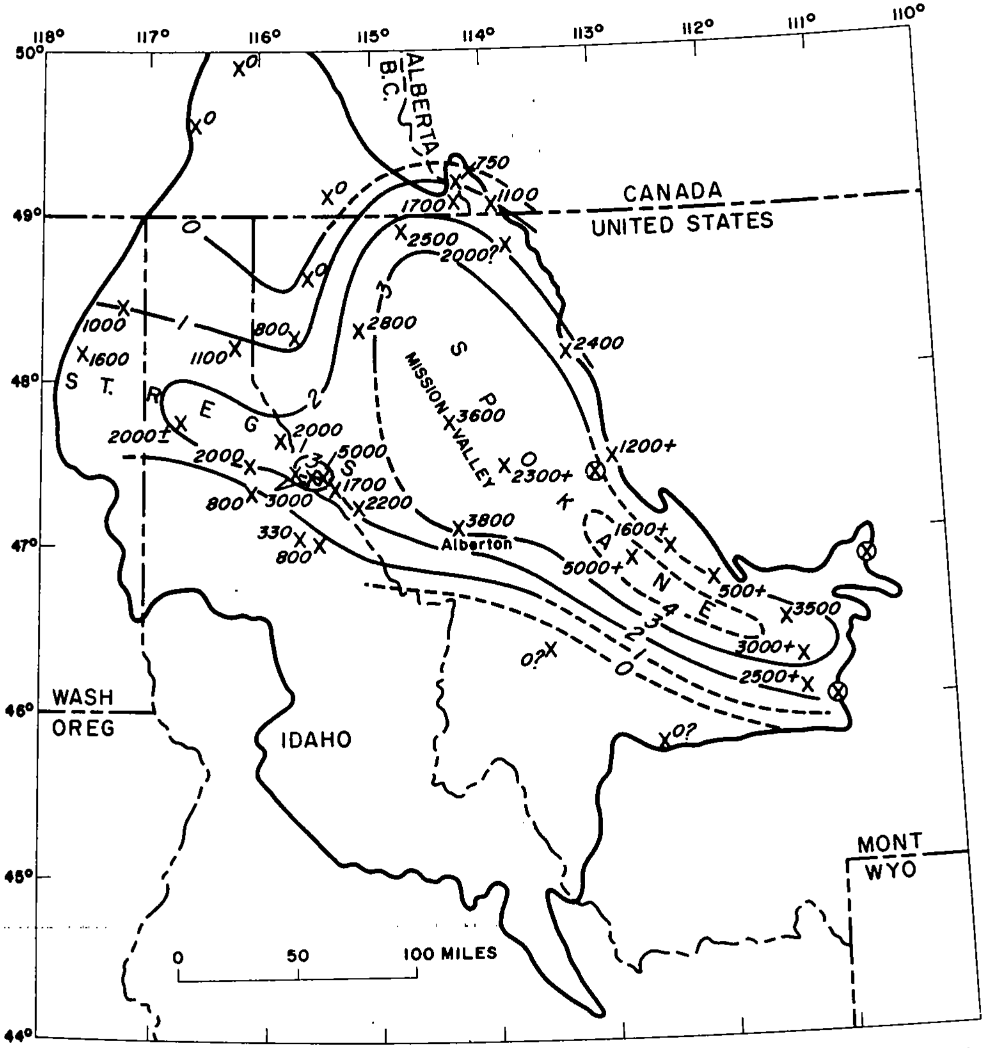


Figure 10. Isopach map of the upper part of the Ravalli Group (St. Regis and Spokane Formations). Circled locality indicates section not exposed. Isopachs dashed where inferred. Interval is 1,000 ft.

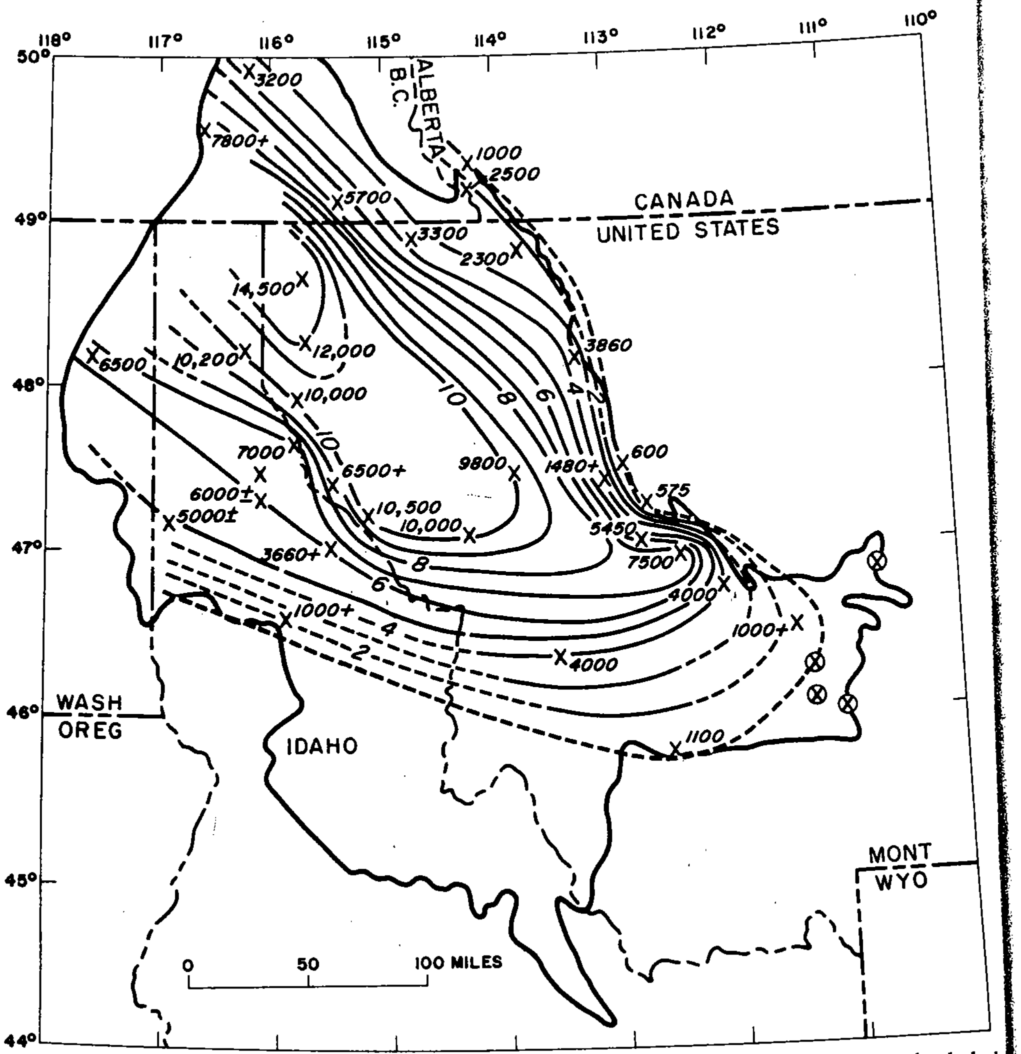


Figure 11. Isopach map of the middle Belt carbonate (Helena, Wallace, and Kitchener Formations). Circled locality indicates section not exposed. Isopachs dashed where inferred. Interval is 1,000 ft.

GENERAL OBSERVATIONS ON THE SEDIMENTARY RECORD

Geometry and sedimentation in the Belt basin clearly show an epicratonic re-entrant of a sea to the west and not a lake as proposed by some authors in the past. The thick sedimentary column had source areas around the re-entrant. The remarkable uniformity of sediments in mineralogy and in fineness of grain size and the general geochemical similarity of sediments from different source areas (Harrison and Grimes, 1970) indicate a tremendous homogenization of clastic components that were contributed by low-gradient streams from low-terrane sources.

Many tectonic adjustments can now be identified in the basin, but even the most spectacular of these—a dome formed in early Missoula time—was a relatively gentle warp when viewed in true scale (Fig. 7). The sedimentary record contains almost no conglomerate (except near the Willow Creek fault), and angular unconformities are rare. Disconformities are difficult to identify, but more of these are coming to light as both detailed and regional studies proceed. The point seems clear, however, that slow gentle warping—more down than up—was the habit of the basin.

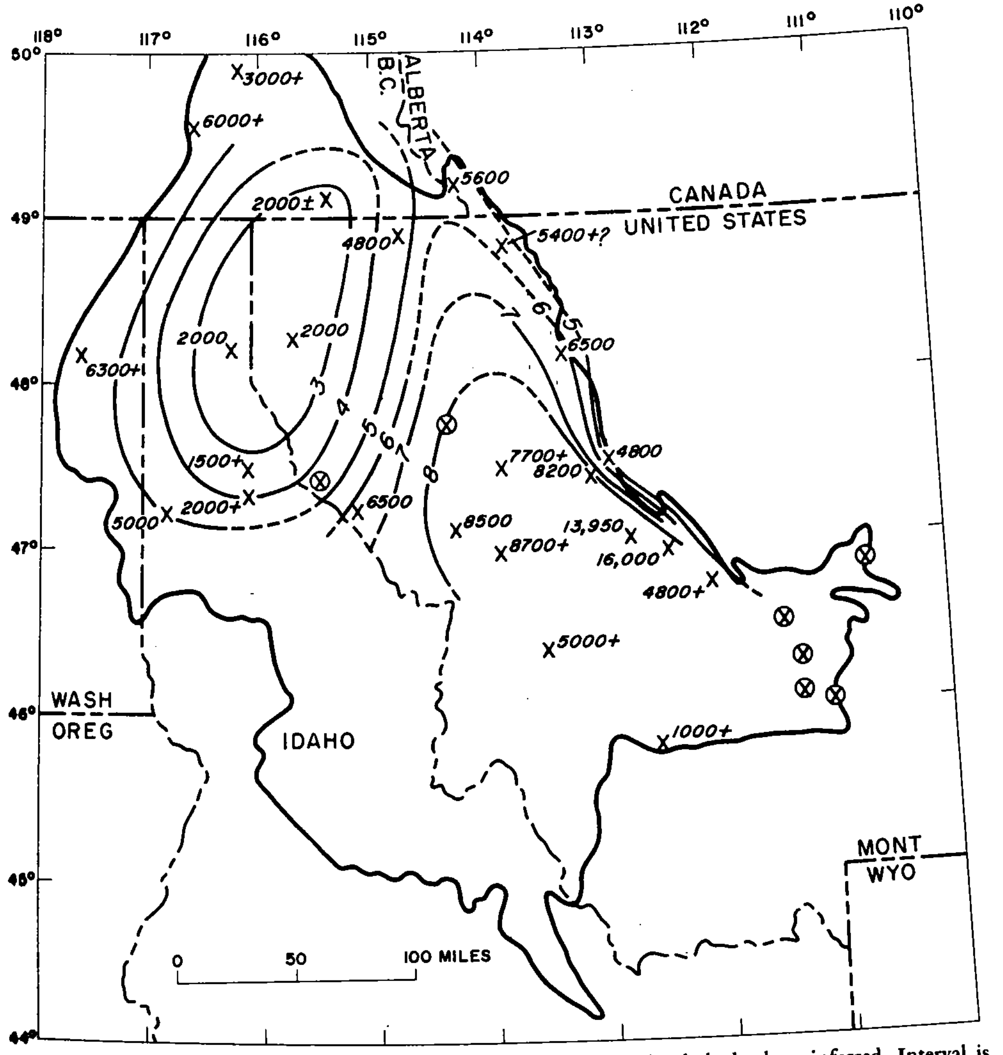


Figure 12. Isopach map of the lower part of the Missoula Group (to the top of the Bonner Formation and equivalents). Circled locality indicates section not exposed. Isopachs dashed where inferred. Interval is 1,000 ft.

The granitic to granodioritic bulk chemical composition of the graywacke-like rock assemblage (Harrison and Grimes, 1970) indicates a cratonic source. Although the chemistry is permissive of reworked sedimentary rocks, no such rocks are known in Belt basin source terranes. R. R. Reid (1967, written commun.) suggested that part of the Belt sediment may have been reworked from lower units that were slightly to highly metamorphosed at places around the edge of the basin. Although this concept may be applicable for limited areas in the southwestern part of the basin, most of the clastic sediment must have been derived as first-cycle sediment from older crystalline terrane.

Sedimentation rate for Belt rocks is, of course, speculative. Some geologists (for example, Price, 1964) have compared the Belt with sediments of the Mississippi delta. A comparison of sedimentation rates may be instructive, although the Mississippi sediments are largely recycled (Gilluly and others, 1970, p. 367). The erosion rate for the Mississippi drainage (Judson and Ritter, 1964), and thus the sedimentation rate on an equal area of deposition, is 0.167 ft per thousand years. The Belt sediments are known to be 67,000 ft thick without top or bottom exposed, and it seems reasonable to believe that it was at least 75,000 ft thick and averaged at least 50,000 ft of basin fill. At a rate of 0.167 ft per thousand years, it would have required about 300 m.y. for deposition of the sediment from source areas equal in size to the basin. This time span is about half the presumed time span of Belt rocks (about 1,450 to 850 m.y. ago). Obradovich and Peterman (1968, p. 746) suggested that the Belt was deposited in three relatively short episodes separated by two substantial hiatuses of 200 m.y. or more. This would seem to require an unusually high sedimentation rate for the fine-grained Belt sediments and to infer two substantial basin-wide unconformities that are yet to be identified. The geologic record seems to indicate long semicontinuous deposition of sediments interrupted by many hiatuses.

STRATABOUND COPPER

Anomalous amounts of copper are found in sedimentary or low-grade metasedimentary rocks of Belt age in Africa, Australia, Russia, and Canada, as well as in the Belt basin. Within the Belt basin, anomalous copper (at least 100 ppm) has been found in virtually all parts of the basin and in almost all formations except the Prichard and the Bonner and their equivalents. The distinct habit for copper minerals to be concentrated along bedding planes, in minor sedimentary structural features or in certain layers in the rock has led most geologists to refer to the copper occurrences by the nongenetic term "stratabound." Many mining companies are actively searching for stratabound copper deposits, and much information on individual properties or prospects is still held in confidence by these companies. Thus, only the general distribution of copper in various formations in the basin is shown in Figure 13, and this should be considered as minimal information. The worldwide occurrence of anomalous amounts of copper in rocks of Belt age and the extensive lateral and vertical distribution within the Belt basin indicate that the copper was originally introduced into the rocks as an element either syngenetically or diagenetically. Whether the original concentrations were sufficient to make ore or whether some form of epigenetic reconcentration was required to form ore is a current point of study and disagreement.

Concentration of copper in a 1-ft zone, for example, ranges from a "background" of about 20 ppm or less, depending on rock type and geographic area (Harrison and Grimes, 1970, Fig. 8), to ore grade (10,000 to 20,000 ppm). A complete spectrum of copper values exists between these two end members. On Figure 13, this spectrum of anomalous copper values is arbitrarily classified into three groups.

The principal copper minerals are chalcopyrite, chalcocite, digenite(?), and bornite (Trammell, 1970; A. L. Clark, 1971). These are accompanied commonly by covellite and various secondary hydrous copper minerals. In general, the anomalous copper occurrences of low concentration are largely chalcopyrite with some chalcocite; higher anomalous amounts of copper contain more chalcocite and bornite; and the ore is principally bornite. All anomalous copper occurrences tend to contain anomalous amounts of silver and mercury, but the mineralogy of these metals is unknown. Silver occurs in sufficient amounts to be an economic factor in determining ore grade of the copper. A. L. Clark (1971) described an outer zone of galena associated with copper ores in Revett quartzites near the Idaho-Montana line.

Various occurrences of anomalous copper related to rock type or particular stratigraphic zones have been noted. In many occurrences, the higher amounts of copper are associated with sandier or siltier laminae, layers, or parts of formations. Locally, however, the copper is more concentrated in thin beds of argillite or limestone. Where beds are alternating red and green, the higher copper contents are consistently in the green beds. Chemical analyses confirm what seems obvious in outcrop and thin section, namely that the reds or purples represent oxidized iron (mostly in hematite), whereas the green is reduced iron (largely in chlorite). Carbonate rocks generally contain chalcopyrite crystals and blebs as anomalous copper concentrations. In all these occurrences, the primary copper minerals commonly are along bedding planes, in certain laminae or layers, and even in sedimentary microstructures such as cross laminae, mud-crack casts, or cut-and-fill structures. Stromatolitic zones and carbonate lenses or pods are also favorable hosts in some, but not all, rocks. Secondary copper minerals, and locally some of the primary copper sulfides, can also be found in small fractures in many occurrences.

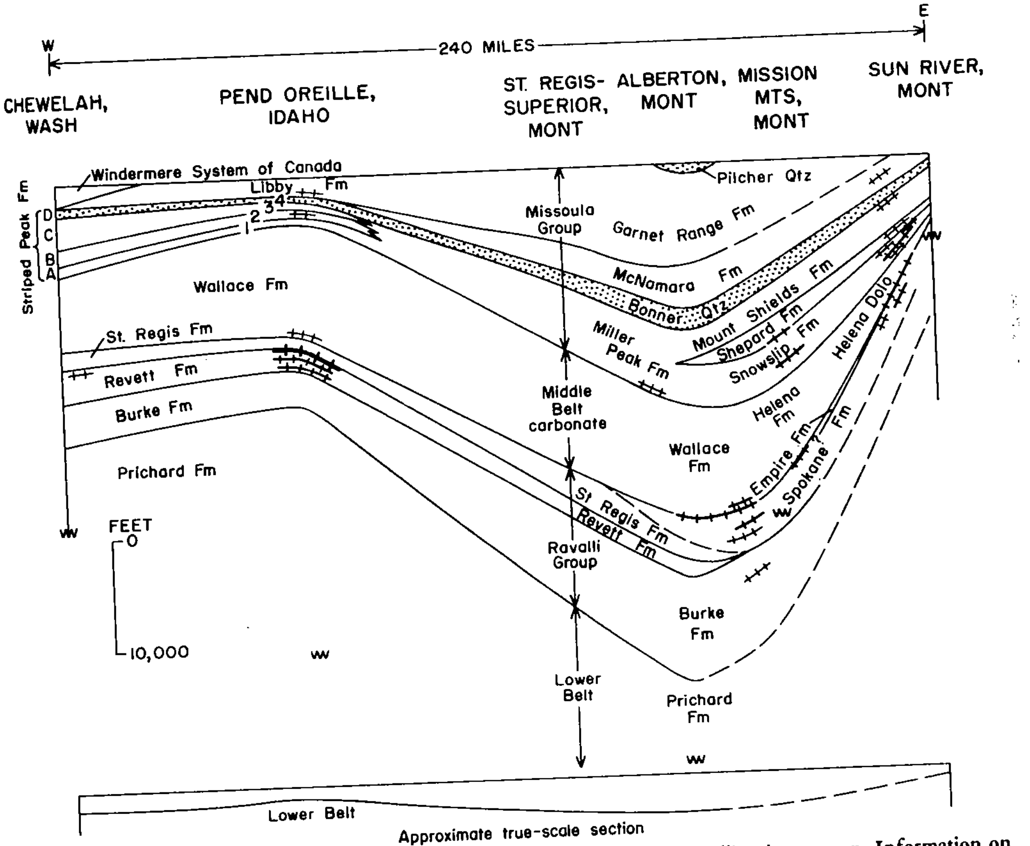


Figure 13. Distribution and relative amount of anomalous copper in Belt rocks. Heavy line indicates ore grade; medium line indicates several thousand parts per million is common; light line indicates several hundred parts per million is common. Information on copper should be considered minimal and classification arbitrary.

Favorable stratigraphic zones appear to be common, but the amount of copper in them ranges from background to thousands of parts per million. In the western part of the basin, the western Montana copper sulfide belt, a geographic area about 40 mi wide extending north from the eastern end of the Coeur d'Alene mining district almost to Canada (A. L. Clark, 1971), contains ore-grade copper in siltites and especially in the coarse blocky quartzite layers, particularly the uppermost quartzite, of the Revett Formation (Fig. 13). The green-bed zone at the base of or beneath the Helena-Wallace Formations contains anomalous copper in many places (Fig. 13). In the eastern part of the basin, certain zones within the Snowslip and Shepard Formations (Fig. 13) commonly contain several hundred parts per million of copper (Harrison and others, 1969; Mudge and others, 1971). Within the Missoula Group, copper appears to be more abundant in the eastern part of the basin, and this has been attributed to higher copper content of the eastern source area (Harrison an Grimes, 1970).

Current working hypotheses for genesis o the occurrences and the ores generally favo syngenetic or diagenetic processes of concentration. Some migration and reconcentration o copper in silty or sandy layers or in smal fractures is suggested. This appears to be reasonable hypothesis for many of the coppe occurrences. The geometry and tectonic hi tory of the basin, however, also suggest that major epigenetic reconcentration of copper possible for the ore deposits in the Reve Formation in the western Montana coppe sulfide belt. Evidence for a major compone of epigenetic reconcentration of copper could increase significantly the number of working hypotheses used in the search for stratabound ores, and so the following few paragraphs will focus on the possibility of epigenetic reconcentration.

A composite diagram showing the Revett sedimentary prism and the early Missoula dome as outlined by isopachs, and the western Montana copper sulfide belt is shown in Figure 14. The copper sulfide belt, which contains ore only in the Revett Formation, is about perpendicular to the Revett sedimentary prism and nearly parallel to the dome. The Revett Formation contains at least three thick sandstone lenses in that area, and it is overlain by silty and argillitic layers of the St. Regis Formation. A reasonable conclusion is that concentration of ore is related to the dome and that the occurrence of ore in siltites and quartzites is related to permeability of this unique stratigraphic zone of former siltstone and blocky sandstone. In other words, differential subsidence or doming of the Prichard through Wallace strata in early Missoula time formed a stratigraphic trap. The lead zone above the copper ore described by A. L. Clark (1971) is also compatible with an epigenetic component in the origin of the ore. A recent paper by White (1971) suggests a paleohydrologic model for origin of the famous White Pine copper deposits. Although the geologic conditions at White Pine differ somewhat from those in the western Montana copper sulfide belt, a migration of copper-bearing fluids through Belt strata (and perhaps fractures) is entirely possible. Such fluids could have been derived from connate water, ground water, water released during metamorphism, or fluids related to intrusive rocks. Until the sequence of geologic events affecting the basin and the geochronologic age of the events are better known, views on possible source of fluids or time(s) of migration following formation of the stratigraphic trap are only speculations. Obviously, migration of copper-bearing fluids probably either preceded or accompanied metamorphism to the biotite zone, because the metamorphism resulted in recrystallization, suturing and interlocking of quartz and feldspar grains, and a considerable reduction of rock permeability.

One further observation is pertinent if such a migration of copper-bearing fluids did indeed help reconcentrate the copper to ore. A somewhat similar geologic situation exists at the eastern edge of the basin where permeable silty and sandy facies of many formations form the updip edge of the basin. Abundant copper in potential source green beds is evident in the deeper part of the basin (Fig. 13).

In neither of these geologic situations is the sequence of sedimentologic, tectonic, metamorphic, and hydrologic processes sufficiently worked out to positively identify source beds, fluid migration paths, or processes of copper concentration. The concept of epigenetic concentration does appear plausible for the Revett copper ores, and a working hypothesis of epigenetic reconcentration seems well worth considering for other copper occurrences in addition to the prevailing theory of late diagenetic concentration.

STATUS OF ISOTOPIC DATING OF PRECAMBRIAN EVENTS

Geochronologic data on the Belt Supergroup and Precambrian rocks intrusive into Belt rocks are scarce, and some of the chronometric data are either in conflict or are difficult to rationalize with the apparent geologic record. The Belt cannot be older than about 1,700 m.y., which is the general age of crystalline terrane bordering Belt rocks in southwestern Montana (Giletti, 1966). The Belt is overlain by the Windermere System of Canada, which is dated indirectly as sedimentation corresponding in time to the East Kootenay orogeny of White (1959), which in turn is dated by thermal events resulting in K-Ar dates of about 750 to 850 m.y. ago (Leech and others, 1963; Gabrielse and Reesor, 1964). In addition, a minimum age for the Garnet Range Formation (upper part, Missoula Group) is set by a K-Ar age of 750 m.y. on biotite from a basic sill in that formation (Obradovich and Peterman, 1968). Thus, the Belt is reasonably well bracketed in age between about 1700 and 850 m.y.

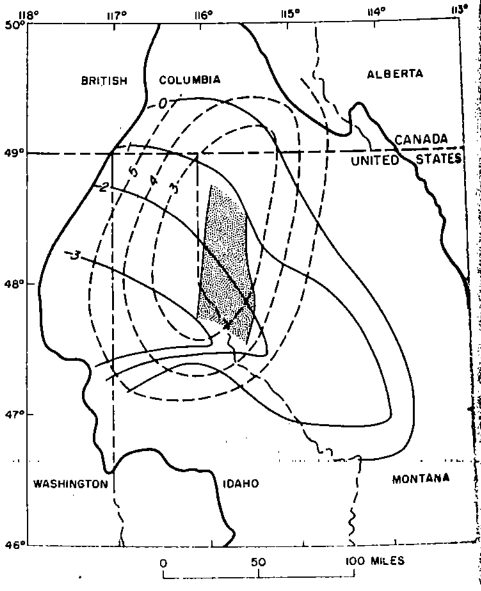


Figure 14. Composite of isopach maps of Reve Formation (solid lines) and lower part of the Missou Group (dashed lines) showing relation to wester Montana copper sulfide belt (stippled).

Maximum ages for the Belt are also shown by K-Ar ages from the Little Belt Mountains and the buried basement of Alberta (Burwash and others, 1962). In fact, the basement ages may be of significance in interpreting early Belt history. The K-Ar biotite age (20 samples) for the basement is 1,740 m.y. If we follow the recent suggestion of Harper (1967) that the uniformity of K-Ar ages in shield areas represents passage of a deep crustal zone through a horizon of thermal stability for K-Ar isotopes by regional uplift rather than representing rock-forming events, and we assume that the basement beneath the Belt was also uplifted at this time, then an amount of time equivalent to removal of several kilometers of material must be subtracted from the 1,740 m.y. to obtain the maximum age of the Belt. Or, if the uplift were differential, with the area now occupied by the Belt remaining negative, the uplift of surrounding areas at 1,740 m.y. could have contributed detritus to the earliest Belt. In view of the fine-grained nature of the sediments which seem to require a low source terrane and the fact that Belt sediments lie on 1,700 m.y. basement at a few places, the first case seems most acceptable.

Geochronologic data on rocks of the Belt basin available through 1967 were summarized by Obradovich and Peterman (1968), who not only presented new data on the sediments themselves but also attempted the first geochronologic synthesis for the entire basin. Only a few ages have been determined since that synthesis:

1. Ryan and Blenkinsop (1971) reported that Rb-Sr data indicate that a granitic intrusion into the Aldridge Formation and Moyie sills—the Hellroaring Creek stock of southeastern British Columbia—is at least 1,300 m.y. old (recalculated to the 50-b.y. half-life for Rb^{87}).

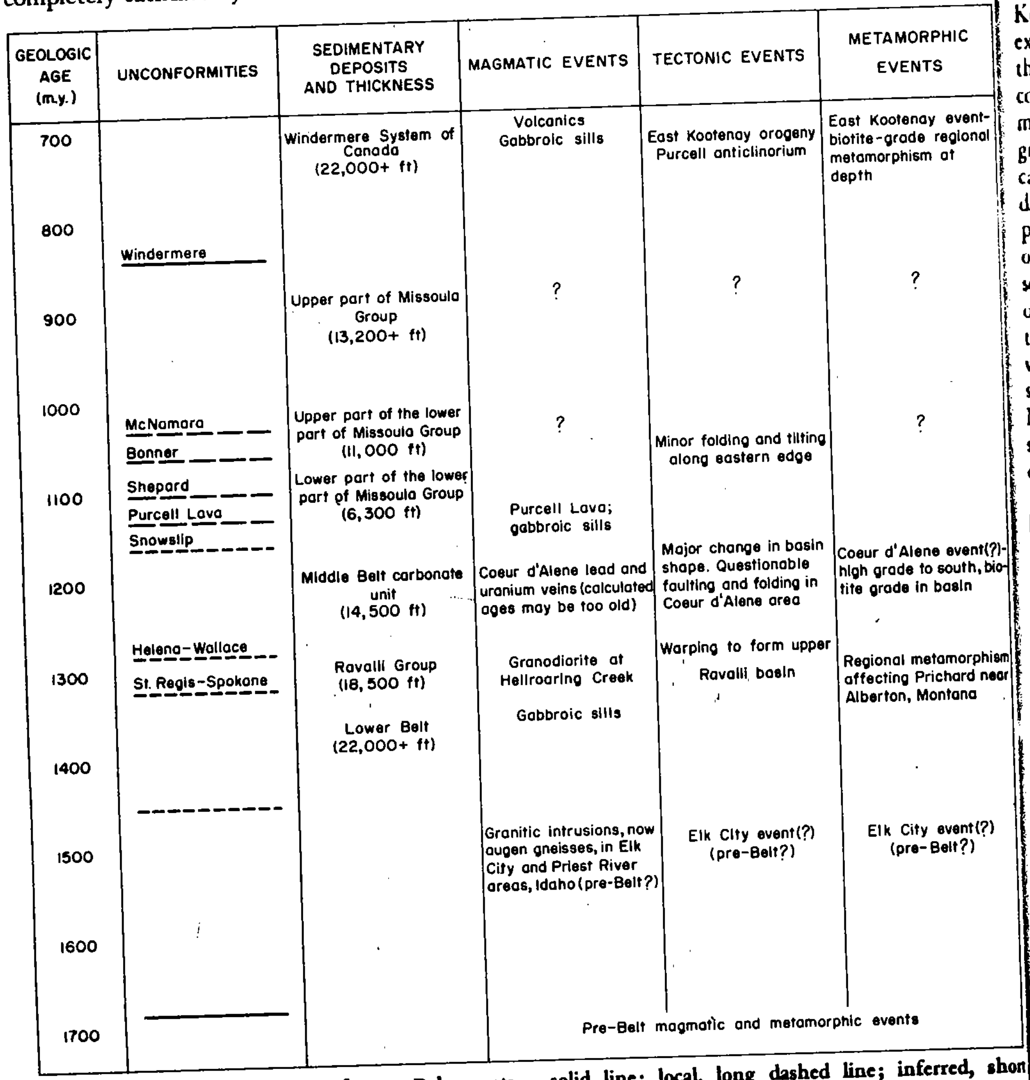
2. Reid and others (1970) discussed a U-Pb age of 1,525 m.y. (Pb^{207}/Pb^{206}) on zircon from an augen gneiss in high-grade metamorphic rocks in a roof pendant in the Idaho batholith near Elk City, Idaho. They believe the augen gneiss intruded the Prichard Formation and perhaps the Ravalli Group and that it is synkinematic with a deformation that also affected the Wallace Formation.

3. S. Clark (1971) suggested that a similar isotopic age of about 1,500 m.y. on zircon from an augen gneiss in high-grade metamorphic rocks at the western edge of the Purcell Trench near Priest River, Idaho, can be interpreted also as dating an intrusive into lower Belt or pre-Belt.

4. Zartman and Stacey (1971) sampled a wide geographic distribution, but particularly along the Lewis and Clark line, of galena in faults. The lead isotope ratios in the galena are interpreted as evolving in a single stage with emplacement between 1,500 and 1,200 m.y. ago.

Some problems in geologic and geochronologic interpretation are indicated in Figure 15 in which generalized information is arrayed opposite a time line. The unconformities are those discussed in previous parts of this report and are shown as solid lines if they have been positively identified anywhere in the basin; only the top and bottom unconformities are currently believed to be basinwide. Thickness of the sedimentary deposits are the maximum reported anywhere in the basin, and the total exceeds by 18,000 ft the maximum thickness exposed at any one place. The sedimentary units are placed opposite the time line in the approximate position suggested by Obradovich and Peterman (1968) from isotopic dating of the sediments in the eastern part of the basin except that the Helena-Wallace and Ravalli units are distributed more evenly through time than they suggested. Magmatic events are those dated on intrusive bodies or veins except the volcanics (now metavolcanics and greenstones) which were extruded in Windermere time and which have not been dated isotopically. At least three ages of gabbroic sills are known; two were mentioned by Obradovich and Peterman (1968), and an older one was documented by Ryan and Blenkinsop (1971). The tectonic events are those displayed in the geologic record, but only the East Kootenay orogeny and faults that contain lead or uranium veins have been dated indirectly. Metamorphic events are those proposed by White (1959), Leech (1962), Reid and Greenwood (1968), and Reid and others (1970). Clearly all these data on sedimentation, intrusion, tectonism, and metamorphism as interpreted by individual workers are not completely compatible, and Figure 15 is merely an attempt to make them as compatible as possible.

Several alternatives in interpretation of the various kinds of data are possible, but none is completely satisfactory at this time. Any proposed working hypothesis will, therefore, satisfy few and outrage many. I will point out a few inconsistencies and enigmas and suggest some alternative interpretations that have not necessarily been considered previously.



GEOLOGIC AGE (m.y.)	UNCONFORMITIES	SEDIMENTARY DEPOSITS AND THICKNESS	MAGMATIC EVENTS	TECTONIC EVENTS	METAMORPHIC EVENTS
700		Windermere System of Canada (22,000+ ft)	Volcanics Gabbroic sills	East Kootenay orogeny Purcell anticlinorium	East Kootenay event-biotite-grade regional metamorphism at depth
800	Windermere				
900		Upper part of Missoula Group (13,200+ ft)	?	?	?
1000	McNamara Bonner	Upper part of the lower part of Missoula Group (11,000 ft)	?	Minor folding and tilting along eastern edge	?
1100	Shepard Purcell Lava Snowslip	Lower part of the lower part of Missoula Group (6,300 ft)	Purcell Lava; gabbroic sills	Major change in basin shape. Questionable faulting and folding in Coeur d'Alene area	Coeur d'Alene event(?)-high grade to south, biotite grade in basin
1200		Middle Belt carbonate unit (14,500 ft)	Coeur d'Alene lead and uranium veins (calculated ages may be too old)		
1300	Helena-Wallace St. Regis-Spokane	Ravalli Group (18,500 ft) Lower Belt (22,000+ ft)	Granodiorite at Hellroaring Creek Gabbroic sills	Warping to form upper Ravalli basin	Regional metamorphism affecting Prichard near Alberton, Montana
1400					
1500			Granitic intrusions, now augen gneisses, in Elk City and Priest River areas, Idaho (pre-Belt?)	Elk City event(?) (pre-Belt?)	Elk City event(?) (pre-Belt?)
1600					
1700			Pre-Belt magmatic and metamorphic events		

Figure 15. Estimated times of some Belt events. Extent of unconformities: basinwide, indicated by solid line; local, long dashed line; inferred, short dashed line.

1. The occurrence of the possibly oldest event at about 1,500 m.y. (Reid and others, 1970; S. Clark, 1971) that involves a high degree of deformation and a high-grade metamorphism of what are believed to be Prichard (and perhaps Ravalli and Wallace) rocks seems open to question because the event is not reflected in the sedimentation record of the basin. Reid and others (1970) recognized the problem and suggested that the sedimentary reflection is an unconformity at the top of the Wallace and the bottom of the Helena, which they suggest is younger than the Wallace (but which now appears to be an eastern facies of the Wallace). Also this 1,500-m.y. event would result in an unconformity in the middle of the 1,100 m.y. isochron of Obradovich and Peterman (1968). Alternatively, it would require a 400-m.y. hiatus between 1,500-m.y.-old Wallace and 1,100-m.y.-old lower part of Missoula Group during which time a basinwide disconformity was formed without any angular unconformity anywhere in the 40,000-sq-mi area. The area described by S. Clark (1971) is in the Kootenay arc mobile belt, which is an area of extensive Mesozoic-Cenozoic intrusion and thrusting. The area of high-grade rocks that contains the 1,500-m.y.-old augen gneiss is almost completely surrounded regionally by low-grade Belt rocks and may have been tectonically thrust into that position. Perhaps the old dates are identifying a previously unknown pre-Belt terrane younger than the 1,700-m.y.-old crystalline known to underlie the Belt in some places. Further support for a 1,500-m.y.-old crystalline basement under at least part of the Belt can perhaps be found in the recent work of Reynolds and Sinclair (1971). Their studies of rock and ore lead isotopes from the Nelson batholith and the Kootenay Arc of southern British Columbia led them to conclude that one of the lead sources is from 1,530-m.y.-old upper crustal rocks. The old lead was mixed with younger lead from Belt rocks to form ores emplaced in Phanerozoic rocks in Mesozoic time. This inferred 1,530-m.y.-old crystalline basement is within a few tens of miles of the exposed 1,500-m.y.-old rocks described by S. Clark (1971).

2. I suggest that the 1,100-m.y. isochron of Obradovich and Peterman that includes rocks of Empire through McNamara Formations is insensitive, as they noted it might be. This "isochron" includes two major changes in basin shape, four known unconformities, two probable unconformities, and more than 30,000 ft of sediment somewhere in the basin. On the other hand, the 1,100-m.y. age seems reasonably documented by them for the lower part of the Missoula Group. It seems likely, however, that the Wallace-Helena and Empire Formations will eventually prove to be more than 1,100 m.y. old.

3. Faulting and fracturing, particularly along the Lewis and Clark line but also at other places in the basin, permitted entrance of fluids that deposited uranium in the Coeur d'Alene district and galena both there and in many other areas. Isotopic data are interpreted to indicate a period of mineralization at about 1,200 m.y. or older (Zartman and Stacey, 1971), although the possibility of remobilization of lead at a later time is briefly mentioned. None of the minerals come from veins that cut rocks younger than the Wallace Formation, although the same fault zones cut Missoula Group rocks. No evidence of faulting in this zone during deposition of Belt sediments has been found, which means that (1) an erosional unconformity at the top of the Wallace removed the evidence, or (2) fault movement at the time of ore emplacement was entirely lateral and left no significant scarps, or (3) the ores are actually post-Missoula Group. Isotopic analysis of a few samples of galena from veins in the Lewis and Clark line where it cuts the Missoula Group (if such veins exist) could aid considerably in limiting the present possible interpretations. A reasonable working hypothesis at present (1971) is that the Precambrian lead ores were emplaced post-Belt during the East Kootenay orogeny at about 800 m.y. ago.

4. The age and cause of regional metamorphism (or metamorphisms) and folding of Belt strata is not everywhere established. Leech (1962, *in* Leech and others, 1963, p. 132–135) argued convincingly for a Precambrian regional metamorphism between 700 and 800 m.y. ago in southern British Columbia, and he related this event to the East Kootenay orogeny of White (1959). The broad open folding and some faulting is datable as pre-Flathead (Middle Cambrian) because of overlap of these structures by Flathead Quartzite. An even younger contributor to regional metamorphism involves the thermal effects of Mesozoic-Cenozoic intrusive rocks—particularly in the western and southeastern parts of the basin where they increase in abundance and size toward the west and south—which have altered rocks to biotite grade stratigraphically as high as the middle part of the Wallace Formation. The thermal effects of Mesozoic-Cenozoic intrusives are more widespread than previously supposed, and two K-Ar dates on biotite from normal looking rocks from the Prichard in the Pend Oreille area give ages of 68 and 92 m.y. (Harrison and others, 1972). Older metamorphism is also suggested by the

available data. K-Ar and Pb-α dates on minerals in higher grade metamorphic rocks cited by Reid and Greenwood (1968, p. 76–77) establish a minimum age of about 1,200 m.y. for their "Coeur d'Alene event." Obradovich and Peterman (1968) noted that a low-grade regional metamorphism in rock from the upper part of the Prichard is indicated by a 1,330-m.y. age of metamorphic biotite in the Alberton, Montana, area. This older metamorphism appears to have caused some of the basinwide regional metamorphic effects where intrusives are scarce. Such a metamorphism results from depth of burial and thermal gradient. The column of rocks available to cause such a metamorphism was apparently not very thick, and this leads to the inference of a relatively high heat flow through the basin as a principal contributor to regional metamorphism. If this heat flow was available, regional metamorphism may have proceeded as the rock stack accumulated. This, or any other metamorphism, should be considered as a possible driving force for redistribution of copper (and perhaps other metals) in both Precambrian and later time.

CONCLUDING REMARKS

This synthesis of the geometry and sedimentary record in the Precambrian Belt basin leaves many questions unanswered. The purpose of this paper is to present and analyze new stratigraphic data, to point out conflicts in various types of data and to suggest possible resolutions of these conflicts, and to indicate relations known to date between the stratigraphic framework and the stratabound copper occurrences.

Generalized outlines of the size and shape of the basin combined with sedimentological data on facies changes of rocks within the basin clearly show multiple source areas around the basin. Major adjustments in the basin are indicated at the end of Ravalli and Helena-Wallace times, but the relations of these changes to metamorphic and tectonic events of inferred Belt age around the edge of the basin are problematical.

Copper as an element in the basin is surely syngenetic or diagenetic. Widespread occurrences of anomalous amounts of copper or of copper ore may be syngenetic or diagenetic, but a major component of epigenetic reconcentration seems likely for at least the Revett ores. The basin has had various types of paleohydrologic processes operating within it, ranging in age from time of diagenesis to time of intrusion of Mesozoic-Cenozoic plutons. None of these sources of migrating fluids can be eliminated as yet as a possible transporter of metals.

ACKNOWLEDGMENTS

I am deeply indebted to many of my U.S. Geological Survey colleagues, particularly A. B. Campbell, A. L. Clark, S.H.B. Clark, Anna Hietanen, S. W. Hobbs, M. R. Mudge, J. D. Obradovich, Z. E. Peterman, G. D. Robinson, and R. E. Zartman, for stimulating discussions of Belt geology and geochronology. I am especially indebted to A. B. Griggs, F. K. Miller, E. T. Ruppel, and J. D. Wells of the U.S. Geological Survey for their generous permission to use unpublished data. Others who have contributed some of their knowledge include John Trammell, University of Washington; R. R. Reid and D. T. Bishop, Idaho Bureau of Mines and Geology; and W. M. Johns, Montana Bureau of Mines and Geology. None of these scientists is necessarily convinced that the interpretations presented in this report are entirely correct.

M. R. Mudge and Z. E. Peterman not only found errors in an earlier draft of this paper, but they also kindly called my attention to pertinent published papers that I had overlooked.

REFERENCES CITED

Bierwagen, E. E., 1964, Geology of the Black Mountain area, Lewis and Clark and Powell Counties, Montana [Ph.D. thesis]: Princeton, New Jersey, Princeton Univ.

Burwash, R. A., Baadsgaard, H., and Peterman, Z. E., 1962, Precambrian K-Ar dates from the western Canada sedimentary basin: Jour. Geophys. Research, v. 67, no. 4, p. 1617–1625.

Calkins, F. C., and Emmons, W. H., 1915, Description of the Phillipsburg quadrangle, Montana: U.S. Geol. Survey Geol. Atlas, Folio 19 25 p.

Campbell, A. B., 1960 [1961], Geology and mineral deposits of the St. Regis–Superior area, Mineral County, Montana: U.S. Geol. Survey Bull. 1082–I, p. 545–612.

Childers, M. O., 1963, Structure and stratigraphy of the southwest Marias Pass area, Flathead County, Montana: Geol. Soc. America Bull. v. 74, no. 2, p. 141–164.

Clark, A. L., 1971, Stratabound copper sulfides in the Precambrian Belt Supergroup, northern Idaho and northwestern Montana, U.S.A. Proceedings of the IMA-IAGOD Meeting, 1970 IAGOD Volume, Soc. Mining Geologists of Japan Spec. Issue No. 3, p. 261–267.

Clark, S.H.B., 1971, Structure and metamorphism in a high-grade Precambrian terrane in northern Idaho [abs.]: Geol. Assoc. Canada Cordilleran Section Program, p. 8–9.

Freeman, V. L., Ruppel, E. T., and Klepper, M. R., 1958, Geology of part of the Townsend Valley, Broadwater and Jefferson Counties, Montana: U.S. Geol. Survey Bull. 1042-N, p. 481–556.

Gabrielse, Hubert, and Reesor, J. E., 1964, Geochronology of plutonic rocks in two areas of the Canadian Cordillera, *in* Geochronology of Canada: Royal Soc. Canada Spec. Pub. 8, p. 96–138.

Gibson, Russell, 1948, Geology and ore deposits of the Libby quadrangle, Montana, *with sections on* Pleistocene glaciation by W. C. Alden and Physiography by J. T. Pardee: U.S. Geol. Survey Bull. 956, 131 p.

Giletti, B. J., 1966, Isotopic ages from southwestern Montana: Jour. Geophys. Research, v. 71, no. 16, p. 4029–4036.

Gilluly, James, Reed, J. C., Jr., and Cady, W. M., 1970, Sedimentary volumes and their significance: Geol. Soc. America Bull., v. 81, no. 2, p. 353–376.

Harper, C. T., 1967, On the interpretation of potassium-argon ages from Precambrian shields and Phanerozoic orogens: Earth and Planetary Sci. Letters, v. 3, no. 2, p. 128–132.

Harrison, J. E., and Campbell, A. B., 1963, Correlations and problems in Belt Series stratigraphy, northern Idaho and western Montana: Geol. Soc. America Bull., v. 74, no. 12, p. 1413–1428.

—— 1968, Correlation of and facies changes in the carbonaceous, calcareous, and dolomitic formations of the Precambrian Belt–Purcell Supergroup—Discussion: Geol. Soc. America Bull., v. 79, no. 8, p. 1093–1095.

Harrison, J. E., and Grimes, D. J., 1970, Mineralogy and geochemistry of some Belt rocks, Montana and Idaho: U.S. Geol. Survey Bull. 1312-0, 49 p.

Harrison, J. E., and Jobin, D. A., 1963, Geology of the Clark Fork quadrangle, Idaho-Montana: U.S. Geol. Survey Bull. 1141-K, 38 p.

—— 1965, Geologic map of the Packsaddle Mountain quadrangle, Idaho: U.S. Geol. Survey Geol. Quad. Map GQ–375.

Harrison, J. E., Reynolds, M. W., Kleinkopf, M. D., and Pattee, E. C., 1969, Mineral resources of the Mission Mountains Primitive Area, Missoula and Lake Counties, Montana: U.S. Geol. Survey Bull. 1261-D, 48 p.

Harrison, J. E., Kleinkopf, M. D., and Obradovich, J. D., 1972, Tectonic events at the intersection between the Hope fault and the Purcell Trench, northern Idaho: U.S. Geol. Survey Prof. Paper 719, (in press).

Hietanen, Anna, 1968, Belt Series in the region around Snow Peak and Mallard Peak, Idaho: U.S. Geol. Survey Prof. Paper 344-E, 34 p.

Hobbs, S. W., Griggs, A. B., Wallace, R. E., and Campbell, A. B., 1965, Geology of the Coeur d'Alene district, Shoshone County, Idaho: U.S. Geol. Survey Prof. Paper 478, 139 p.

Johns, W. M., 1970, Geology and mineral deposits of Lincoln and Flathead Counties, Montana: Montana Bur. Mines and Geology Bull. 79, 182 p.

Judson, Sheldon, and Ritter, D. F., 1964, Rates of regional denudation in the United States: Jour. Geophys. Research, v. 69, no. 16, p. 3395–3402.

Keefer, W. R., 1972, Geologic map of the west half the Neihart quadrangle, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-726 (in press).

King, P. B., 1969a, Tectonic map of North America: U.S. Geol. Survey spec. map, scale 1:5,000,000.

—— 1969b, The tectonics of North America—a discussion to accompany the tectonic map of North America, scale 1:5,000,000: U.S. Geol. Survey Prof. Paper 628, 95 p.

Kleinkopf, M. D., Mudge, M. R., and Harrison, J. E., 1968, Aeromagnetic and gravity studies across the northern disturbed belt in northwestern Montana [abs.]: Am. Geophys. Union, v. 41, no. 1, p. 330.

Knopf, Adolph, 1963, Geology of the northern part of the Boulder bathylith and adjacent area, Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-381.

Leech, G. B., 1958, Fernie map-area, west half, British Columbia: Canada Geol. Survey Paper 58–10, 40 p.

—— 1962, Metamorphism and granitic intrusions of Precambrian age in southeastern British Columbia: Canada Geol. Survey Paper 62–13, 8 p.

Leech, G. B., Lowdon, J. A., Stockwell, C. H., and Wanless, R. K., 1963, Age determinations and geological studies: Canada Geol. Survey Paper 63–17, 140 p.

Maxwell, D. T., and Hower, John, 1967, High-grade diagenesis and low-grade metamorphism of illite in the Precambrian Belt Series: Am. Mineralogist, v. 52, nos. 5–6, p. 843–857.

McGill, G. E., 1970, Belt Supergroup correlation, Helena to Glacier National Park, Montana: Am. Assoc. Petroleum Geologists Bull., v. 54, no. 2, p. 349–352.

McGill, G. E., and Sommers, D. A., 1967, Stratigraphy and correlation of the Precambrian Belt Supergroup of the southern Lewis and Clark Range, Montana: Geol. Soc. America Bull., v. 78, no. 3, p. 343–352.

McKelvey, G. E., 1968, Depositional environment of the middle Belt carbonate units of Belt Supergroup, Montana and Idaho: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 858–864.

McMannis, W. J., 1963, LaHood Formation—a coarse facies of the Belt Series in southwestern Montana: Geol. Soc. America Bull., v. 74, no. 4, p. 407–436.

Mertie, J. B., Jr., Fischer, R. P., and Hobbs, S. W., 1951, Geology of the Canyon Ferry quadrangle, Montana: U.S. Geol. Survey Bull. 972, 97 p.

Mudge, M. R., 1970, Origin of the disturbed belt in northwestern Montana: Geol. Soc. America Bull., v. 81, no. 2, p. 377–392.

—— 1972, Pre-Quaternary rocks of the Sun River Canyon area, northwestern Montana: U.S. Geol. Survey Prof. Paper 663-A, 138 p.

Mudge, M. R., Earhart, R. L., Watts, K. C., Jr., Tuchek, E. T., and Rice, W. L., 1971, Mineral resources of the Lincoln Back Country area, Powell and Lewis and Clark Counties, Montana, *with a section on* Geophysical surveys by D. L. Peterson: U.S. Geol. Survey open-file rept., 320 p.

Nelson, W. H., 1963, Geology of the Duck Creek Pass quadrangle, Montana: U.S. Geol. Survey Bull. 1121-J, 56 p.

Obradovich, J. D., and Peterman, Z. E., 1968, Geochronology of the Belt Series, Montana: Canadian Jour. Earth Sci., v. 5, no. 3, pt. 2, p. 737–747.

Price, R. A., 1962, Fernie map-area, east half, Alberta and British Columbia: Canada Geol. Survey Paper 61-24, 65 p.

—— 1964, The Precambrian Purcell System in the Rocky Mountains of southern Alberta and British Columbia: Bull. Canadian Petroleum Geology, v. 12, spec. issue, Guidebook, August 1964, p. 399–426.

Ransome, F. L., 1905, Ore deposits of the Coeur d'Alene district, Idaho: U.S. Geol. Survey Bull. 260, p. 274–303.

Reesor, J. E., 1956, Dewar Creek map-area with special emphasis on the White Creek batholith, British Columbia: Canada Geol. Survey Mem. 292, 78 p.

Reid, R. R., and Greenwood, W. R., 1968, Multiple deformation and associated progressive polymetamorphism in the Beltian rocks of the Idaho batholith, Idaho, U.S.A.: Internat. Geol. Cong., 23rd, Prague, 1968, v. 4, p. 75–87.

Reid, R. R., Greenwood, W. R., and Morrison, D. A., 1970, Precambrian metamorphism of the Belt Supergroup in Idaho—Discussion: Geol. Soc. America Bull., v. 81, no. 3, p. 915–917.

Reynolds, P. H., and Sinclair, A. J., 1971, Rock and ore-lead isotopes from the Nelson batholith and the Kootenay arc, British Columbia, Canada: Econ. Geology, v. 66, p. 259–266.

Rice, H.M.A., 1941, Nelson map-area, east half, British Columbia: Canada Geol. Survey Mem. 228, 86 p.

Robinson, G. D., 1967, Geologic map of the Toston quadrangle, southwestern Montana: U.S. Geol. Survey Misc. Geol. Inv. Map I-486.

Ross, C. P., 1959, Geology of Glacier National Park and the Flathead region, northwestern Montana: U.S. Geol. Survey Prof. Paper 296, 125 p.

—— 1963, The Belt series in Montana, *with* geologic map compiled by B.A.L. Skipp, *and* *section on* Paleontologic criteria by Richard Rezak: U.S. Geol. Survey Prof. Paper 346, 122 p.

Ryan, B. D., and Blenkinsop, J., 1971, Geology and geochronology of the Hellroaring Creek stock, British Columbia: Canadian Jour. Earth Sci., v. 8, p. 85–95.

Smith, A. G., and Barnes, W. C., 1966, Correlatio of and facies changes in the carbonaceou calcareous, and dolomitic formations of th Precambrian Belt-Purcell Supergroup: Geol Soc. America Bull., v. 77, no. 12, p. 1399–1426

Trammell, John, 1970, Stratabound base meta sulfides in the Belt Supergroup of Montana Geol. Soc. America, Abs. with Program (Rocky Mountain Sec.), v. 2, no. 5, p. 352.

Wagner, W. R., 1949, The geology of part of th south slope of the St. Joe Mountains, Shoshon County, Idaho: Idaho Bur. Mines an Geology Pamph. 82, 48 p.

Walcott, C. D., 1899, Pre-Cambrian fossiliferou formations: Geol. Soc. America Bull., v. 10, 199–244.

Wallace, R. E., and Hosterman, J. W., 195 Reconnaissance geology of western Miner County, Montana: U.S. Geol. Survey Bu 1027-M, p. 575–612.

White, W. H., 1959, Cordilleran tectonics British Columbia: Am. Assoc. Petroleu Geologists Bull., v. 43, no. 1, p. 60–100.

White, W. S., 1971, A paleohydrologic model mineralization of the White Pine copp deposit, northern Michigan: Econ. Geolog v. 66, p. 1–13.

Willis, Bailey, 1902, Stratigraphy and structu Lewis and Livingston ranges, Montana: Ge Soc. America Bull., v. 13, p. 305–352.

Zartman, R. E., and Stacey, J. S., 1971, The use lead isotopes to distinguish between P cambrian and Mesozoic-Cenozoic minerali tion in Belt Supergroup rocks, northwest Montana and northern Idaho: Econ. Geolo v. 66, no. 6, p. 849–860.

MANUSCRIPT RECEIVED BY THE SOCIETY AUGU 17, 1971

REVISED MANUSCRIPT RECEIVED DECEMBER 1971

PUBLICATION AUTHORIZED BY THE DIRECTOR, U GEOLOGICAL SURVEY

A. J. ERICKSON *Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*
C. E. HELSLEY *Geosciences Division, University of Texas at Dallas, Dallas, Texas 75221*
GENE SIMMONS *Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

Heat Flow and Continuous Seismic Profiles in the Cayman Trough and Yucatan Basin

ABSTRACT

The average of 8 heat-flow measurements in the western half of the Cayman Trough is 2.07 ± 0.25 HFU, markedly higher than the averages of 1.46 ± 0.19 HFU (n = 9) and 1.38 ± 0.19 HFU (n = 3) obtained on the Yucatan Basin and Cayman Ridge, respectively. There is a tendency for the highest heat-flow values to be situated in the deepest areas of the trough. No systematic variation of heat flow with distance along the trough was observed. The existence of a long, narrow zone of uniformly high heat flow along the floor of the Cayman Trough, along with other geophysical data, suggest a tectonic origin for the trough by extension normal to the axis of the trough and/or by strike-slip faulting related to the eastward movement of the Caribbean lithospheric plate relative to the Atlantic plate. The mean heat flows through the Yucatan Basin and Cayman Ridge are nearly equal to the average world heat flow. Seismic profiler data and piston cores from the Cayman Trough and Ridge and in the Yucatan Basin show that the Cayman Trough is a geologically young feature, probably having originated since the early Tertiary, when the trough and adjacent ridge developed simultaneously. Subsequently, the western end of the trough has received terrigenous sediment from a source located near the Gulf of Honduras, rather than from the Yucatan Basin or Honduras. The central and eastern parts of the trough have been and remain isolated from any major sediment sources. Tectonic activity in the trough has been largely restricted to the margins, as evidenced by the location of the deepest basins, fault structures, and seismicity along the southern margin of the trough west of 83° W. and along the base of the Cayman Ridge east of 81° W.

INTRODUCTION

Statement of the Problem

The Cayman Trough is a young, elongate depression in the floor of the northwestern Caribbean Sea. It is well defined structurally by an extraordinarily thin crust (Ewing and others, 1960) and topographically by water depths of 7 km or more (Hersey and Rutstein, 1958). The occurrence of earthquakes, the presence of thin sediments, rugged topographic relief on the floor and walls of the trough, and the basic linearity and parallelism of geophysical and topographic features of the trough that extend over a distance of 1600 km, all suggest that the trough is a major, active tectonic feature of the Caribbean. The origin of the trough and the sense and magnitude of displacements along or across the trough are poorly understood and are of great interest because the history and dynamics of crustal plates in the eastern Pacific west of Central America (Molnar and Sykes, 1969) and in the Atlantic Ocean (Funnell and Smith, 1968) appear to be related intimately to tectonic movements in the Caribbean.

Continuous seismic profiler and bathymetric data were obtained along more than 2,600 km of track in the western Cayman Trough and in the Yucatan Basin. The locations of the seismic profile lines and of the 13 heat-flow measurements obtained as part of this survey are shown in Figure 1. The results of these measurements, their interpretation, and their relevance to the sedimentary and tectonic history of the western Caribbean are presented in the following sections.

Previous Investigations

Bathymetric Data. Maximum water depths in the Caribbean occur within the Cayman

---

Geological Society of America Bulletin, v. 83, p. 1241–1260, 9 figs., May 1972