Tectonic Features of the Precambrian Belt Basin and Their Influence on Post-Belt Structures

GEOLOGICAL SURVEY PROFESSIONAL PAPER 866

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By JACK E. HARRISON, ALLAN B. GRIGGS, and JOHN D. WELLS

ABSTRACT

The Belt basin represents a slowly sinking reentrant on the North American craton that began to form about 1,500 m.y. ago and persisted for more than 600 m.y. This sinking block somewhat resembles an aulacogen, but the basin is not a true grabenlike trough extending into the craton at a plate separation. The sinking block was at times almost triangular in shape; a central platform was bounded by the North American craton and associated narrow troughs on the south and northeast, and on the northwest by the Cordilleran miogeocline that extended past several reentrants along the North American craton. Following the end of Belt sedimentation and the onset of the East Kootenay orogeny about 850 m.y. ago, the Belt basin has been subjected to a variety of stresses. Within the basin the strain appears to reflect the inhomogeneities of the platform and troughs formed in Belt time. During and after the East Kootenay orogeny the central platform acted as a somewhat rigid block and contains gentle folds and vertical block faults; the southern trough contains a series of tear faults and tight folds of the Lewis and Clark line; the northeastern trough and old cratonic edge are the site of the Montana disturbed belt; the intersection of the two troughs forms an embayment that contains the Boulder batholith and related volcanics; and the old miogeocline on the northwest is the site of the Kootenay arc mobile belt, which contains gneiss domes and thrusts that rode eastward up over the platform block.

Although this model aids in explaining many tectonic elements of the basin, some elements are still enigmatic. Unexplained are the genesis and location of the Idaho batholith, the Coeur d'Alene mining district, and the Montana disturbed belt.

INTRODUCTION

The influence of Precambrian structures on Phanerozoic tectonic patterns of continents has become more apparent as information on the Precambrian accumulates. Within the past decade much of the terrane containing Belt rocks of Precambrian age (about 1,500-850 m.y.) has been remapped or mapped in modest detail for the first time. Compilation of the major tectonic features (fig. 3) based on this new information, together with a significant increase in knowledge of Belt geologic history, provides an opportunity to update and reexamine the tectonics of the basin. Completion of a new geologic map of the basin at 1:250,000 is still perhaps a decade away, so this report should be considered to be interim and preliminary.

Among the many tectonic events recorded in rocks of the basin, some can now be reinterpreted with confidence, some can be reinterpreted with trepidation in view of new data and geologic restraints, and others must still be considered as controversial, or at least unresolved. We will focus herein on (1) genesis of the basin; (2) Paleozoic events previously neglected in analyzing basin tectonics because of limited preservation in the geologic record; (3) some aspects concerning the origin of the Montana disturbed belt; and (4) tectonic events along the Lewis and Clark line—a zone first noticed by Calkins and Jones (1914), named and brought to geologic prominence by Billingsley and Locke (1939), and speculated about by many geologists. We, too, will speculate about the Lewis and Clark line, even though some structures within the line still, in our opinion, do not have a satisfactory geologic explanation.

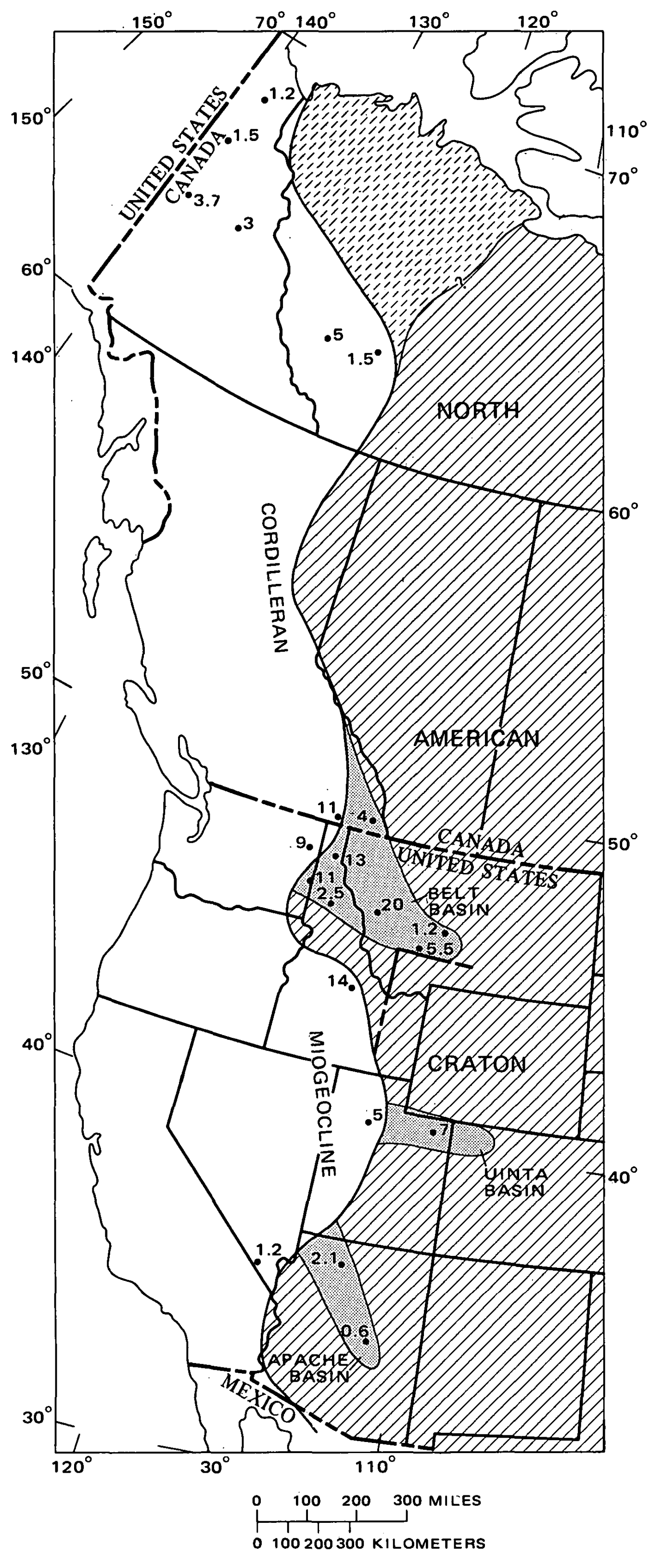
We gratefully acknowledge helpful discussion with S. W. Hobbs, G. D. Robinson, M. R. Mudge, and R. L. Earhart on basin tectonics and problems. We especially thank E. T. Ruppel, who contributed his knowledge of and thoughts about Belt rocks and other rocks of Belt age in southwestern Montana and adjacent parts of Idaho, and whose help was fundamental to construction of a paleotectonic model of the Belt basin. The manuscript benefited from critical reviews by S. S. Oriel, J. L. Talbot, R. M. Weidman, and R. L. Earhart. W. G. Pierce not only made constructive suggestions but also called our attention to pertinent literature we had overlooked. R. A. Price patiently noted factual errors in the original manuscript and persuaded us to rethink or qualify certain interpretations.

GENESIS AND FILLING OF THE BELT BASIN

Our working hypothesis is that the Belt basin is one of several epicratonic reentrants formed along the eastern edge of the Cordilleran miogeocline during Precambrian Y time[1] (fig. 1). The most complete record of sedimentation in both the reentrants and the miogeocline appears

[1] The letter refers to an interim time scale for the Precambrian adopted for use by the U.S. Geological Survey (James, 1972). Terms used in this manuscript are Precambrian Y (1,600 to 800 m.y. ago) and Precambrian Z (800 to 570 m.y. ago). Time of deposition of the Belt Supergroup corresponds approximately to Precambrian Y, and that of the Windermere Group or the Windermere System of Canada, approximately to Precambrian Z.

to be that of the Belt basin, where 20 km of relatively undisturbed low-grade metasedimentary rock still remains. Correlations between the extensive Belt section and other sediments deposited during the 800-m.y. time span



of Precambrian Y time are not yet completely worked out, because of scattered limited exposures, insufficient mapping at some places, and difficulties in geochronologic dating of sedimentary rocks (Crittenden and others, 1972). However, nearly continuous deposition of sediments from the North American craton clearly filled the reentrants and at places dumped a clastic wedge into the miogeocline (fig. 1).

Broad tectonic elements within the Belt basin can now be identified with various degrees of certainty from recently accumulated data on stratal thicknesses, composition of detritus, directions of clast coarsening, and various primary structures. These elements are shown in figure 2, where we have also named some of them for convenience in discussion. The Flathead and Coeur d'Alene troughs, the Helena embayment, and a dome of late Belt time in the area of the Purcell platform were identified (but not named) by Harrison (1972) from isopach maps of various Belt formations. Isopach maps, facies, and fan-shaped directions of deltaic sedimentary transport radiating outward from south to north show clearly that sediments of many Belt formations had a cratonic source area from the south side of the Belt basin (Harrison, 1972; Hrabar, 1971) and thus indicate that at least at times a large cratonic prong or island formed the south side of the Belt basin reentrant. The basin boundary fault and associated coarse facies (LaHood Formation) of old Belt age in the Helena embayment were studied in some detail by McMannis (1963). Recent investigations by Winston (1973) indicated that much of the youngest Belt rock had a source area from the south and that a coarse conglomeratic facies of young Belt age occurs along the west side of the Dillon block. This leads to our inference that the older Precambrian crystalline rocks of the Dillon block are bounded by high-angle faults on the north and west, a structure similar to that bounding the southeastern part of the Beartooth block about 100 km to the east. Whether the Belt basin connected through to the south to form our inferred Belt seaway or whether these younger conglomerates accumulated in a southern arm of the Belt basin is a matter of conjecture, from currently available data. In figure 2 we have shown the Belt seaway in patterns of both craton and Belt basin to indicate that the craton may have connected with Belt island at various times during Precambrian Y.

Ruppel (1973) has mapped and described a thick sequence of clastic rocks of Belt age in the area we call the Belt seaway. The uppermost part of the section is similar to Belt rocks, but the great bulk of the section is quartz-

FIGURE 1 (left).—Principal basins of sedimentation along the U.S.-Canadian Cordillera during Precambrian Y time (1,600-800 m.y. ago). Compiled largely from Gabrielse (1972), King (1969), and Harrison (1972). Numbers show approximate thickness, in kilometers, of remnant Precambrian Y sedimentary rocks. Dashed-line pattern in northwest part of craton indicates possible extension of craton.

ite and siltite containing negligible carbonate and red beds, and thus it only slightly resembles Belt. The lower and middle parts cannot be matched directly with the Belt stratigraphic section without calling upon what appear to be unreasonable facies changes and drastic changes in sedimentation environment over very short distances—a sedimentational characteristic contrary to the habit in the Belt basin itself. Ruppel suggested that the section has been telescoped by eastward transport on thrusts having 160 km or more of tectonic translation. The estimated amount of eastward translation (160 km) is approximately the same order of magnitude as that proposed by Price and Mountjoy (1970) for eastward translation in the southern Canadian Rockies (200 km) and by Peterson (1973) for that of the thrust and fold belt in northern Utah and southern Idaho (80-120 km). Ruppel inferred that the lower part of the rock stack is Precambrian Y age, but it is a clastic section of the Cordilleran miogeocline that has been brought subjacent to Belt basin rocks which were deposited in the Belt seaway. We accept Ruppel's tentative interpretation, and it requires that the Cordilleran miogeocline of Belt time be located relative to Belt island and the Belt seaway approximately as shown in figure 2.

A final bit of evidence for Belt island and the Belt seaway comes from a study by Myers (1952) of Belt age rocks in thrust plates now in the northeastern part of the Belt seaway (fig. 2). There, westward coarsening in grain size and increase in feldspar content of highly feldspathic quartzites indicate a granitic source terrane to the west—our proposed Belt island. The amount of tectonic transport necessary to put these rocks in their present position far east of the proposed source area is, again, about 160 km.

Sedimentation within the Belt basin and along the Cordilleran miogeocline occurred over the interval from about 1,500 to 850 m.y. ago during Precambrian Y time. Within the Belt basin, early deposits, particularly along the join of the basin and the miogeocline, contain abundant turbidites (Edmunds, 1973). Later deposits were largely red-bed assemblages and minor carbonate both within the basin and in adjacent parts of the miogeocline. The thickest young Belt deposits accumulated in the Helena embayment. Except for the rare conglomerates deposited along the faults separating the Belt basin from the Dillon block, the sediments are all fine grained; disconformities are difficult to identify, angular unconformities are rare, and facies changes are subtle. Thus, although troughs and a dome are identifiable tectonic elements of the basin, the total picture of basin filling is one of slow sinking and warping of an epicratonic reentrant in almost perfect balance with a slowly rising craton of probable low relief. Even the low dome of late Belt time received sediment during most of its existence, attesting to differential subsidence rather than to uplift as its primary cause.

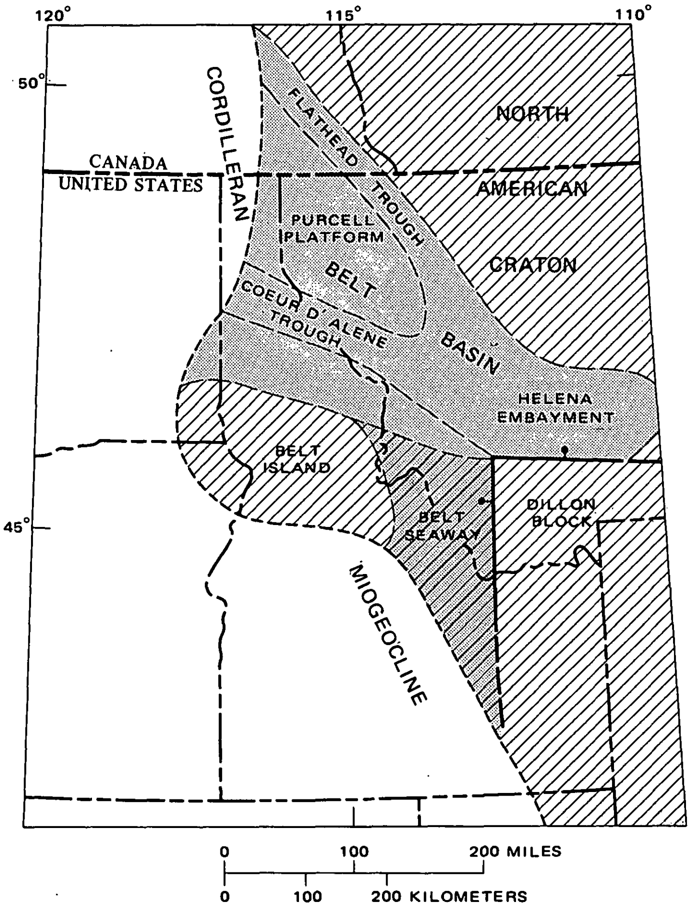


FIGURE 2.—Principal tectonic elements of the reentrant that formed the Belt basin, as inferred from the sedimentation record. Shading represents Belt depositional area. Paleotectonic reconstruction as interpreted by J. E. Harrison and E. T. Ruppel. Bar and ball on downthrown sides of faults.

Magmatic activity in the Belt basin during Precambrian Y time appears to have been minimal. The first (about 1,300 m.y. old) of two groups of basic sills were intruded in particular abundance into sedimentary rocks along what we infer to have been the border between the reentrant and the miogeocline, as were the only known granitic plutons—the Hellroaring Creek stock and its associated bodies. A local deformation of Belt rocks in that area is the only known folding of any significance during Belt time. One volcanic event that resulted in the Purcell Lava occurred in late Belt time (about 1,100 m.y.) in the northeastern part of the basin.

By the end of Belt time several crustal inhomogeneities had developed in and near the Belt basin. These include not only the reentrant itself, the sharp bend of the Cordilleran miogeocline around Belt island, and the intersection of the reentrant with the miogeocline, but also several sags and swells that must have been reflected in the basement of the reentrant. Each irregularity affected many subsequent geologic events.

Figure 3 is a compilation of the major structures in the Belt basin. Many of these will be discussed in detail in later pages, but even a cursory comparison of figures 2 and 3 shows some striking similarities between the broad tectonic elements of the Belt basin of sedimentation and major patterns of post-Belt deformation.

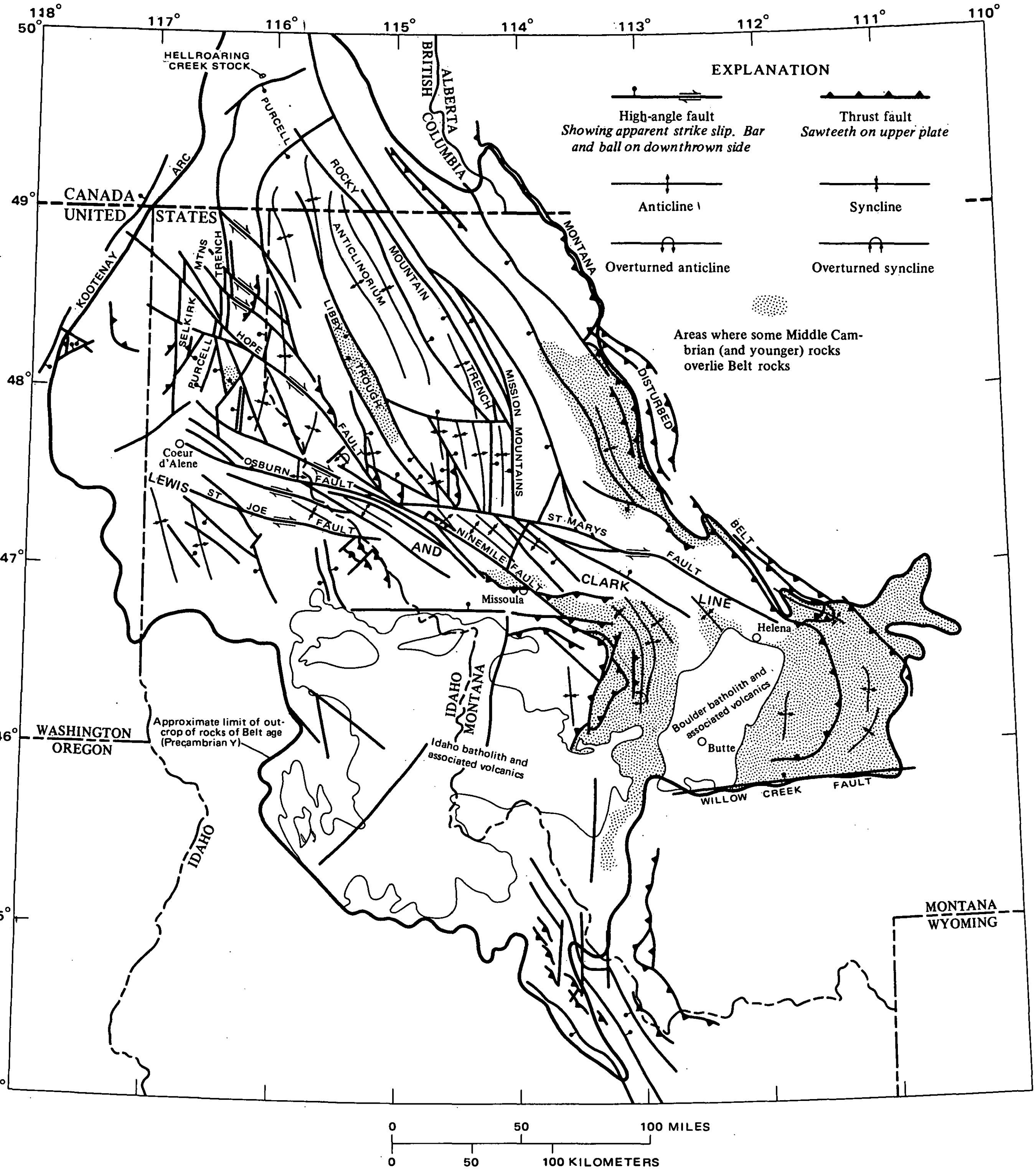


FIGURE 3.—Principal folds and faults in Belt terrane. Compilation by J. E. Harrison; revised from Bayley and Muehlberger (1968), largely through application of as-yet-unpublished 1:25,000 and 1:250,000 geologic mapping by various members of the U.S. Geological Survey, including A. B. Griggs, J. D. Wells, M. R. Mudge, R. L. Earhart, J. E. Harrison, F. K. Miller, G. D. Robinson, and E. T. Ruppel.

IS THE BELT BASIN AN AULACOGEN?

The subsiding block resulting in the Belt basin has some features in common with an aulacogen (Salop and Scheinmann, 1969) or a taphrogeosyncline. Aulacogens were described by Hoffman, Dewey, and Burke (1974) as "long lived deeply-subsiding transverse troughs, at times fault-bounded, that extend from orthogeosynclines far into adjacent foreland platforms." The Belt basin also meets some of the other requirements for an aulacogen, such as evidence of internal tectonic movement that was largely vertical and absence of much high-grade metamorphism. It does lack, however, "periodic alkalic basalt and fanglomerate," although some of each is known in Belt time. Paleocurrents in Belt rocks are both parallel and transverse to the structural trend, perhaps because of the triangular shape of the reentrant, whereas those of the ideal aulacogen are parallel to the graben-shaped epicontinental reentrant. Hoffman, Dewey, and Burke noted that many aulacogens form at plate separations and that sediment sources from both sides provide infill to the orthogeosyncline. For Belt and Windermere sediments, however, no evidence has yet been found for a western sediment source, other than Belt island, either within the Belt basin or along the geosyncline (Price, 1964; Stewart, 1970; Gabrielse, 1972; Harrison, 1972; Edmunds, 1973). The concept, however, that the Belt basin is a modified aulacogen or taphrogeosyncline is certainly viable and should prove to be a useful working hypothesis.

PRECAMBRIAN Z EVENTS

Rocks of Precambrian Z age unconformably overlie rocks of Precambrian Y age in parts of Canada (Gabrielse, 1972) and conformably or unconformably overlie Precambrian Y rocks in some parts of the United States (Crittenden and others, 1971, 1972; Stewart, 1972). In the northern Cordillera and in southeastern British Columbia, uplift and mild deformation followed by erosion reflect, respectively, the Racklan and East Kootenay orogenies of about 800 m.y. ago (Gabrielse, 1972). During uplift the now-filled reentrants behaved as part of the craton, and Windermere and equivalent strata overlapped and were deposited seaward from Belt and equivalent strata of the older Cordilleran miogeocline. Windermere sediments and volcanic rocks unconformably overlie Belt strata only along the western edge of the Belt basin. Stewart (1970, 1972) considered Precambrian Z strata as the first deposits in the Cordilleran geosyncline and argues for a continental separation at that time. It seems to us, however, that the Cordilleran geosyncline was present all along the western edge of the North American continent in Precambrian Y time. We are not aware of evidence for a western source for either Precambrian Y or Z sediments. We, therefore, find it difficult to accept genesis of the Cordilleran geosyncline as a plate separation during either Precambrian Y or Z time.

The Precambrian Z sedimentation continued uninterrupted through Lower Cambrian (Stewart, 1970), but there are no known sedimentary rocks belonging to that sedimentation cycle within the Belt basin. The uplift during the East Kootenay orogeny apparently was sufficient to expose Belt rocks, and they underwent their first major period of erosion.

We assume that tectonic and magmatic events recorded beneath the Middle Cambrian quartzites (Flathead Quartzite and equivalents) in the United States part of the Belt basin represent effects of the East Kootenay orogeny. These events include gentle folding, high-angle faulting, and intrusion of another group of basic sills. Middle Cambrian quartzites overlie the Belt rocks disconformably in many areas (fig. 3) and with low angular relation at some places. Steep block faults of pre-Flathead age with several hundred meters of throw have been mapped in the area northwest of Coeur d'Alene (King and others, 1970), in the area just west of Missoula (Campbell, 1960; Wells, 1974), and in the area just east of Missoula (Maxwell, 1959, 1965). Lead isotopes interpreted to be of Precambrian age have been found in galena along high-angle faults of the Osburn and Hope fault zones as well as along many other faults scattered throughout the basin (Zartman and Stacey, 1971). Basic sills folded in with broad open structures in many parts of the basin give ages in the range 750-850 m.y. (J. D. Obradovich, unpub. data; Harrison and others, 1972; Mudge, 1972). Basic sills near the Purcell Trench thin toward or stop at the Hope fault, which suggests that the Hope fault predates the sills (Harrison and others, 1972).

We interpret these data as indicating very gentle folding along north- to northwest-trending axes (fig. 3) that probably extended over most of the basin but now is most evident in the Purcell anticlinorium where it is well preserved on the Purcell platform. This folding was accompanied or followed by block faulting, mostly along the trends of the folds in many parts of the basin. The Osburn fault zone may have formed during the East Kootenay orogeny, a possibility that we discuss later in the report.

PHANEROZOIC EVENTS

Phanerozoic geologic history of the general area including the Belt basin is most conveniently discussed in units—Paleozoic through early Mesozoic, late Mesozoic through early Tertiary, and late Cenozoic to Holocene. We will depart from this format at one point to discuss the Lewis and Clark line—a zone of tear faults, controversial in origin, formed essentially along the Coeur d'Alene trough (figs. 2, 3) and intermittently active from Precambrian Z through Tertiary time.

PALEOZOIC THROUGH EARLY MESOZOIC

Beginning with the encroachment of Middle Cambrian seas and extending through Middle Jurassic time the Belt basin behaved as somewhat inhomogeneous pseudobasement. As noted by McMannis (1965), the Helena embayment continued to sink intermittently, and it consistently received thicker sediments than adjacent areas of the shelf. Wheeler (1966, p. 41) summarized part of the history for the southern Canadian Cordillera by stating:

> From Early Mississippian to mid-Jurassic time much of the eastern belt was, at intervals along its length, an intermittently emergent sill, or mobile geanticline which separated a deeply subsiding region on the west [the Cordilleran geosyncline], in which accumulated an abundance of volcanics and sediments, from a variably subsiding shallower basin to the east which received sediments almost entirely.

The "mobile geanticline" projected into the United States includes the Purcell platform—the site of the late Belt dome—and perhaps Belt island. The "shallower basin to the east" corresponds roughly to the Canadian part of the Rocky Mountain Trench and is outlined in part on isopach maps by McMannis (1965). McMannis showed that the shallow basin extended back onto the craton but clearly included thicker sediments deposited in the Flathead trough, the Helena embayment, and the Belt seaway. In the United States, the Rocky Mountain Trench follows along the eastern edge of the Purcell platform and thus swings away from the old craton edge, but the sag containing Paleozoic and Mesozoic sedimentary rocks follows along the old craton edge as it did in late Belt time.

Identification of tectonic events in most of the basin during Paleozoic to early Mesozoic is difficult owing to limited preservation of sedimentary rocks (fig. 3) and lack of intrusive episodes. Middle Cambrian Flathead and equivalent quartzites, however, were deposited over the entire basin on very gently folded rocks or, at the eastern margin, on gently tilted rocks (Mudge, 1972, p. 18-19). As described previously, pre-Flathead block faulting is known and may have been widespread. Unfortunately for the geologic historian, no Flathead is preserved on the tight folds of the Coeur d'Alene mining district along the Osburn fault zone, so the evidence to prove or disprove Precambrian tight folding is missing. Wheeler discussed mid-Paleozoic tectonism and plutonism north of the Belt basin as well as possible movement on faults in the trench during the early Paleozoic, but effects within the Purcell platform are not known. The Antler orogeny of Nevada, another major tectonic disturbance of middle to late Paleozoic age, may have extended as far north as central Idaho (Roberts and Thomasson, 1964), but there, too, effects if any within the Belt basin are unknown. The preservation of Cambrian strata in the Libby trough (fig. 3) seems to us to require subsidence of the graben in Paleozoic time, inasmuch as the Purcell platform was essentially positive and was being eroded from the mid-Paleozoic through the Mesozoic.

In summary, the meager data suggest only slight vertical movement in the Belt basin during Paleozoic and early Mesozoic time. The Purcell platform was at times a positive mass, and the various troughs of Belt age again received marine sediments. How much, if any, sedimentary rock of Devonian and younger age was deposited on the Purcell platform, Belt island, and the intervening area will forever remain a conjecture, because none are now preserved in that area. We suggest that the vertical adjustments of the time were probably expressed in renewed movement on high-angle faults formed in Precambrian Z time, some of which bounded and others of which were in the Purcell platform.

LATE MESOZOIC THROUGH EARLY TERTIARY

The rather quiet, nonmagmatic, tectonic regime dominated by vertical displacements in and around the old Belt basin ended dramatically with the tectonic magmatic upheaval that began in the Jurassic and extended to the Eocene. The broad regional events were described succinctly by Robinson (1971), who wrote:

> The entire Cordilleran orogenic belt in Canada and U.S. may be viewed as a zone along which the upper Precambrian-Paleozoic geosynclines moved relatively eastward in late Mesozoic and early Tertiary time against the lower Precambrian crystalline craton, and over the Phanerozoic platform.

During this time the many inhomogeneities of the old Belt basin, some of which had already affected post-Belt sedimentation, were reemphasized in the strain patterns that still dominate the geologic textures of the basin today (fig. 3).

Most of the old Belt basin became a positive tectonic element. Significant amounts of sedimentation occurred only along the eastern edge, where sediments shifted from marine to dominantly nonmarine and volcaniclastic (McMannis, 1965; Mudge, 1972). A conglomerate of limited areal extent filled the Purcell Trench (fig. 3) in the western part of the basin (Harrison and others, 1972).

Tectonic or tectonic-magmatic features that were formed or reactivated during that time include the Kootenay arc, the Idaho batholith, the Boulder batholith, the northern Montana disturbed belt, and the Lewis and Clark line. Of these, all but the Idaho batholith appear to be readily relatable to Precambrian structures of the old Belt basin.

KOOTENAY ARC AND MOBILE BELT

The Kootenay arc (fig. 3), which has been defined in several ways, is identifiable on most geologic maps (see Wheeler, 1966, fig. 10-1, for example) as the arcuate contact between Belt rocks and Windermere rocks or the subparallel contact a few kilometers to the west between

Precambrian and Paleozoic rocks. The Kootenay arc is near, but not at, the eastern edge of a zone of intensive deformation, metamorphism, and intrusion—the Kootenay arc mobile belt. This mobile belt extends as far east in the old Belt basin as the Purcell Trench (fig. 3), and it extends northward into Canada to include the fan-folded gneiss dome of the Shuswap terrane (Wheeler, 1966). The mobile belt encompasses the highly metamorphosed and thrust zones between the Kootenay arc and the Purcell Trench recently mapped by Clark (1973) and by F. K. Miller (written commun., 1972) and may extend 160 km to the west where Fox and Rinehart (1973) recently identified another gneiss dome. The belt is the "mobile infrastructure" of Price and Mountjoy (1970), and the zone of gneiss domes appears to follow along the old Cordilleran miogeocline (fig. 1) at least from mid-Canada to mid-United States (Price, 1971).

The Kootenay arc marks the limits of exposure of Belt rocks, and a pertinent question is whether the arc is a primary or a secondary feature. The Belt rocks are still very thick and show no evidence of depositional thinning where they pass westward under a cover of younger sediments in the zone of the Kootenay arc or under an extensive cover of Columbia River Basalt, which also masks the southern end of the arc. Thus the actual configuration of the Belt sedimentary prism may always be conjectural, but it surely extended many kilometers westward from the westernmost exposures seen today. Several facts suggest, however, that the arc was a significant crustal feature during late Precambrian time: (1) conglomerates (or diamictites) are associated with volcanics in the Windermere along the arc, (2) the western part of the basin bordering the arc contains the most abundant and thickest basic sills of Precambrian age, and (3) in the zone with the basic sills are the only known granitic intrusives of Belt time as well as the unique Sullivan lead-silver deposits. As noted by Yates (1973), the zone of the Kootenay arc was one of alternating eugeosynclinal and miogeosynclinal sedimentation beginning with Windermere time; he concludes, therefore, that the arc is not a plate junction and that the curvature is primary. Our paleotectonic reconstruction (fig. 2) requires hinge lines or fault boundaries completely around an epicratonic reentrant, and we suggest that the join between the Belt basin and the Cordilleran miogeocline represents a deep-seated break that provided access for the intrusives and extrusives of late Precambrian age along the arc. We concur with Yates (1973) and further suggest that the primary curvature of the arc represents the zone where the Cordilleran miogeocline swung out and around Belt island. Belt sedimentation covered the old hinge line, and some sediments may actually thicken westward where they filled the shallow basin and spilled over into the deeper miogeocline (see Harrison, 1972, figs. 7, 12, for example). The Kootenay arc was, in our opinion, established in Belt time, rejuvenated at the beginning of Windermere time, and reemphasized during Mesozoic-Cenozoic time when the mobile belt rode eastward and upward to shove the miogeoclinal sediments up the old hinge line onto the edges of Belt island and the Belt basin.

IDAHO BATHOLITH

The Idaho batholith is an irregular but generally hourglass-shaped compound body. No detailed study of the batholith and related tectonics has been published, but the batholith appears to contain both Cretaceous (100 m.y. or older) and Tertiary intrusives and related volcanic rocks. Thrusting on the eastern side and around the northeastern end shows tectonic transport away from the batholith (fig. 3) and involves rocks as young as Early Cretaceous (Calkins and Emmons, 1915; Gwinn, 1961; Nelson and Dobell, 1961; Kauffman and Earll, 1963; McGill, 1965; Maxwell, 1965).

The northern half of the batholith occupies the eastern end of the old Belt island, adjacent parts of the Belt seaway, and the Belt basin as far north as the Coeur d'Alene trough. At least part of the batholith has gneiss dome characteristics (Chase and Talbot, 1973) and may involve mobilization of pre-Belt rocks. Whether some high-grade metamorphic rocks in roof pendants of the batholith are Belt or pre-Belt is moot, in part because no means has been found to establish the kinds and ages of rocks that may have ridden up on or over Belt island during formation of the Cordilleran fold and thrust belt. Because Belt island was necessarily a source for some Belt sediments (Harrison, 1972) it seems likely that at least some of the high-grade metamorphic rocks isolated in the batholith represent the pre-Belt crystalline basement. We have no explanation for the location of the batholith.

The southern half of the batholithic hourglass occupies a part of the old Belt miogeocline, and the wasp waist of the hourglass coincides with our reconstruction of the join (hinge zone) between the old miogeocline and Belt island. Regional gravity studies by Don R. Mabey (oral commun., 1973) show a line bounding a regional gravity differential that cuts through the Idaho batholith at this same point and extends southeast across the Snake River Plain to the Wasatch Front. This line of gravity change was discovered independently of our geologic reconstruction, but the line is identical with our inferred hinge zone along and southeast of Belt island (fig. 2). The southern half of the batholith, in our opinion, is in the old miogeocline south of Belt island as is the Kootenay arc mobile belt on the north; it thus has the potential for a causative relation to the thrust zone now in the Belt seaway (fig. 3). This causative relation has been investigated by Scholten (1971) and by Ryder and Scholten (1973), who believe that the eastward-directed thrusts on to the old craton are "regional gravity gliding features, with the energy provided by a crustal undation in the area of the Idaho Batholith ***" (Scholten, 1971). Whatever the cause of the thrusting, at least 160 km of eastward translation would have been required to bring Precambrian Y rocks of the miogeocline against Belt rocks of the Belt seaway (Ruppel, 1973).

BOULDER BATHOLITH

The vast amount of magma represented by the Boulder batholith and its associated volcanics welled up from the anomalously deep depression of the Helena embayment. Overlapping plutonism, volcanism, and tectonism of the Boulder batholith has been well documented by Robinson, Klepper, and Obradovich (1968), who noted that all these events took place within 20 m.y., between 85 and 65 m.y. ago. Folding and thrusting near the batholith began somewhat earlier and ended sooner than folding and thrusting in the Montana disturbed belt which ended in late Eocene about 40 m.y. ago; however, the main period of deformation in the two areas was approximately at the same time (Mudge, 1970). These disturbances are younger than some of the tectonic events associated with the 100+-m.y.-old Idaho batholith. Thrusting on the eastern side of the Idaho batholith involves rocks as young as Early Cretaceous. In at least one area midway between the Idaho and Boulder batholiths, thrusts and overturned folds indicate transport to both east and west (Gwinn, 1961); there, the west-directed stress from the Boulder batholith has overridden, tilted, or refolded older east-directed thrusts and folds associated with the Idaho batholith (McGill, 1965).

NORTHERN MONTANA DISTURBED BELT

Our analysis of the basin and its influence on tectonic patterns can be applied to the controversy regarding genesis of the Montana disturbed belt. Two opposing views on the genesis of the imbricate thrust structures in the disturbed belt have been advocated: gravity gliding off a vertical uplift (Mudge, 1970, 1971), and lateral gravitational spreading from a deeply rooted zone of upwelling in a mobile infrastructure (Price and Mountjoy, 1970; Price, 1971).

In our opinion both sides of the argument have merit for the original areas for which they were conceived, and the peculiarities of the Belt basin reentrant can be used to explain the differences. The mobile infrastructure referred to by Price is exposed in the Shuswap terrane, whose oldest recognizable sedimentary rocks are highly metamorphosed formations of Windermere age that are subjacent to the foreland fold and thrust belt. These Windermere rocks are inferred to rest on a Hudsonian (pre-Belt) basement having a remarkably uniform gentle slope away from the old craton. This inference requires that at least 12 km of Belt rocks has disappeared along strike in the old miogeocline within a few tens of kilometers, which seems unlikely to us. But this is actually a minor point to Price's interpretation, for the relatively smooth surface he requires may be a combination of Hudsonian crystalline rocks of the old craton and a wedge of low-grade metamorphic Belt rocks smoothed by erosion to a nearly flat surface during the East Kootenay orogeny before or during deposition of the Windermere System. What is of consequence is that the zone of mobile infrastructure, which lies close to the old hinge line and downdip from the old craton in the geosynclinal structure of southeastern British Columbia, follows along the Kootenay arc and the wider zone of the Kootenay arc mobile belt as it approaches the U.S. border. In our interpretation, mobile infrastructure formed at geosynclinal depths and, consequently, follows the main geosyncline and not the Belt reentrant. Although Mudge (1971) is correct in stating that no mobile infrastructure exists in western Montana, complex gneiss domes and fold and thrust structures do occur in eastern Washington and western Idaho in the Kootenay arc mobile belt. There, the "mobile infrastructure" is separated from the Montana disturbed belt by 240 km of gently folded Belt rocks of the Purcell platform; the Belt rocks are cut by some high-angle faults of several thousand meters of throw that surely involve basement and that are both pre-Middle Cambrian and possibly Paleozoic in age. Therefore, no smooth surface is now evident along which to translate the Jurassic through Cretaceous updip movement from the Kootenay arc mobile belt through the Purcell platform to the Montana disturbed belt. Neither can we find evidence for a now-missing Phanerozoic prism of sediments thick enough to transmit the stress. Thus, Price's hypothesis may be acceptable for observed structures in southern British Columbia and other parts of the Cordilleran fold and thrust belt where no rigid block exists between mobile infrastructure and old cratonic edge. It may apply to genesis of the thrust structures in Belt (and pre-Belt?) rocks at the eastern edge of the Kootenay arc mobile belt in the United States where no Phanerozoic rocks exist to take up thin-skinned deformation, but the Montana disturbed belt seems related to the southern Canadian thrust and fold belt only insofar as both occur at the edge of the old Belt craton. In other words, the zone of mobile infrastructure goes around, not through, the old Belt basin. One might suspect that the Cordilleran thrust belt, like the Rocky Mountain Trench (Leech, 1964, 1972), shows some topographic or geologic continuity related to the hinge zone of the old craton but may not everywhere have the same structural genesis.

When we consider what we believe are serious objections to Price's proposed mechanism operating within the Belt basin, Mudge's hypothesis of gravity sliding seems more enticing. Nevertheless, it leaves unexplained some critical points. Mudge (1970) showed his main glide surface (décollement) cutting gently and smoothly up section from lower Belt at the Rocky Mountain Trench into Paleozoic rocks in the thrust belt. Evidence is abundant for block faulting of pre-Middle Cambrian age in many parts of the Belt basin and of prethrusting age in the Rocky Mountain Trench (Leech, 1964); such evidence conflicts with Mudge's smooth décollement as it did with Price's. Mudge also calls on the now-classic abnormal fluid pressures to buoy and lubricate the slide surface. Most of the inferred décollement, however, is in rocks of lower Belt which were proglraded into the biotite zone of the greenschist facies in Precambrian time and whose "bed" permeability is about zero owing to extensive recrystallization of the rock. This metamorphism presents serious problems to application of the fluid pressure hypothesis in metamorphic rocks as noted originally by Davis (1965). And finally, new mapping in the Rocky Mountain Trench and adjacent areas subsequent to Mudge's compilation and analysis has failed to reveal any trace of either a breakaway zone or a glide plane, but, more significantly, it has revealed an open fold structure with opposing dips of 20° or more, which contrasts sharply with the monoclinal structure of the Mission Mountains on the east (fig. 3). Mudge's hypothesis, which suggests extension in the heel zone of 47 km or slightly more, then requires that the simple monoclinal dip of about 20° found in the Mission Mountains be restored over the folds to the west in the Mission Valley. Such restoration does not match structures even if we allow significant eastward tilting of the Mission Mountains block during the formation of the frontal fault zone on the west face of the Mission Mountains. Thus, we do not believe that either hypothesis fully explains all geologic data now available. Nor do we, at present, have data to support an alternative hypothesis; this places us in agreement with Robinson (1971), who, on the basis of a related but somewhat different approach, reached essentially the same conclusions.

TECTONICS ALONG THE LEWIS AND CLARK LINE

Originally the Belt basin part of the Lewis and Clark line was defined as the zone of tear faults between Helena and Missoula on the east and Spokane on the west (Billingsley and Locke, 1939, p. 36). For convenience in our discussion we will consider the Hope fault zone also to be a part of the Lewis and Clark line, although for esthetic (fig. 3) as well as some geologic reasons, such an addition is not totally warranted. We will refer to this zone simply as "the line" in the rest of this report.

New geologic data have been collected along virtually the entire length of the line between Missoula and Sandpoint (fig. 4) in the past few years. Among the principal new discoveries are continuity of the Hope and Ninemile faults, recognition and extent of the St. Marys fault, extension of the zone of tight west-northwest folds south of the Osburn fault into the area south of the St. Marys fault and north of Missoula, recognition of major thrusts from the southwest that ride out into the line, and discovery of a series of small thrusts hinged at the north showing maximum displacement where they abut the Hope or St. Marys faults. It has also become obvious that the Rocky Mountain Trench, the Libby trough, and probably the Purcell Trench terminate at the line as defined by the Osburn and St. Marys faults; those faults must, then, be as old as or older than the trenches.

Tectonics along the line appear deceptively simple. Many geologists, using a standard technique of interpreting tectonic events from gross structural "patterns," have concluded that the angle of tight folds within the line (fig. 3) or a supposed continuity between batholithic terrane south of the line and that in the Kootenay arc mobile belt demonstrates left-lateral movement of many kilometers along the line. In our opinion, such assumptions of apparent continuity of "patterns" are not only unwarranted but also unsupported by details of the geology. For example, first, our studies of facies and formations of Belt rocks across the line indicate that the apparent offset in units not affected by major thrusts can be only a few kilometers. Two illustrations of this lack of major offset are (1) exceptionally thick sections of the Burke Formation (Wells, 1974) match almost directly north across the line; and (2) the Empire Formation, which thins rapidly both east and west from its maximum thickness of 450 m in the Mission Mountains north of the line, shows approximately the same thicknesses in contiguous parts of the formation within the line. Second, if the fold pattern were formed by left-lateral movement, then the movement must be as young as the Upper Cretaceous rocks involved in the pattern. However, (1) Coeur d'Alene veins older than Late Cretaceous cut folds of the "pattern," and (2) geologic offset of other folds of the "pattern" was several kilometers right lateral in Cretaceous-Tertiary time, which would require a large left-lateral movement followed immediately by an even larger right-lateral movement—a strange if not unreasonable geologic event. We concur with Weidman (1965), who cautioned against attributing the fold and fault patterns along the line to a single event. In the following paragraphs we will analyze data now available and attempt to establish a credible sequence of events.

The tectonic record for Belt time shows an almost stable but slowly sinking platform accumulating sediment that was slightly thicker in a shallow trough parallel to the line. The sedimentation record along the line shows no evidence of any significant folding or faulting during Belt sedimentation.

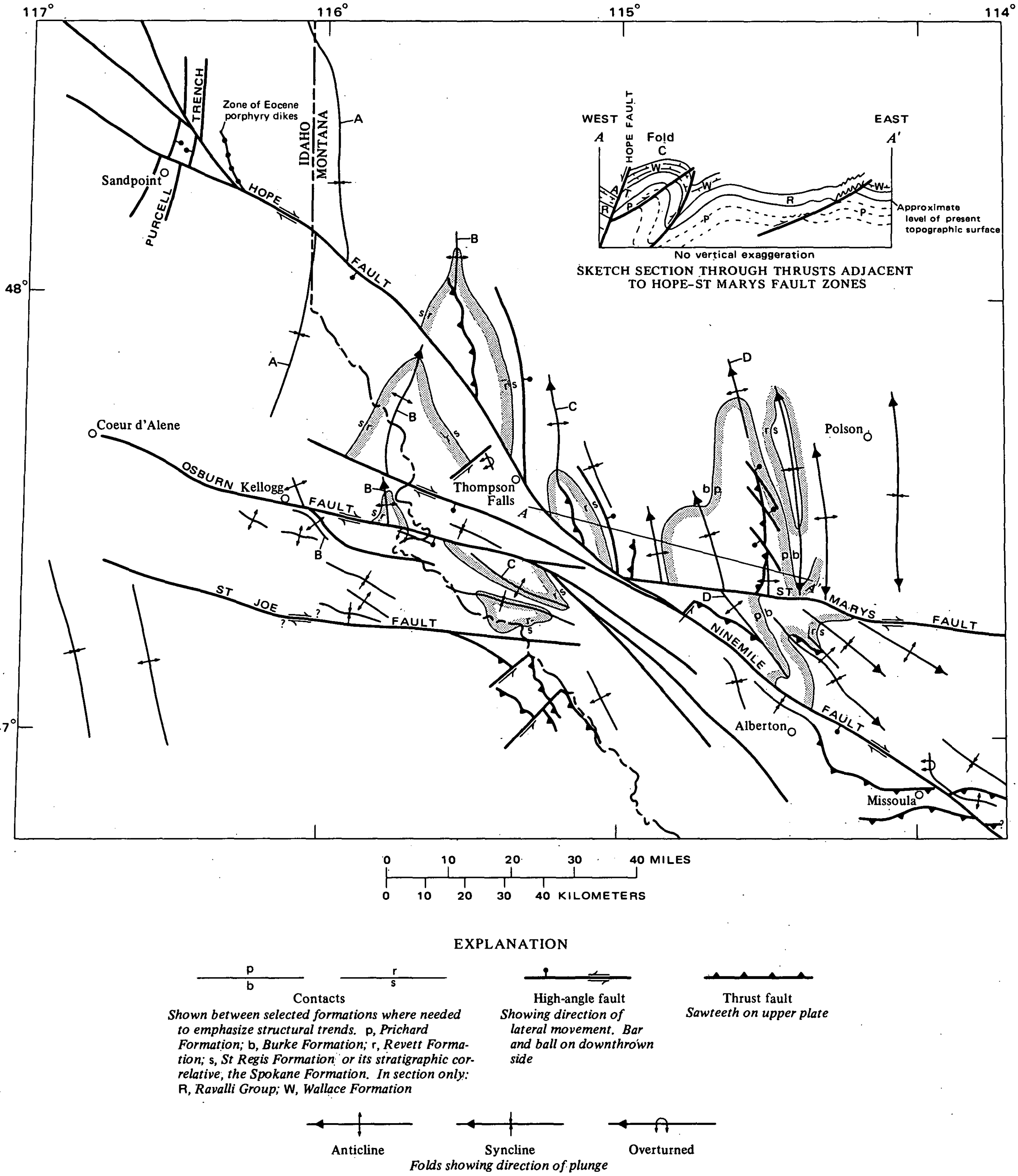


FIGURE 4.—Principal folds and faults near the junction between the Hope, Ninemile, and St. Marys faults. Fold axes labeled A, B, C, and D are probable correlatives across major faults. Principal sources of data: Sandpoint area, Harrison, Kleinkopf, and Obradovich (1972); Kellogg-Coeur d'Alene area, Griggs (1974); Alberton area, Wells (1974); remainder of area, 1:250,000 unpublished mapping by Griggs, Harrison, and Wells. Fault movement in section: A, away from viewer; T, toward viewer.

Precambrian Z (Windermere time) and Early Cambrian events along the line can be inferred only by identification of events occurring pre-Middle Cambrian (Flathead and equivalent rocks) or events occurring prior to or during intrusion of dated basic sills at about 850 to 750 m.y. ago. Some steep block faults of several thousand feet throw formed in pre-Flathead time, as shown by overlap of offset Belt strata by Flathead Quartzite in the area northwest of Coeur d'Alene (King and others, 1970), in the area just west of Missoula (Campbell, 1960; Wells, 1974), and in the area just east of Missoula (Maxwell, 1959, 1965). Basic sills folded in with the broad open structures at the north edge of the Lewis and Clark line—one just east of the Purcell Trench (Harrison and others, 1972) and one just west of the Rocky Mountain Trench (J. D. Obradovich, unpub. data)—are about 850 m.y. old, or East Kootenay orogeny in age. Some thick basic sills that persist to the north for tens of kilometers near the Purcell Trench thin toward or end at the Hope fault, which suggests that the Hope fault existed in some form at the time of sill intrusion (Harrison and others, 1972). Whether any other major faults of the line formed in latest Precambrian time is moot. Thus, the regional patterns previously described and the local patterns along the line combine to indicate that broad open folds, some steep block faults, and a precursor of the Hope fault formed at about 850-750 m.y. ago.

At this point in the discussion we must face squarely the controversial issue of genesis and age of the tight west-northwest folds within the line south of the Osburn and St. Marys faults (figs. 3, 4). We become involved immediately in long-standing controversies over age and genesis of the Coeur d'Alene lead-silver ores on the west end of the line as well as relations of tectonic events along the line to tectonism accompanying intrusion of the Idaho and Boulder batholiths and formation of the thrust belt on the east end of the line. Pertinent geologic relations are described below.

A zone about 40 km wide of west-northwest-trending folds lies south of the Osburn and St. Marys faults along their entire length. The folds tend to be tight or slightly overturned in the western two-thirds of the zone and somewhat more open in the eastern third. A pervasive cleavage accompanies the tight to overturned folds. In the Coeur d'Alene district steep veins cut the folds or are along their flanks; although some veins are faulted off or sheared, they are not folded (Hobbs and others, 1965). Thus the veins are definitely post-folding. Lead isotope studies (Zartman and Stacey, 1971) suggest a model lead age of about 1,200 m.y., but a different set of geologically valid assumptions to determine the youngest reasonable age for remobilized lead yields an age of mineralization of 825 (+395, -500) m.y. The age of pitchblende from the Sunshine mine in the Coeur d'Alene district has been calculated as about 1,100-1,200 m.y. by Eckelmann and Kulp (1957, p. 1130); those authors also noted that the high content of fine-grained galena and the low content of thorium prompted certain assumptions concerning best values to use for corrections, and these caused a change from an earlier determination that gave an age of about 885 m.y. for the pitchblende. Because the stratigraphic column lacks evidence of a tectonic disturbance at 1,200 m.y. (about mid-Belt or Wallace Formation time), we prefer to accept a young(post-Belt) age as more realistic geologically than the model lead or "corrected" uranium-lead age. Our interpretation supports that of other investigators who have suggested that the Coeur d'Alene ores were remobilized from depth—perhaps from Sullivan-like deposits in lower parts of the Prichard Formation—sometime in post-Belt but pre-Cretaceous time.

Toward Missoula the zone of tight folds becomes complicated. In the Missoula-Alberton area additional structural elements are present; westerly trending thrusts showing transport to the northeast occur, and Cambrian strata are folded along with the Precambrian rocks. Imbricate thrusts with tear faults bounding them are now known 60 km west of Alberton (fig. 4) where the thrust plates override broad open folds south of the line. Thrusts of similar trend and direction of tectonic transport are also found within the line. At least one such thrust south of the Ninemile fault has sheared along the south flank of an overturned fold but when traced to the west terminates abruptly into a northwest-trending fold (Wells, 1974), indicating that the thrust formed from continuation of the same stress that caused the overturned folds. Several thrusts are present in both the southern and the northern parts of the line, an indication that stresses extended across it. The Ninemile fault appears to offset one of the thrusts where the two intersect southeast of Missoula (fig. 4); however, the actual amount of offset, if any, is conjectural, inasmuch as the intersection is buried beneath Tertiary and younger valley fill.

Between the Ninemile and St. Marys faults is a zone where the more competent rocks—Helena and Wallace Formations and younger—form relatively open northwest-trending folds, whereas along the axis, down section, toward the center of the parallel fold, the less competent rocks of the Prichard Formation show tight overturned folds having prominent axial-plane cleavage. The relief of the stress created by compression of the strata in the center of the fold was by movement upward and to the northeast, as shown by the inclination of the cleavage and the asymmetry of the folds. Here, too, the stress that caused the folding was also relieved eventually by thrusting up the south-facing flanks of anticlines. The abrupt change in tectonic style at the St. Marys fault to open uncleaved north-trending folds north of the fault (fig. 3) shows that the St. Marys fault acted as a tectonic boundary at the time of the tight folding and thrusting south of it.

Here then, the northwest-trending thrusts and related folds are younger than Cambrian but are older than movement on the Ninemile fault that tilted Tertiary strata as well as cut off a tear fault associated with one of the thrusts north of the fault (fig. 4).

This zone continues eastward from Missoula, where it contains west-northwest-trending folds and thrusts north of the Ninemile fault but near to it (fig. 3). Some of the folds that parallel the thrusts involve Cambrian rocks (Nelson and Dobell, 1961; Kauffman and Earll, 1963). Still farther east, folds of the zone not only involve rocks as young as Cretaceous but also turn south, and although the inflection point may be at or near the projected position of the Ninemile fault or a branch from it (fig. 3), the folds are not offset along a fault (Gwinn, 1961). Thrusts definitely related to the tight to overturned north-trending structures and that show translations both eastward and westward are abundant in the area between the Idaho and Boulder batholiths (fig. 3).

Farther toward Helena only the St. Marys fault is still traceable. The various splays of the line pointing toward the Boulder batholith are not identifiable in or beneath either younger (Eocene) volcanics or older (Late Cretaceous) volcanics associated with the batholith and do not cut through either the volcanics or the batholiths.

Our analysis of the events leading to the geologic picture described above should be classified somewhere between a speculation and an interpretation. In our opinion, the data suggest the following: (1) The west-northwest folds are of several ages and origins, (2) no fault of the line is through going, (3) various faults have taken up the stress at various times, and (4) the apparent continuity of folds and faults of the zone is misleading in terms of origin and timing just as in the examples previously discussed of the Rocky Mountain Trench and the Cordilleran thrust belt.

Weidman's (1965) concise summary of the interpretations of tectonic events along the line presents the variety of thoughts by many different geologists and the enigmas inherent in many of these interpretations. Not all these explanations are repeated here, but by careful selection of various parts of previous interpretations one could arrive at ours, which hardly makes ours original. Nonetheless, ours does have an input of more data from additional mapping that puts some restraints on sequence and timing and thus on interpretations. We suggest that the tight folds within the line in the Coeur d'Alene district are post-Belt and pre-Flathead. Although their echelon arrangement and angle suggest to some a left-lateral movement on the Osburn fault, all geologic evidence of offset on the Osburn, Hope, Ninemile, and St. Marys shows right-lateral displacement. Direction of movement on the St. Joe fault is equivocal from all published geologic data; only a sketch map published by Reid and Greenwood (1968) suggests the direction of the relative slip, which would be left lateral if thrusts at the east end (figs. 3, 4) actually connect with the St. Joe fault. If the thrusts override the St. Joe fault or are cut off by it, then data are still not adequate for determining relative movement. As all other faults in the line are right lateral, we infer that the St. Joe also is right lateral. We, therefore, accept the concept of a wedge caught between converging right-lateral structures—essentially the Osburn and St. Joe faults—as sustaining drag and compression, similar to the proposal by Hobbs, Griggs, Wallace, and Campbell (1965, fig. 34). A wedge was also proposed by Smedes (1958), but its southern boundary was considered as the Idaho batholith; this explanation no longer seems possible, because broad open folds are now known south of the St. Joe (fig. 4). The wedges and consequent tight folding, which we infer to be pre-Flathead, could not have extended past the junction of the Osburn and Ninemile faults, because Cambrian rocks are in only slight angular unconformity with Belt rocks east of that junction.

In our opinion, the Coeur d'Alene ores fit best into this episode of Precambrian Z tectonism. The "minimum" ages previously cited (p. 11) calculated by both the lead-lead and the uranium-lead methods fall in the 800- to 900-m.y. bracket, the time of the East Kootenay orogeny.

We attribute the tight folds in the Missoula-Alberton area (fig. 4) to accommodation of stress accompanying intrusion of the Idaho batholith, stress that was resolved into upward and northeast-directed strain as far north as the St. Marys fault. Some stress probably was transmitted through (about at right angles) some faults of the line, but thrusts also eventually rode across the line. West from Missoula we suggest that the southward curving of thrusts and tight folds (fig. 3) reflects the stresses related to emplacement of the Idaho batholith of Early Cretaceous age. Opposed overturned folds and thrusts of westward transport reflect the Late Cretaceous and early Tertiary tectonics associated with the Boulder batholith, one of several alternatives offered by McGill (1965).

Apparent right-lateral movement determined from offset of major contacts is about 26 km along the Osburn fault (Hobbs and others, 1965), 26 km along the Hope fault (Harrison and Jobin, 1963), 29 km along the Ninemile fault (Wells, 1974), and 13 km along the St. Marys fault (J.E. Harrison, unpub. data). The Osburn, Hope, and Ninemile faults also all have an apparently large component of dip slip (all down to the south in a down-to-basin configuration to the Coeur d'Alene trough), which complicates determination of true slip.

Offset of fold axes (fig. 4) suggests that the true strike-slip component on the Osburn is about 26 km, whereas the true strike-slip component on the Hope is 10-13 km. At least for the Hope fault a Tertiary movement of 5-7 km right lateral can be demonstrated from offset of the Purcell Trench and Selkirk Mountain frontal fault of Cretaceous age (fig. 3) and from dating of 50-m.y.-old porphyry dikes (fig. 4) that fill tension fractures of the pull-away zone north of the Hope fault at the Purcell Trench (Harrison and others, 1972). Because the Tertiary movement does not account for the total displacement, the faults evidently existed before the Tertiary. Branches from the Ninemile-Osburn system (fig. 3) appear to be identifiable in upper plates of thrusts (Maxwell, 1965) associated with the Idaho batholith southeast from Missoula, which suggests that some faults of the line are Early Cretaceous or older. Evidence for a Windermere age for inception of the Hope and possibly the Osburn and St. Joe has been presented previously. The line, therefore, seems to have begun forming late in Precambrian time and has had movement intermittently along it ever since.

The 5-7 km of right-lateral movement identifiable at the intersection between the Hope fault and the Purcell Trench appears to have been taken up mainly along the Hope and St. Marys faults and to a lesser extent along the Ninemile. The apparent offset of the Cretaceous thrusts along the Ninemile fault near Missoula (fig. 4) is 1.2 km or less. The reason for this selective Tertiary movement largely on the Hope and St. Marys becomes evident when we realize that by early Tertiary time all eastern segments of the line except the St. Marys fault were blocked by the deep-seated (Klepper and others, 1971) intrusion of the Boulder batholith.

Stress in early Tertiary time caused the block north of the line to move east. Such movement was proposed by Harrison, Kleinkopf, and Obradovich (1972) on the basis of data from the Hope fault-Purcell Trench area, and our new mapping adds further conclusive evidence to that interpretation. Hinged, or flap, thrusts north of the Hope-St. Marys faults are shown in plan and cross section in figure 4. None of the thrusts extend northward for more than a few kilometers, each ends in a slight warp, all abut and do not cross the Hope or St. Marys faults, and each has greatest displacement along those faults. The strain pattern results from an eastward-directed stress that compressed, then sheared, along the west-facing limb of an anticline in rocks previously folded moderately (B fold and C fold) or sheared along a gentle anticline with consequent accordion pleating in the upper plate of an old open fold (D fold). The total measurable crustal shortening on all three thrusts and associated folds is on the order of a few kilometers, which is consistent with the total crustal lengthening in the pulled-apart zone at the trench (Harrison and others, 1972). This tectonic event, therefore, appears to require some eastward movement and counterclockwise rotation of the block north of the Hope and St. Marys faults to generate the unusual strain pattern that increases adjacent to the faults. If the St. Marys fault extends into the disturbed belt, the relatively small amount of movement along the St. Marys fault could not have contributed significantly to the thin-skinned deformation of the disturbed belt and may be unimportant in the major cause of the thrusting.

LATE CENOZOIC BLOCK FAULTS

Cenozoic block faulting (Pardee, 1950) that formed Basin and Range structures is the final basinwide tectonic event, although some fault movement is recorded by tilting or faulting of some Tertiary basin-fill sediments. Details of the fault pattern far exceed in number of faults and in complexity those shown in figure 3, and an appreciation of them must await completion of mapping and publication of 1:250,000 geologic maps now being prepared. The pattern is remarkably similar to, but much better exposed than, the pattern described by Stewart (1971) for the Basin and Range structure in Nevada. The horst-and-graben structure of the Belt basin terrane clearly is an expression of tensional stress, but as is obvious from previous discussions, we believe that such stress has affected the basin many times since the Belt rocks were deposited. Surely, extensive block faulting occurred during the early Cenozoic, and the U.S. part of the Rocky Mountain Trench was formed at that time, but we hasten to point out that much of the Cenozoic faulting may represent renewed movement on much older faults. The 12-15 km of tectonic relief between the Montana disturbed belt and the crest of the Purcell anticlinorium horst, for example, is assumed by Mudge (1970) to have formed entirely during "Laramide" time. This assumption not only seems to require what to us is excessive vertical movement in a short time but also ignores all evidence of pre-Tertiary vertical movements. If, however, part (perhaps half) of the apparent tectonic relief was formed (and eroded) during latest Precambrian to Jurassic, then the measurable tectonic relief is more readily understood even though a smaller amount of post-Jurassic relief is somewhat detrimental to Mudge's thesis.

CONCLUSIONS

Tectonic patterns apparent at first glance on geologic and tectonic maps that include the Belt basin appear to be Mesozoic to Cenozoic ("Laramide") in age. The accumulating data indicate that the puzzling 600-m.y. gap in tectonic events (end of Belt to Jurassic) is more apparent than real. Also, with increased knowledge of the geometry, sedimentation, and genesis of the Belt basin, the influence of that basin on subsequent tectonic events can be better understood. Thus, we can now demonstrate a probable nearly continuous succession of the events and explain the reasons for location of some of them.

Four structural elements prominent in Belt time have been key factors that influenced subsequent reaction of the basin to various stresses. These main elements are:

1. The Cordilleran miogeocline, which extended along the North American craton during Belt and Windermere time and which apparently formed the western boundary of a shallow miogeocline or modified aulacogen, the Belt basin. Later features related to the miogeocline or its junction with the Belt basin in our opinion are the Kootenay arc, the Kootenay arc mobile belt, and perhaps the Sullivan lead-silver ores and the Purcell Trench.
2. The west-northwest sedimentation trough of early to mid-Belt time, referred to in this report as the Coeur d'Alene trough. This zone of crustal weakness is now occupied by the right-lateral shear zone known as the Lewis and Clark line and contains on its western end the Coeur d'Alene lead-silver ores.
3. The hinge of the Canadian Shield, which defined the northeast edge of the Belt basin. Major broad folds, block faults including the grabens of the Libby trough and the Rocky Mountain Trench, and the northern Montana disturbed belt all parallel this old feature. In addition, continued sagging along the hinge zone provided a sedimentation trough along the craton in both Belt and Phanerozoic time. A deep basin where that sag joins the sag along the Lewis and Clark line now contains not only Phanerozoic sediments but also the Boulder batholith and associated volcanics.
4. The Purcell platform, a triangular-shaped block formed by the intersection of the three structural elements just listed. The platform is approximately in the position of a low dome formed in late Belt time, and it seems to have acted as a somewhat rigid block ever since. Although it is gently folded internally, the major tectonic relief in the block is vertical along high-angle faults. The Kootenay arc mobile belt rides up on its west edge, and the Rocky Mountain Trench follows along its east side.

Several important elements in the Belt basin are still not well understood. Among these are the geometry and sedimentation of the southernmost part of Belt terrane, the Idaho batholith, and the reason for and genesis of the Montana disturbed belt and the ores of the Coeur d'Alene district. Our lack of understanding for the first two is in part due to lack of data in areas where little geologic work has been done. By contrast, abundant information on the Montana disturbed belt and the Coeur d'Alene district still lends itself not to definitive analysis but only to various speculations within broad geologic constraints.

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