5. A PRELIMINARY PALINSPASTIC MAP OF THE MESOPROTEROZOIC BELT-PURCELL SUPERGROUP, CANADA AND USA: IMPLICATIONS FOR THE TECTONIC SETTING AND STRUCTURAL EVOLUTION OF THE PURCELL ANTICLINORIUM AND THE SULLIVAN DEPOSIT

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ABSTRACT

The Sullivan deposit occurs in an "accretionary wedge" of supracrustal rocks that were scraped off the under-riding North American plate and accreted to the over-riding tectonic collage of Cordilleran terranes. Palinspastic reconstruction is required for interpreting both the initial configuration and location of the Belt-Purcell basin and the role of pre-existing basement structures in its formation and subsequent deformation. Our area-balanced palinspastic map is based on 12 restored balanced cross sections. The net horizontal shortening across the Cordilleran foreland thrust and fold belt decreases from >250 km at 52°N to <20 km near Helena, Montana (near 47°N). The displaced rocks, including the Sullivan deposit, evidently underwent a clockwise rotation of about 30° about an Euler pole near Helena, Montana.

The Belt-Purcell basin formed as a branching intracontinental rift. An asymmetric east-northeast-trending branch extends along the Central Montana trough, and was bounded to the south by a transfer fault along the uplifted margin of the Wyoming Archean craton. The main branch, which was symmetrical and northwest-trending, is distinguished by voluminous syn-rift mafic sills and a very thick syn-rift fill of relatively fine-grained basin-plain turbidites. The main rift and its sedimentary fill abut against the transfer fault, but swarms of northwest-trending Mesoproterozoic mafic dikes extend southeast into the Wyoming Archean craton. The turbidite fill, which is of distant provenance and entered the basin from the southwest in a large fan delta, must have been supplied by a very large river system draining a continent that subsequently was removed, probably by Neoproterozoic rifting and subsequent drift.

The Sullivan deposit formed in the axial zone of the northwest branch of the rift where structures that controlled this branch were intersected by the Vulcan structure. The Vulcan structure is a major northeast-trending Paleoproterozoic structure in the Alberta basement that is outlined by a conspicuous negative magnetic anomaly (the "Vulcan low"). It truncates the northwest-trending Archean structures of the Medicine Hat block. Seismic reflection imaging suggests that it is a depressed block that is overlain by Precambrian strata and is bounded by steep fault zones. It marks the northern boundary of Montania, a long-lived tectonically positive block that coincides with a 200 km right-hand offset in the eastern boundary of the Cordilleran miogeocline, and a major cross-strike discontinuity in the foreland thrust and fold belt. The history of deformation in the vicinity of the Sullivan deposit is dominated by reactivation of transverse northeast-trending structures inherited from the Vulcan structure. These structures were crustal-scale block faults during Neoproterozoic (Windermere) and Early Paleozoic rifting and sediment accumulation, but became right-hand reverse faults during the Mesozoic thrust faulting and basin inversion.

INTRODUCTION

The Sullivan deposit and most of the other Mesoproterozoic rocks of the Belt-Purcell Supergroup occur within the Cordilleran foreland thrust and fold belt (Fig. 5-1). They form the lower part of the northeastward-tapering "accretionary wedge" of supracrustal rocks that were scraped off the under-riding North American plate and accreted to the over-riding tectonic collage of Cordilleran terranes that "collided" obliquely with North America (Price, 1994). The accretionary wedge was compressed and thickened as it was displaced eastward and northeastward, first during a Late Jurassic-Early Cretaceous episode of left-lateral transpression, and then during a Late Cretaceous-Paleocene episode of right-lateral transpression (Price, 1981, 1994, 1995). It also was locally fragmented and stretched during an early Tertiary episode of crustal extension and right-lateral shear (Price, 1979; Ewing, 1981; Price and Carmichael, 1986; Parrish et al., 1988; Harms and Price, 1992; Struik, 1993; Janecke, 1994; Constenius, 1996).

The Sullivan deposit, along with most of the other Belt-Purcell rocks, underwent substantial displacements relative to the North American craton during these successive deformational episodes. Accordingly, palinspastic reconstruction that compensates for the effects of both episodes of transpressional deformation, as well as for the superimposed transtensional deformation, is an essential prerequisite for interpreting the initial configuration and location of the Belt-Purcell basin. Palinspastic reconstruction also provides the essential framework for analyzing the role of pre-existing basement structures both in the formation of the Belt-Purcell basin and of the Sullivan deposit, and in the subsequent

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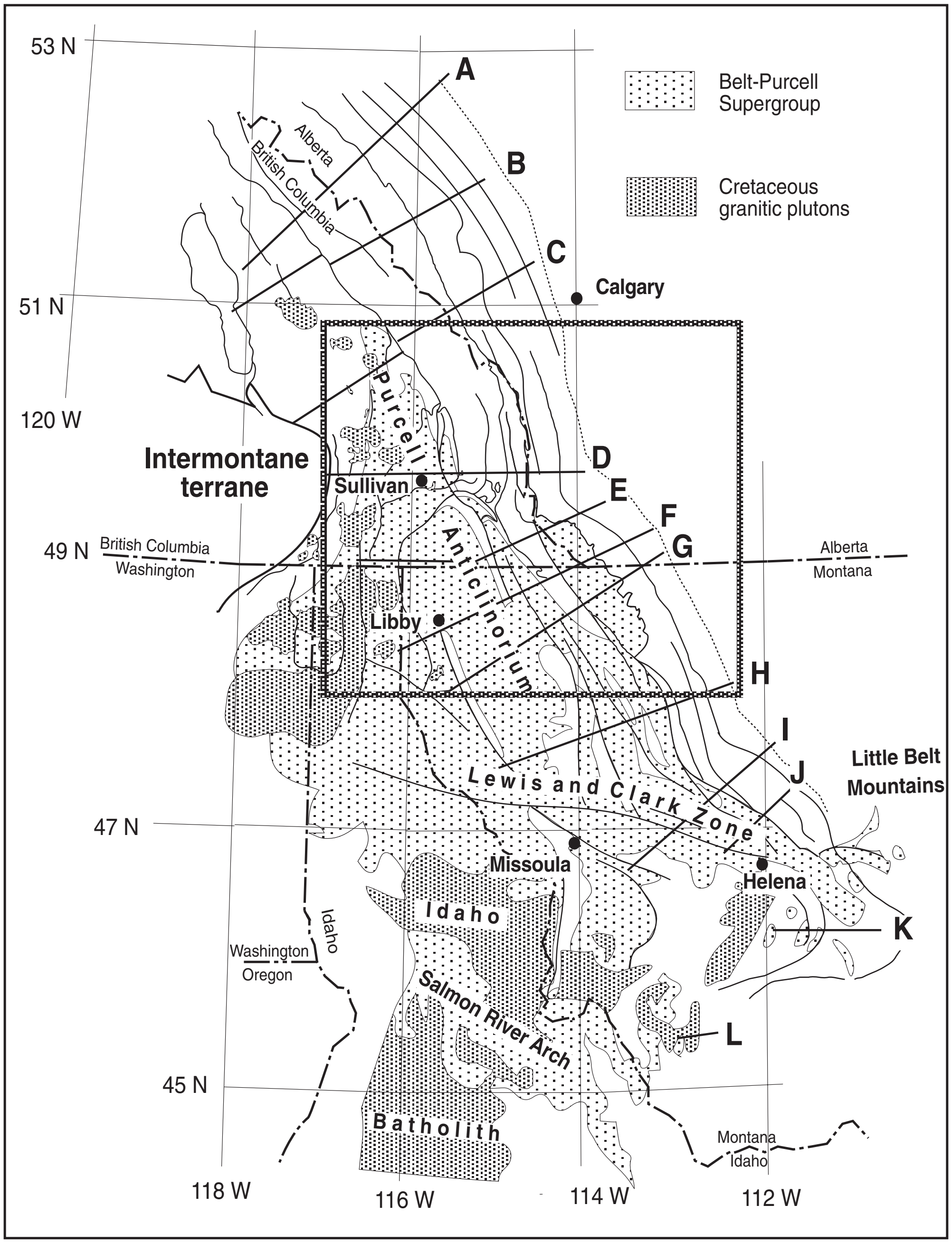


Figure 5-1. Tectonic index map of the Cordilleran foreland thrust and fold belt of part of Canada and the USA, showing: (1) the present distribution of Belt-Purcell rocks, (2) the main faults, and (3) the locations of structure sections that were used in the preparation of the palinspastic map of Figure 5-2. The rectangle outlines the area that is included in Figure 5-5. Sources of information for the palinspastically restored structure sections are as follows: A: Price and Mountjoy, 1970; B: Monger, et al., 1985; C: Price, 1981; Price and Fermor, 1985; D: Price, 1981; E: Fermor and Moffat, 1992; F: Bally, 1984; G: Harris, 1985; H: Sears and Buckley, 1998; I: Sears, 1988; J: Figure 5-4a, this paper; K: Burton, et al., 1998; L: Sears, et al., 1989.

deformation of the Belt-Purcell rocks and the Sullivan deposit.

We have prepared a new preliminary palinspastic map of the Belt-Purcell rocks and the adjacent parts of the foreland thrust and fold belt within the interval extending from about 45°N to about 53°N (Fig. 5-2). We have used this preliminary palinspastic map together with (a) the available aeromagnetic anomaly maps (Bond and Zietz, 1987; Ross, 1995), (b) the results of recent studies of the basement structure of the Western Canada Sedimentary Basin (Ross, 1995), and (c) the available information on the stratigraphy of the Belt-Purcell Supergroup and overlying Neoproterozoic and Paleozoic rocks, to outline the tectonic setting of the Belt-Purcell basin, including the role of pre-existing basement structures in the formation of the basin and in the subsequent detachment, deformation and displacement of the Belt-Purcell rocks (including the Sullivan deposit).

THE PALINSPASTIC MAP

Our preliminary palinspastic map (Fig. 5-2) portrays the distribution of the rocks as they existed in the Middle Jurassic, prior to the displacements that were associated with two episodes of transpressional deformation, and with the ensuing early Tertiary crustal extension. The map is based on twelve published palinspastically restored, balanced, regional structural sections of the foreland thrust and fold belt (Fig. 5-1): five in southern Canada (Price and Mountjoy, 1970; Monger et al., 1985; Price and Fermor, 1985; Price, 1981; Fermor and Moffat, 1992); one extending from southern Canada into Montana, (Bally, 1984); and six in northern Montana (Harris, 1985; Sears, 1988; Sears et al., 1989; Burton et al., 1998; Sears and Buckley, 1998; and Fig. 5-4a of this paper). It is a balanced palinspastic map on which the lengths of lines (such as traces of thrust faults) are approximately the same as on the geological maps upon which the palinspastic interpretation is based.

The palinspastic interpretation also takes into account two simple, but complementary basic observations concerning this part of the Rocky Mountain foreland thrust and fold belt:

(1) The gross structure of the Rocky Mountain foreland thrust and fold belt is a tectonically inverted counterpart of the structure of the sedimentary basins in which the displaced strata were deposited. Structural culminations occur where thick sequences of strata, displaced out of the basins in which they accumulated, are now juxtaposed over the relatively flat surface of the continental craton; structural monoclines or depressions occur where displaced strata are juxtaposed over the ramps that mark the edges of the sedimentary basins from which the fill has been displaced (Price et al., 1972; Price, 1981; Sears, 1988, 1994).

(2) The net shortening across the Rocky Mountain foreland thrust and fold belt decreases progressively southward from > 250 km in the vicinity of the North Saskatchewan and Athabasca Rivers (Fig. 5-1, Section A) to about 40 km northeast of Missoula (*see* Fig. 5-1, Section I; *see also* Fig. 5-4), and to < 20 km in the Little Belt Mountains of west-central Montana, near Helena, Montana. This observation is tantamount to describing the net horizontal displacement across this part of the thrust and fold belt as a homogeneous (“rigid block”) rotation of about 30° around an Euler pole near Helena, Montana (Fig. 5-3). This is because the thrust sheets were not stretched parallel with their strike during thrusting, as would be required if the direction of displacement were rectilinear rather than curvilinear (Sears, 1994). Thus, our palinspastic reconstruction is based on displacements that follow concentric small-circle arcs about an Euler pole near Helena, Montana. This rotational reconstruction is preferred because it matches the hanging wall ramps that mark the margin of the Belt-Purcell basin within the displaced rocks above the basal detachment of the thrust and fold belt, with the monoclines that mark their matching counterpart in the autochthonous rocks below the basal detachment, whereas a palinspastic reconstruction that is based on rectilinear displacement trajectories does not.

On the palinspastic map, the rocks are divided into four categories: (1) Cretaceous plutons; (2) the Lower Belt-Purcell rocks (the deeper water deposits comprising the Aldridge and Prichard Formations, together with their shallow-water lateral equivalents); (3) the remainder of the Belt-Purcell Supergroup; and (4) the overlying Neoproterozoic and Phanerozoic rocks. The restored positions of the hanging wall traces of the major thrust faults are shown as thick solid lines and the corresponding restored positions of the footwall traces are shown as thin solid lines in Figure 2. The unpatterned area between the restored hanging wall trace and the restored footwall trace of a thrust fault illustrates the amount of horizontal overlap due to the displacement on that fault (*see also* Fig. 5-4b). The sizes and configurations of these unpatterned areas illustrate the pattern of variation in the displacements and the displacement gradients on the thrust faults. Normal faults are shown on the palinspastic map by heavy dashed lines that mark the restored position of the hanging wall trace of the fault. The horizontal gap that was produced by the normal faulting is eliminated by the palinspastic reconstruction (*see* Fig. 5-4b), and therefore, the amount of horizontal extension due to normal faulting is not illustrated on the palinspastic map.

To understand the context and scope of the palinspastic reconstruction it is necessary to consider briefly the main features and the inter-relationships of the early Tertiary crustal extension and of the two preceding episodes of Mesozoic transpressional deformation.

CENOZOIC AND MESOZOIC DEFORMATION

Eocene right-lateral transtension

Early Tertiary southwest-dipping listric normal faults are a dominant feature of the regional geological structure of the Rocky Mountain foreland thrust and fold belt in the region extending southward from southeastern British Columbia into the northern United States. However, normal faulting diminishes and becomes an incidental feature of the regional geological structure of the foreland thrust and fold belt north of 50°N latitude (Fig. 5-1). The net northeast-southwest extension across the thrust sheets that contain the Belt-Purcell rocks amounts to about 35 km near latitude 47°N (Constenius, 1996), but it decreases to < 10 km north of 50°N (Price and Mountjoy, 1970; Price, 1981), mainly because the principal locus of horizontal extension has shifted farther west, beyond the limits of the Belt-Purcell rocks (Price and Carmichael, 1986; Parrish et al., 1988). North of the Lewis and Clark zone, the extensional deformation appears to be entirely thin-skinned in the eastern part of the area. There, the major normal faults merge at depth with underlying thrust faults. This has been well documented in the case of the Flathead normal fault which merges into underlying the Lewis thrust fault (Bally et al., 1966; Dahlstrom, 1970). However, farther west the normal faults extend deep into the crust. They are associated with the exhumation of mid-crustal metamorphic core complexes (Price, 1979; Parrish et al., 1988; Cook et al., 1988; Harms and Price, 1992; Doughty, 1995; Doughty et al, 1998; Doughty and Price, 1999), and they are linked to Eocene right-lateral strike slip on major intra-continental transform faults, including the Tintina-Northern Rocky Mountain trench fault system, the Fraser River Straight-Creek faults system, and the Yalakom-Ross Lake faults system (Price, 1979; Price and Carmichael, 1986; Struik, 1993; Price, 1994). The Belt-Purcell rocks that host the Sullivan deposit have been displaced about 10 km southwestward relative to the North American craton by early Tertiary crustal exten-

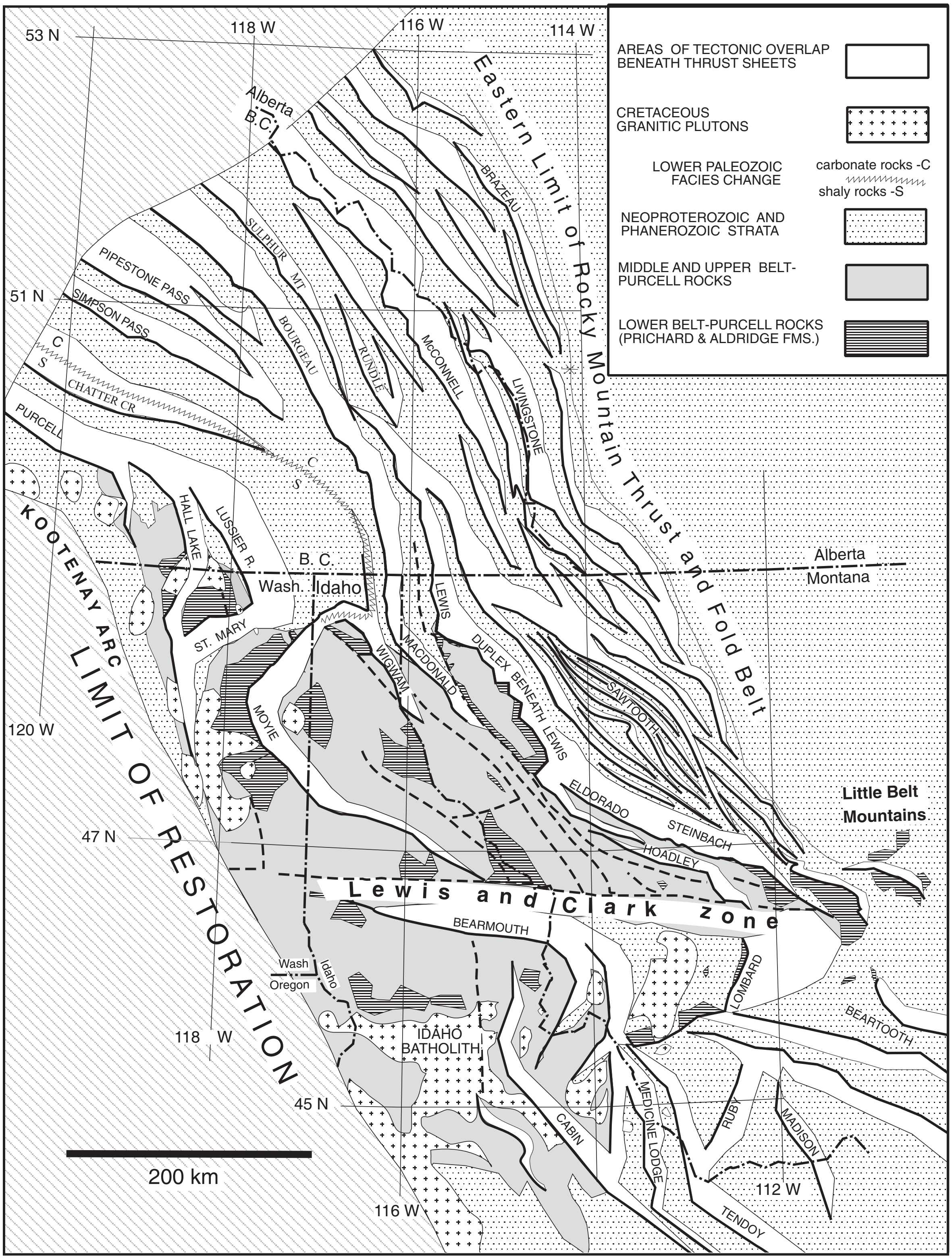


Figure 5-2. Palinspastic map of the Belt-Purcell rocks of the Canadian Rockies, southern Canada and northern United States. The principal thrust sheets are shown in the locations in which they originated. Each thrust sheet is bounded on the northeast by the hanging wall trace of the underlying thrust fault, which is represented by a heavy solid line. The corresponding footwall traces are shown in their palinspastically restored position as light solid lines. The unornamented area between the restored hanging wall and the restored footwall traces represents the amount of horizontal overlap due to displacement on that thrust (*see* explanation in Fig. 5-4). The size and shape of the unornamented area provides a measure of both the magnitude of displacement and the pattern of variation in displacement on the thrust fault. The heavy dashed lines mark the palinspastically restored hanging wall traces of the major normal faults. The horizontal displacement due the normal faulting has been eliminated. The concepts and procedures upon which the map is based are discussed further in the text. The topology of the overlapping and interfingering faults is from the geological compilation maps of Price (1981), Mudge and Earhart (1983), Whipple (1992), Harrison, et al. (1986, 1992), J. W. Sears (unpublished), and Wheeler and McFeely (1991).

sion, mainly as a result of displacement on the southwest-dipping Flathead and southern Rocky Mountain trench listric normal faults (Price, 1981; van der Velden and Cook, 1996). The palinspastic map (Fig. 5-2) takes into account this and other horizontal displacements associated with the Early Tertiary right-lateral transtension.

Late Cretaceous and Paleocene right-lateral transpression

The Late Cretaceous and Paleocene episode of right-lateral transpression was the main "event" in the collapse and tectonic inversion of the Cordilleran miogeocline and of the Belt-Purcell basin. In mid-Cretaceous time, prior to the formation of the Bourgeau, Sulphur Mountain, Lewis, Eldorado, Hoadley, and Steinbach faults, and the other thrust faults that lie east of them (*see* Fig. 5-2), most of the rocks of the Cordilleran miogeocline were still situated outboard of the rifted margin of the North American craton, in the basins in which they had been deposited (Price, 1981, 1994). Most of the Belt-Purcell rocks, which were situated inboard of the Cordilleran miogeocline, were also still in the basin in which they had been deposited. However, during the Late Cretaceous and the Paleocene, as the tectonic collage of Cordilleran accreted terranes converged obliquely ("collided") with North America, the Cordilleran miogeocline and the Belt-Purcell basin were tectonically inverted. The thick successions of Paleozoic rocks that comprise the Cordilleran miogeocline and the underlying Neoproterozoic rocks of Windermere Supergroup were: (1) detached from the underriding North American crystalline basement; (2) displaced up the passive-margin ramp along which they had accumulated; and (3) juxtaposed over the flat surface of the North American craton to form the structural culmination that defines the Main Ranges of the Canadian Rockies (Price, 1981). In a similar fashion the thick succession of Mesoproterozoic strata comprising the Belt-Purcell Supergroup was: (1) detached from the crystalline basement of the basin in which it accumulated; (2) displaced up a basin-margin ramp that underlies the present position of the Lewis and Clark zone (Fig. 5-1 and 5-3); and (3) juxtaposed over the flat surface of the North American craton to form the structural culmination that is the southern end of the Purcell anticlinorium (Sears, 1994).

In the northern Canadian Cordillera, much of the Late Cretaceous and Tertiary displacement between North America and the collage of accreted terranes that lay outboard to the west was taken up by right-lateral strike-slip along the Tintina-Northern Rocky Mountain trench transform fault (Price, 1994). The Tintina-Northern Rocky Mountain trench fault follows a small-circle trajectory southward for more than 1600 km from east-central Alaska to east-central British Columbia (Price and Carmichael, 1986). In east-central British Columbia, at about 55^{0}N, the Tintina-Northern Rocky Mountain trench fault veers eastward from its small-circle trajectory to form a restraining bend. At this restraining bend right-hand strike-slip was transformed southward into oblique, right-hand convergence, which is expressed as transpressive thrust faulting and folding (Price, 1994). As a result, the amount of Late Cretaceous and Paleocene horizontal shortening across the thrust and fold belt increases, relatively abruptly, southward to a maximum of about 200 km near latitude 53^{o}N (near the northern edge of Fig. 5-1 and 5-2). The total horizontal shortening across the thrust and fold belt near latitude 53^{o}N is >250 km, but it includes Late Jurassic and Early Cretaceous shortening as well. Southward from 53^{o}N, the amount of Late Cretaceous and Paleocene horizontal shortening across the thrust and fold belt decreases gradually to a minimum of about 20 km in the vicinity of the Lewis and Clark zone (Fig. 5-2 and 5-3) at about 46^o 30'N (Sears, 1994). This southward decrease in net displacement is clearly expressed by the pattern of a progressive decrease southwards of the displacement by groups of major thrust faults (Fig. 5-2). In the Main Ranges of the Rocky Mountains, the Chatter Creek, Simpson Pass and Pipestone Pass faults all die out southward without transfer of displacement to other nearby thrusts. In the Foothills belt, the outer margin of the thrust and fold belt shifts westward toward the south via a series of right-stepping en echelon overlaps of the frontal, west-verging backthrust, which forms the top of the "triangle zone" (MacKay et al., 1996) that marks the front of the Cordilleran Foreland thrust and fold belt. This pattern of southward decrease in net displacement implies that the displaced rocks within the foreland thrust and fold belt have undergone a clockwise rotation of about 30^0 relative to the North American craton about an Euler pole near 46^o 30'N and 111^{o}W (Fig. 5-3).

Mid-Cretaceous granitic magmatism

A mid-Cretaceous (about 90 - 100 Ma) episode of granitic magmatism separated the Late Cretaceous and Paleocene right-lateral transpression from the Late Jurassic-Early Cretaceous left-lateral transpression. Mid-Cretaceous granitic plutons are widespread in the area west of the Rocky Mountain trench (Fig. 5-1 and 5-5). In the vicinity of the Sullivan deposit, a series of small granitic plutons extends eastward into the Rocky Mountain trench, and locally into the Western Ranges and Western Main Ranges of the Rocky Mountains (Leech, 1958, 1960). Mid-Cretaceous granitic plutons have intruded several major, transverse, northwest-dipping, right-lateral reverse faults that offset the Purcell anticlinorium in the Purcell Mountains, and these intrusive relationships provide the key to dating the most recent displacement on these major faults (Fig. 5-5). The displacement on the St. Mary-Lussier River fault occurred prior to 94 Ma, which is the age of the cross-cutting Reade Lake stock (Höy and van der Heyden, 1988); the displacement on the Hall Lake fault occurred prior to about 96 Ma, which is the age of the cross-cutting White Creek batholith (Wanless et al., 1968; Foo, 1979; Archibald et al., 1984), and the displacement on the Mount Forster fault occurred prior to 95 Ma, which is the age of the cross-cutting Horsethief batholith (Reesor, 1973; Archibald et al., 1984; Root, 1987). These three major transverse faults merge northward along the Rocky Mountain trench to become the Purcell thrust fault (Fig. 5-2 and 5-5). Some of the displacement on a fourth major transverse fault, the Moyie-Dibble Creek fault (Fig. 5-5), apparently occurred somewhat later, at least near its southern end, adjacent to the Dry Creek stock in northwestern Montana (Fig. 5-5). There, thrust displacement on the

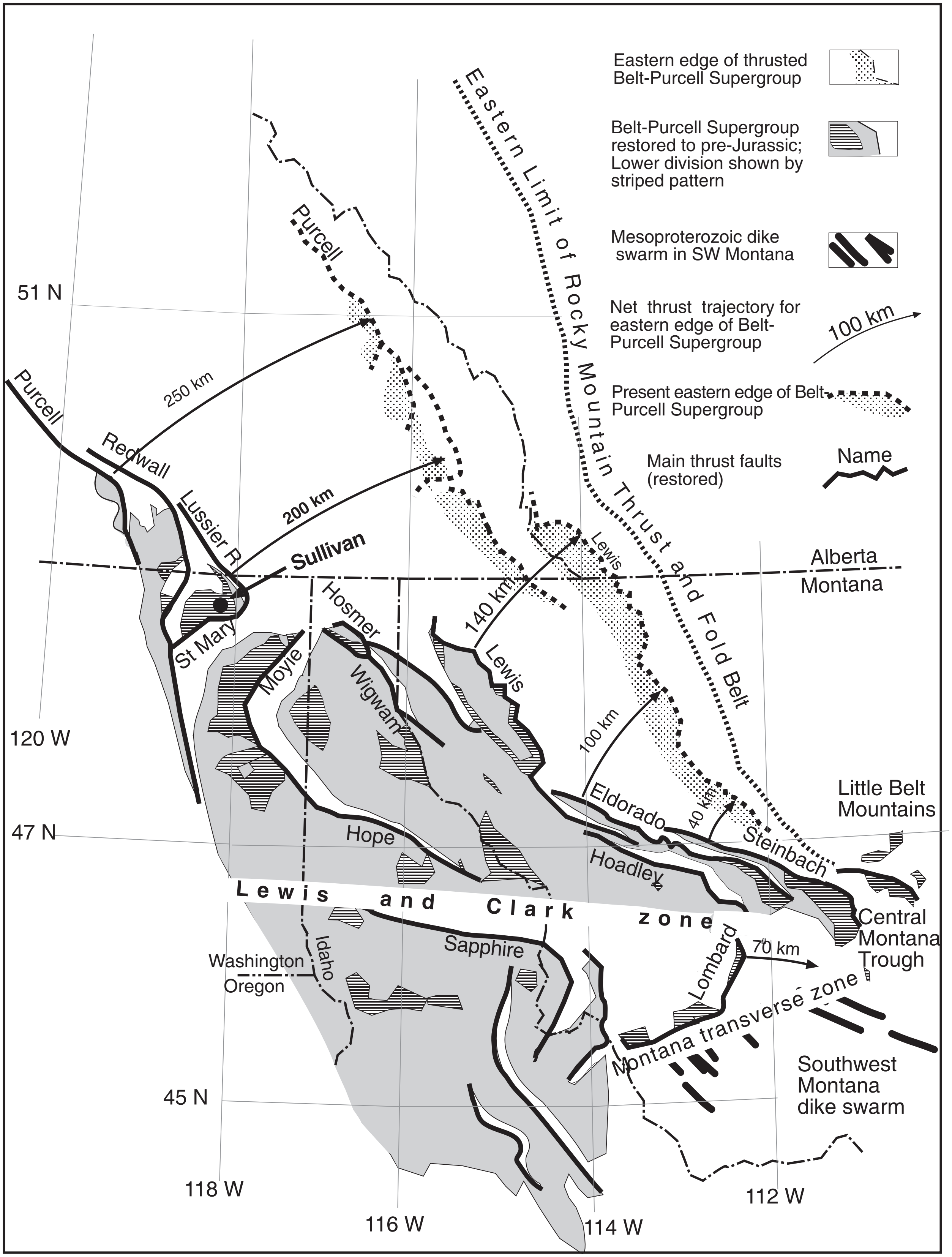


Figure 5-3. Tectonic rotation of the Belt-Purcell rocks relative to the North American craton. The concentric lines with arrow heads connect the positions of points in the palinspastic reconstruction to their present position, and show the direction and amount of net horizontal displacement for those points. The change in direction of rotation north and west of the Moyie fault occurs because the rocks there were affected by a Late Jurassic-Early Cretaceous episode of left-lateral transpression, as well as the Late Cretaceous-Paleocene episode of right-lateral transpression.

Moyie fault resulted in deformation of the western margin of the 71 Ma-old Dry Creek stock (Fillipone and Yin, 1994).

The cross-cutting, "stitching" plutons show that by mid-Cretaceous time thrusting and folding within the Belt-Purcell rocks north and west of the Moyie fault had ended. During the Late Cretaceous, these rocks, which by then were consolidated, were displaced northeastward en masse, along with the Intermontane terrane, as the tectonic collage of Cordilleran accreted terranes converged obliquely with North America, and the Cordilleran basal detachment propagated northeastward from beneath the Cordilleran miogeocline to form the thrust and fold structures of the Front Ranges and Foothills of the Canadian Rockies (Price, 1981).

Late Jurassic-Early Cretaceous left-lateral transpression

The Late Jurassic-Early Cretaceous episode of left-lateral transpression is documented mainly by the four major transverse, northwest-dipping faults that cut across and displace the Purcell anticlinorium in the Purcell Mountains (Fig. 5-1 and 5-5). Where they cut across the Purcell anticlinorium, the Moyie-Dibble Creek, St. Mary-Lussier River, Hall Lake, and Mount Forster faults are all major right-lateral reverse faults. All four faults change southward in the western Purcell Mountains, and northward in the Rocky Mountain trench or the western Rocky Mountains, into west-dipping or southwest-dipping thrust faults that are aligned with the regional tectonic grain of the Cordilleran foreland thrust and fold belt. The transverse, northeast-trending segments of the Moyie-Dibble Creek, St. Mary, and Hall Lake faults are known to follow pre-existing (Early Paleozoic, Eocambrian, Neoproterozoic, and Mesoproterozoic) structures (Leech, 1958, 1960; Price et al., 1972; Foo, 1979; Price, 1981, 1996). In the case of the northeast-trending segment of the Moyie-Dibble Creek fault, the antecedent structure had the opposite stratigraphic separation (down-thrown to the northwest) with more than 7 km of structural relief beneath a regional sub-Upper Devonian (sub-Fairholme Group) unconformity (*see* Fig. 5-13). In the case of the northeast-trending segment of the St. Mary-Lussier River fault, the eastern part of the antecedent structure had the same sense of stratigraphic separation (down-thrown to the southeast) during Early Paleozoic time as it has now. However, relationships along the sub-Cambrian unconformity show that the western part of this fault system had the opposite stratigraphic separation (down-thrown about 10 km to the northwest) during Late Proterozoic time (Lis and Price, 1976; *see also* Fig. 5-12). Mesoproterozoic rocks of the Belt-Purcell Supergroup also show conspicuous facies and thickness changes that appear to be controlled by the antecedents of the transverse segments of the Moyie-Dibble Creek and St. Mary faults (Höy et al., 2000; Turner et al., 2000, a and b).

Seismic reflection images that were acquired by Duncan Energy of Denver, during exploration for oil and gas in the Purcell anticlinorium and southern Rocky Mountain trench, show that there are large tectonic overlaps across the transverse, northeast-trending segments of Moyie-Dibble Creek fault and the St. Mary-Lussier River fault (Cook and Van der Velden, 1995). Accordingly, when the Moyie-Dibble Creek and the St. Mary-Lussier River faults formed there must have been a large northwest-southeast component of shortening across these traverse, northeast-trending fault segments of both faults.

Two independent lines of evidence can be used to establish the time of displacement on the Moyie-Dibble Creek and St. Mary-Lussier River faults. (1) The stratigraphic record in the Cordilleran foreland basin shows that a major episode of horizontal shortening occurred within the western part of the Rocky Mountain foreland thrust and fold belt in the Late Jurassic and Early Cretaceous (Price and Mountjoy, 1970; Price, 1973, 1981, and 1994). (2) Cross-cutting, "stitching" plutons (*see* discussion *above* and *also* Fig. 5-5) show that all of the displacement on the St. Mary-Lussier River, Hall Lake and Mount Forster faults occurred prior to mid-Cretaceous time. There are no cross-cutting "stitching" plutons to define the upper limit on the time of displacement on the transverse, northeast-trending segment of the Moyie-Dibble Creek fault. Deformation of the Dry Creek stock (Fillipone and Yin, 1994), which lies adjacent to the northwest-trending part of the Moyie fault, in northwestern Montana (Fig. 5-5), shows that there was some displacement on this part of the Moyie fault during the Upper Cretaceous (after 71 Ma); however, the similarities in structural style and tectonic setting between the Moyie-Dibble Creek fault and the other three northeast-trending transverse faults suggests that most (or all?) of the displacement on the northeast-trending transverse segment of the Moyie fault is also older than mid-Cretaceous. Evidently, the Late Jurassic and Early Cretaceous episode of convergence between the North American craton and Intermontane terrane (the tectonic collage of accreted terranes that lies west of the Cordilleran foreland thrust and fold belt) involved a significant component of northwest-southeast shortening. This northwest-southeast component of shortening can be correlated with a Late Jurassic-Early Cretaceous episode of left-lateral transpression that occurred in the southwestern Canadian Cordillera, between Intermontane terrane and Insular terrane (Monger et al., 1994), and also with oblique left-hand subduction of the Farallon plate under this part of the western margin of North America (Engebretson et al., 1992).

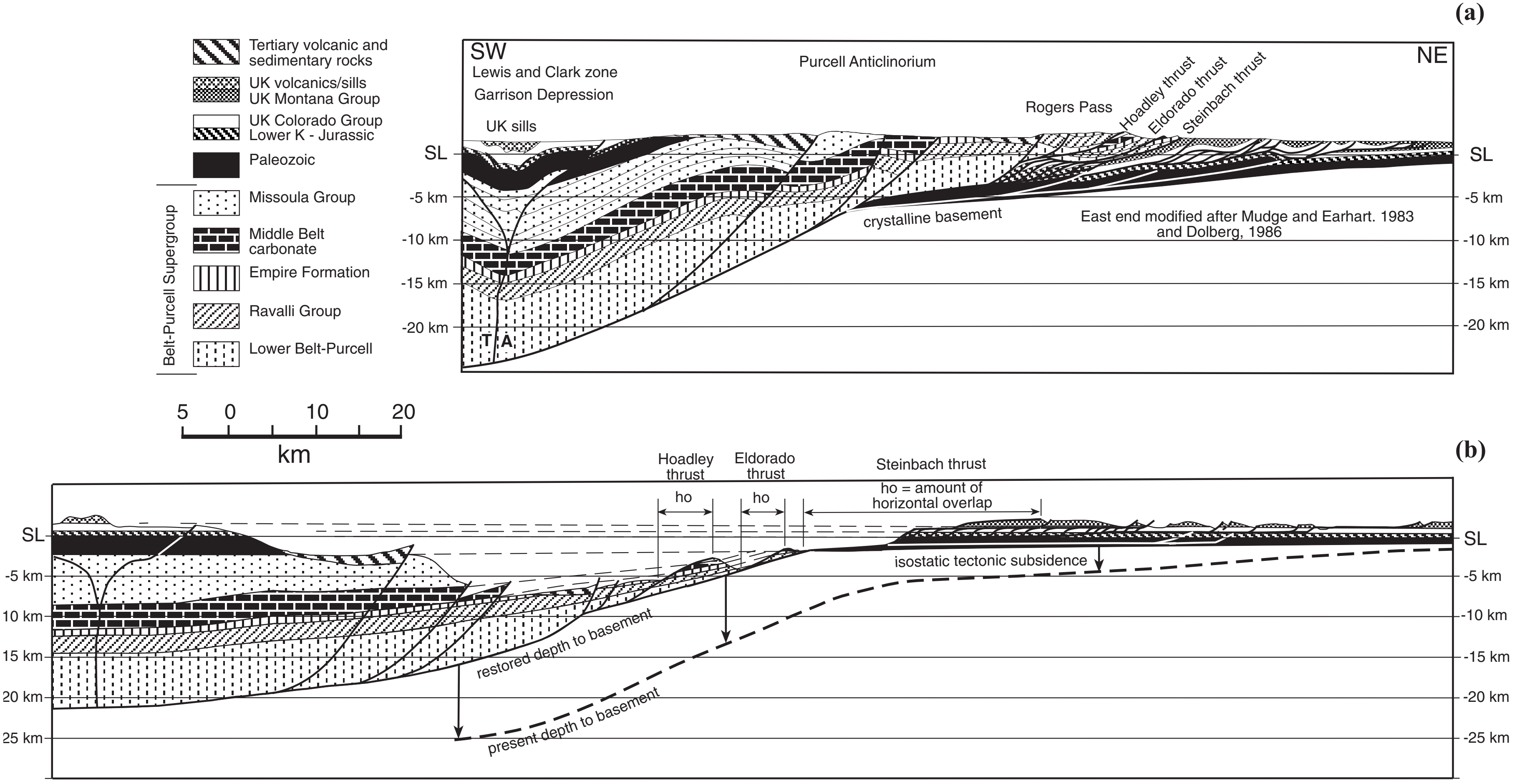
The fact that the Moyie-Dibble Creek and St. Mary-Lussier River faults can be followed, without any significant strike-separation, from the Purcell Mountains, across the southwest-dipping Rocky Mountain trench fault, into the western Rocky Mountains (Leech, 1958, 1960) (*see* Fig. 5-5), demonstrates unequivocally that this part of the Rocky Mountain trench is not a locus of strike-slip faulting. The southern part of the Rocky Mountain trench, which is marked by substantial normal dip separation, is controlled by a listric, southwest-dipping Tertiary normal fault (Bally et al., 1966; Benvenuto and Price, 1979; van der Velden and Cook, 1996).

THE BELT-PURCELL BASIN

Tectonic inversion of the basin-margin ramp

The northeastern edge of the Belt-Purcell basin is marked by a northeastward-tapering stratigraphic wedge, in which all the formations become thinner, change from deeper to shallower water facies, and are truncated northeastward by the

Figure 5-4. Relationships between the eastern part of the Lewis and Clark zone and the basement ramp marking the northeastern margin of the Belt-Purcell basin.
(a) - Balanced structure section along profile I of Figure 5-1 (the eastern part is after Mudge and Earhart, 1983; and Dolberg, 1986; the western part is after Sears, 1996, unpublished). Along this line of section, the Lewis and Clark zone coincides with a south-southwest-facing, crustal-scale monocline within the displaced strata of the foreland thrust and fold belt. The monocline separates a structural culmination to the north-northeast, within which lower and middle Belt-Purcell rocks are exposed, from a structural depression to the south-southwest, within which rocks as young as Upper Cretaceous are exposed. This monocline is a fault-bend fold. It formed as the thick succession of Belt-Purcell rocks that were deposited within this part of the Belt-Purcell rift basin were displaced northeastward, and juxtaposed over the autochthonous ramp marking the flank of the rift basin (compare a with b).
(b) - Corresponding palinspastically restored (retro-deformed) section (after Sears, 1996, unpublished).
The horizontal datum to which the displaced strata have been restored is the unconformity at the base of the Mesozoic rocks. The autochthonous ramp marking the north-northeast side of this part of the Belt Purcell basin has about 20 km of structural relief. The flank of this part of the Belt-Purcell basin, and the adjacent margin of the cratonic platform, subsided "isostatically" in response to the tectonic load imposed by the weight of the overlying rocks that were displaced out of the Belt-Purcell basin. The Mesozoic to Upper Jurassic rocks in this part of the Cordillera were very thin (<~2 km); and therefore, as shown in the figure, this "tectonic subsidence" can be estimated by comparing the present depth to the basement beneath the foreland thrust and fold belt with the restored depth to the basement from the unconformity at the base of the Mesozoic rocks. The intervals along some of the main thrust faults that are labeled "ho" ("= horizontal overlap") show the amounts of horizontal overlap that have occurred, along this line of this section, between strata that occur along the hanging walls of the faults and the strata that occur immediately below, in the footwalls of the same faults. The areas of horizontal overlap in Figure 5-2, (unornamented areas between the restored hanging wall and the restored footwall traces), show how this horizontal overlap varies along strike of the faults.



overlying sub-Paleozoic unconformity. Within the foreland thrust and fold belt, this stratigraphic wedge is allochthonous and has been telescoped by the thrust faults along which the Belt-Purcell rocks were carried northeastward over the craton. The stratigraphic wedge, which formed along the basement ramp that marked the northeastern margin of the Belt-Purcell basin, now coincides with a hanging-wall ramp along the basal detachment of the Rocky Mountain foreland thrust and fold belt. Across this ramp, the thrust faults cut up northeastward through the stratigraphic succession from deeper stratigraphic levels beneath the thicker part of the Belt-Purcell succession to shallower stratigraphic levels beneath the thinner part of the succession. The thrust sheets thin abruptly northeastward across this hanging-wall ramp (Fig. 5-4).

Northeast of the foreland thrust and fold belt, on the cratonic platform northeast of Helena, Montana, (Fig. 5-1) the basin-margin stratigraphic wedge of Belt-Purcell strata is autochthonous. There, in the Little Belt Mountains (Fig. 5-1 and 5-2), a thin succession of platformal facies Belt rocks (Neihart, Chamberlain, and Newland Formations - *see* Winston, 1986a; Chandler, 2000, Fig. 5) unconformably overlie the Archean crystalline basement along the top of the basin-margin ramp, whereas to the south, thicker slope and basinal facies of the lower part of the Belt-Purcell Supergroup (Newland and Greyson Formations) occur over deeper parts of the ramp (Winston, 1986a; Chandler, 2000, Fig. 5). Farther east, on the craton, this ramp forms the northern margin of the autochthonous Central Montana trough. Belt rocks are known in the subsurface of the trough far out into the craton (Winston, 1986b).

The autochthonous basin-margin ramp can be traced west-northwestward under the displaced rocks of the foreland thrust and fold belt because the overlying displaced Mesoproterozoic and Phanerozoic rocks have been draped over it to form a transverse west-northwest-trending, east-southeast facing monocline (Fig. 5-4). This transverse monocline is a fault-bend fold. It was imposed on the overlying Mesoproterozoic and Phanerozoic rocks as they were displaced out of the Belt-Purcell basin in which they had accumulated, up the basin-margin ramp, and over the adjacent flat surface of the North American craton (Sears, 1988, 1994). The monocline involves a 15 to 20 km change in structural level within the allochthonous rocks, and it marks a 15 to 20 km ramp along the basal detachment of the foreland thrust and fold belt. The lower part of the Belt-Purcell succession is exposed in the monocline to the northeast, above the ramp, and Paleozoic and Mesozoic rocks are preserved in the depression on the southwest side of the ramp (for example, *see* Fig. 5-4). This fault-bend monocline coincides with the eastern part of the Lewis and Clark zone (Fig. 5-1 and 5-4); but at about 114ºW longitude it diverges from the Lewis and Clark zone and trends northwestward along the western flank of the Purcell anticlinorium toward Libby, Montana (Fig. 5-1).

Belt-Purcell strata form a conspicuous structural salient in the Lewis thrust sheet where it straddles the International Boundary (Fig. 5-1). The Waterton-Glacier structural salient includes most of Waterton National Park in Canada and Glacier National Park in the United States. It extends southeastward from North Kootenay Pass, which lies just northwest of structure section E (Fig. 5-1) to Marias Pass, which lies approximately midway between structure sections G and H. It is bounded on the northwest, northeast, and the southeast by transverse hanging-wall ramps along which the Lewis thrust cuts up through the stratigraphic section in its hanging wall, from a regional basal detachment in shallow-water lower Belt-Purcell strata (Altyn, Waterton, and underlying formations). These shallow water strata are lateral equivalents of the deep-water turbidites (Aldridge and Prichard Formations) that form the lower part of the Belt-Purcell Supergroup in the basin to the west (Price, 1964; Fermor and Price, 1983; Whipple, 1992). Thickness and facies variations within this salient show that the northwest-trending and southwest-trending transverse ramps coincide with stratigraphic wedges that outline the margins of a northeastward-projecting embayment sub-basin in the main Belt-Purcell basin (Price, 1964; McMechan, 1981). The Belt-Purcell rocks in the region extending southwest from the structural salient are overlain unconformably by a relatively thin succession of Paleozoic shales and carbonate rocks, with a laterally extensive Middle Cambrian quartz sandstone unit (the Flathead Formation) at its base (Norris and Price, 1966). The horizontal datum provided by the unconformity beneath this sandstone shows that in the Middle Cambrian more than 5 km of Belt-Purcell rocks were preserved in the northeastward projecting embayment of the main Belt-Purcell basin. Because of the tectonic inversion that occurred when these Belt-Purcell rocks were detached from their basement and displaced over the flat surface of the craton, they now occur as a regional structural culmination in the Lewis thrust sheet, and they form a tectonic flap that is more than 5 km thick.

Whatever occurs on one side of a fault must have a matching counterpart on the other side. Accordingly, the matching counterparts of the hanging wall ramps that mark

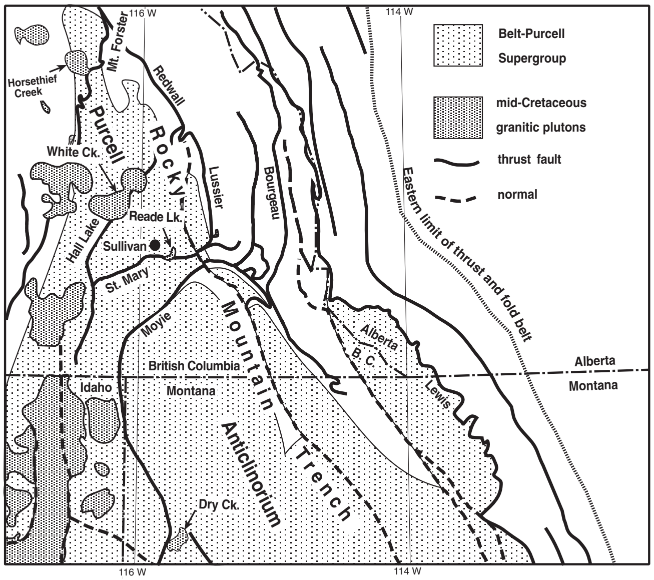


Figure 5-5. Critical cross-cutting relationships between Cretaceous granitic plutons and major thrust faults in the Purcell anticlinorium, southeastern British Columbia and northwestern Washington. See Figure 5-1 for the tectonic setting and location of this area.

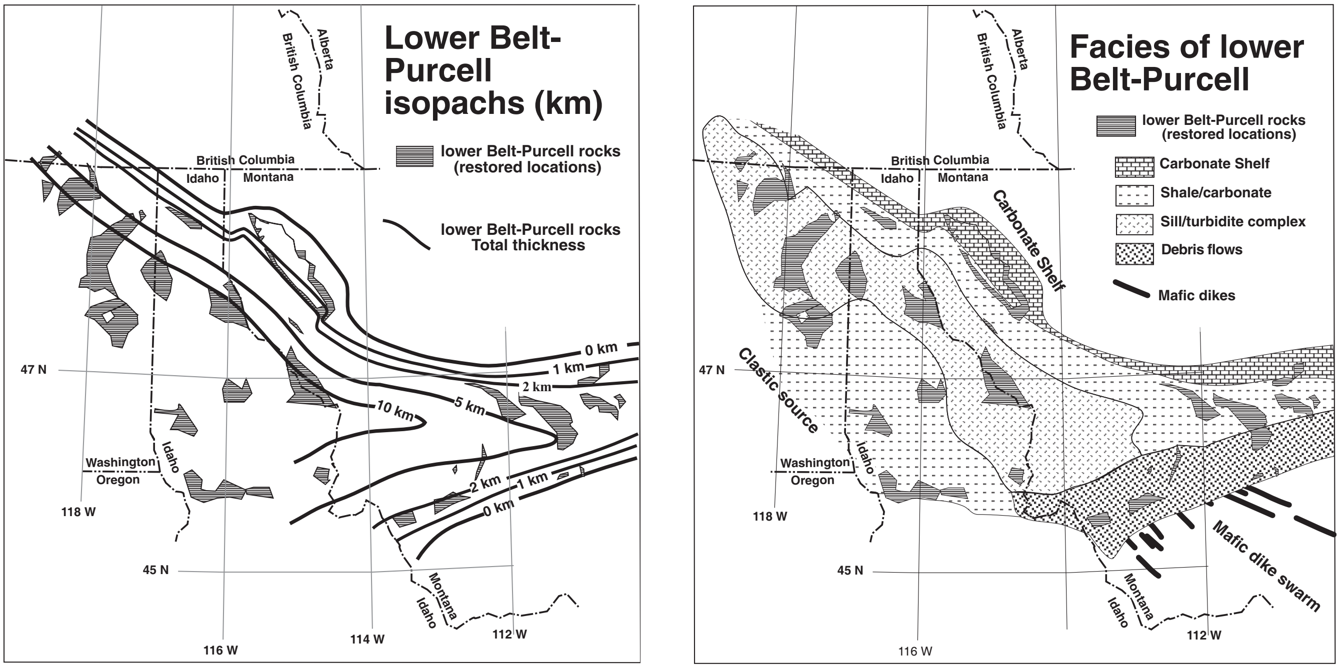


Figure 5-6. **(a)** Palinspastically restored isopach map of lower Belt-Purcell rocks (based on data reported by: McMannis, 1963; McMechan, 1981; Finch and Baldwin, 1984; Cressman, 1989; Höy, 1993; Turner, personal communication, 1994; and Cook and van der Velden,1995; and on the tectonic interpretation illustrated in Fig. 5-2 and 5-3). **(b)** Palinspastically restored facies domains for lower Belt-Purcell rocks (based on data reported by: McMannis, 1963; McMechan, 1981; Finch and Baldwin, 1984; Cressman, 1989; Höy, 1993; Turner, personal communication, 1994; and Cook and van der Velden,1995; and on the tectonic interpretation illustrated in Fig. 5-2 and 5-3).

the northwest and northeast sides of the allochthonous Belt-Purcell rocks in this tectonic flap must occur somewhere to the southwest in the autochthonous rocks in the footwall of the basal detachment of the Cordilleran foreland thrust and fold belt. We conclude that the autochthonous ramps coincide with the northwest, northeast, and southeast sides of a deep (~5 km) structural depression that occurs in the allochthonous rocks of the Purcell anticlinorium southeast of Libby, in northwestern Montana (Fig. 5-1). This structural depression is conspicuous because it contains Cambrian and Devonian strata and is bounded on the northwest, northeast, and southeast by monoclinal folds, across which there is more than 5 km of structural relief (Harrison et al., 1986, 1992). Lower Belt-Purcell rocks are exposed extensively above the monoclines on the northwest, northeast, and southeast of the depression. We suggest that the monoclines are fault-bend folds that formed above the autochthonous ramps marking the northwest, northeast, and southeast margins of the embayment out of which the tectonic flap was displaced. The magnitude of displacement (about 140 km), implicit in this correlation of the monoclines with the displaced and inverted sub-basin that forms the Waterton-Glacier salient of the Lewis thrust sheet, is consistent with the displacement estimated by Fermor and Moffat (1992) from a regional balanced cross-section. However it is substantially more than the minimum value of 115 km in the interpretation by van der Velden and Cook (1996), which was based on the assumption that a ramp outlined by seismic reflectors beneath the Rocky Mountain trench in southeastern British Columbia is the matching footwall ramp for the hanging wall ramp that occurs along the northeast side of the Waterton-Glacier salient of the Lewis thrust sheet.

The lower part of the Belt-Purcell Supergroup

The lower part of the Belt-Purcell Supergroup accumulated within the deeply subsiding axial zone of an evolving intracontinental rift (Chandler, 2000). This part of the rift fill, which comprises the Aldridge and Prichard Formations, consists mainly of relatively fine-grained (sand, silt and mud) basin-plain turbidites. Numerous thick gabbroic sills were intruded into the turbidites before they were compacted and dewatered (Höy, 1989; Sears and Buckley, 1992; Anderson and Davis, 1995; Sears et al., 1998; Anderson and Parrish, 2000). According to Cook and van der Velden (1995, Fig. 5-6D), the seismic reflection data across the Purcell anticlinorium that were acquired by Duncan Energy of Denver indicate that the lower part of the Belt-Purcell Supergroup is more than 10 km thick. The lower part of the Belt-Purcell Supergroup also includes adjacent slope deposits, laterally equivalent shallow-water carbonate and minor siliciclastic shelf deposits that occur along the northeastern margin of the basin (Altyn, Waterton, Tombstone Mountain, Haig Brook, Fort Steele, Neihart and Newland Formations), and the coarse debris-flow conglomerates of the LaHood Formation which occur only along the southern margin of the basin.

On the palinspastic map, variations in thickness, facies, and paleocurrent directions in the lower Belt-Purcell rocks can be used to outline the original configuration and orientation of the Belt-Purcell basin, and its tectonic setting (Fig. 5-6 and 5-7). The thick basin-plain turbidite-mafic sill complex that marks the axial region of the basin was deposited in a deep northwest-trending rift that was bordered on the northeast and the southwest by submarine slopes. There was a conspicuous, shallow-water carbonate shelf along the northeast side of the basin; and locally (in the northwest), the

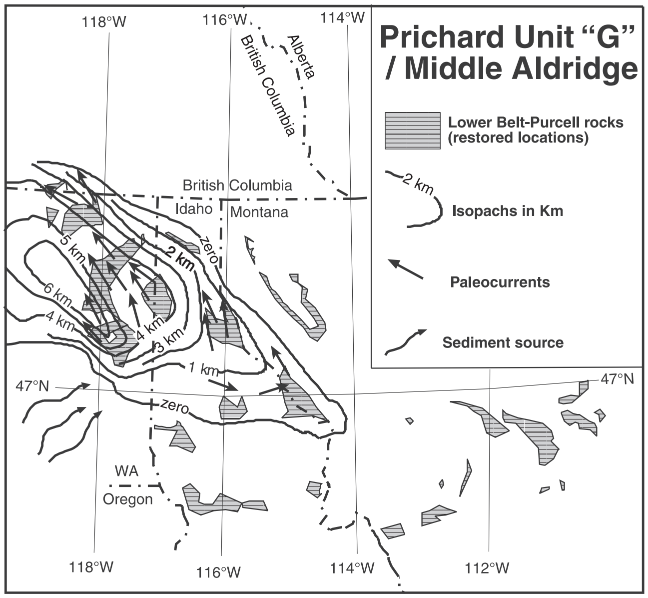


Figure 5-7. Palinspastically restored isopachs and paleocurrent directions for Prichard Formation, Unit G (U.S.A.)/Middle Aldridge Formation (Canada) (based on data reported by: Cressman, 1989; Zieg, 1986; Höy, 1993; and on the tectonic interpretation illustrated in Fig. 5-2 and 5-3).

basin slope was very narrow (Fig. 5-6b). Relationships along the west side of the basin are generally obscured by Mesozoic-Cenozoic magmatism, metamorphism and deformation, and by overlying Neoproterozoic and Early Cambrian rocks. These overlying Neoproterozoic and Early Cambrian rocks evidently were deposited during and after the rifting and drifting that removed the western part of the Belt-Purcell basin before the Cordilleran miogeocline began to form as a "passive" continental margin terrace wedge (Bond et al., 1985).

The east-northeast-trending southern boundary of the basin was an uplifted block of Archean (Wyoming Province) crystalline basement from which debris flows (LaHood Formation) fed into the southern margin of the basin (McMannis, 1963). The episode of greatest crustal stretching and subsidence was accompanied by voluminous mafic magmatism. U-Pb dating of the sills (Anderson and Davis, 1995; Sears et al., 1998; Anderson and Parrish, 2000) has established that this occurred at about 1468 Ma. A northwest-trending Mesoproterozoic mafic dike swarm that occurs within the uplifted Archean basement block south of the Belt-Purcell basin is aligned with the mafic sill-turbidite complex of the axial zone of the Belt-Purcell basin (Fig. 5-6b). The dikes are low K tholeiite in composition, and Rb-Sr geochronometric data show that they were emplaced about 1455 Ma ago, and can be correlated with the mafic sill-turbidite complex (Wooden et al., 1978).

The main source of the large volume of sand, silt, and mud that accumulated along the axis of the rift during the initial stages of its development was to the southwest (Fig. 5-6 and 5-7) in a large delta-fan (Cressman, 1989), that must have been built by a major river flowing out of a large continental craton. This craton, along with the northwestern part of the Belt-Purcell basin, was removed by Neoproterozoic and/or Cambrian rifting and sea-floor spreading. The Sm-Nd signature of the rift-fill sediments confirms that they were derived from a western or southwestern crystalline source, and not from the Archean and Paleoproterozoic basement rocks that occur along the northeastern and southern sides of the basin (Frost and Winston, 1987; Ross et al., 1992).

Older basement structures and the tectonic setting of the Belt-Purcell basin

The Precambrian basement beneath the sedimentary rocks of the Cordilleran foreland basin in Alberta and northwestern Montana, has been subdivided into a series of contrasting tectonic domains (Fig. 5-8) on the basis of magnetic and gravity anomalies and the petrography and geochronology of samples from petroleum exploration wells that have been drilled into it (Ross, 1991; Ross and Parrish, 1991; Villeneuve et al., 1993). It was formed during Paleoproterozoic time as a tectonic collage of fragments of Archean continents, Paleoproterozoic accreted terranes, and Paleoproterozoic magmatic arcs. The dominant structural grain trends northeast-southwest, and is due, in part, to major Paleoproterozoic shear zones that emerge in the Canadian shield and in the basement block uplifts of southwestern Montana.

The basement rocks along the northeast side of the Belt-Purcell basin are of Archean age (Fig. 5-8), and a complex

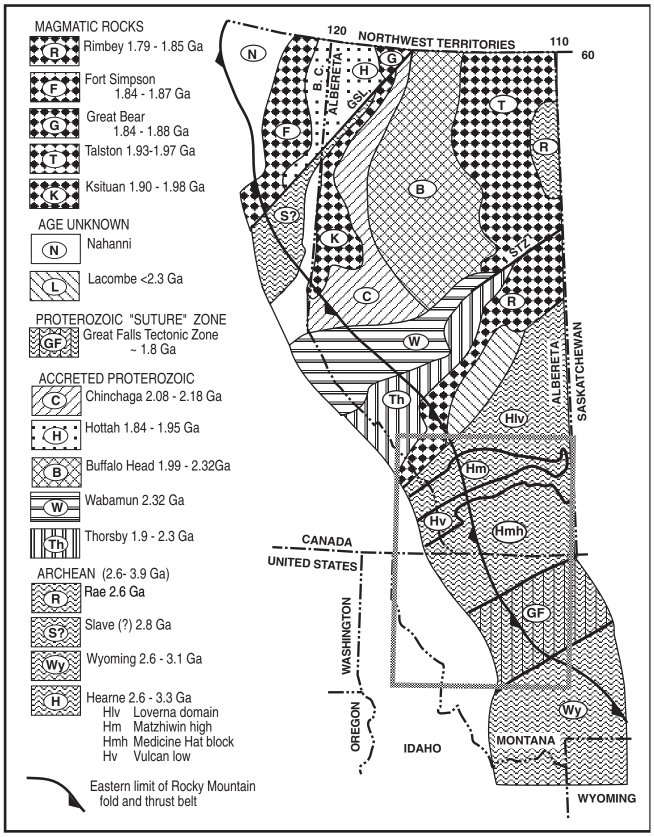


Figure 5-8. Tectonic domains in the Precambrian basement along the foreland margin of the Canadian Cordillera (after Ross, 1991; Ross and Parrish, 1991). The grey rectangle outlines the area shown in Figure 5-9.

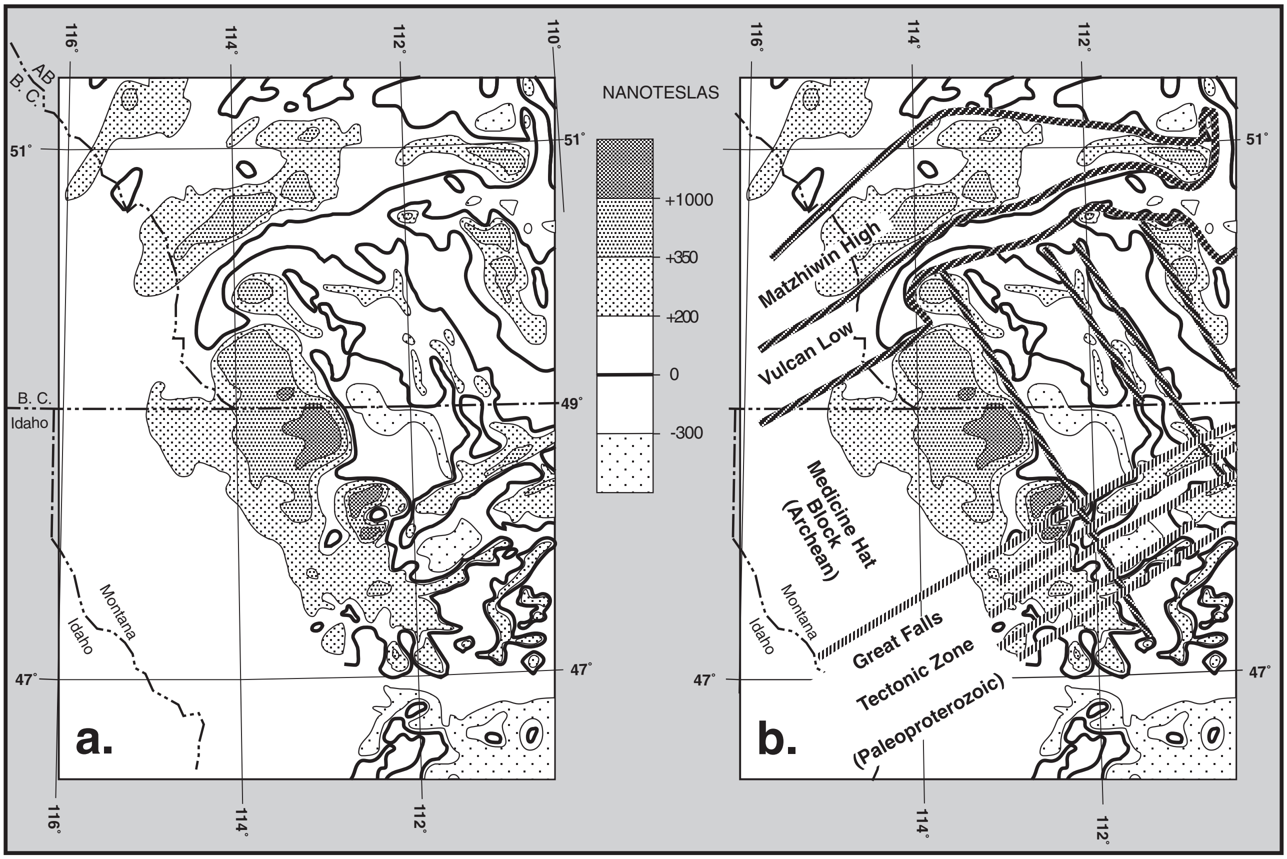


Figure 5-9. **(a)** Magnetic anomaly map of the Precambrian basement of southwestern Alberta, southeastern British Columbia and adjacent parts of northern Montana (after Ross et al., 1991; and Bond and Zietz, 1987). **(b)** Tectonic subdivisions of the Precambrian basement of southwestern Alberta, southeastern British Columbia and adjacent parts of northern Montana (adapted with modifications after Ross et al., 1991; and Ross, 1997).

pattern of superimposed northeast-trending and northwest-trending structures is outlined by the magnetic anomaly field associated with these rocks (Fig. 5-9). The conspicuous northwest-trending Archean structural grain of the Medicine Hat block (Fig. 5-9b) is associated with southwest-dipping crustal-scale structures that have been identified by crustal-scale seismic reflection profiling (Ross, 1997). The northwest-trending structural grain is overprinted to the southeast by the northeast-trending structures of the Great Falls tectonic zone (Fig. 5-9b), which probably represents a Paleoproterozoic shear zone (Boerner, et al., 1998). To the northwest, the northwest-trending, southwest-dipping Archean structures are truncated by the northeast-trending Vulcan structure, which is outlined by conspicuous magnetic anomalies (the “Vulcan low” and “Matzhiwin high” (Fig. 5-9b). On the basis of crustal-scale seismic reflection profiles across the “Matzhiwin high”, “Vulcan low”, and adjacent parts of the Medicine Hat block, the Vulcan structure has been interpreted as marking a suture between the Medicine Hat block and the Loverna domain and “Matzhiwin high” that dips to the southeast at a shallow angle (Clowes et al., 1997; Ross, 1997); but changes in reflectivity characteristics across the Vulcan structure suggest that it is bounded by steep fault zones and is overlain by a basin filled with Precambrian strata (Clowes et al., 1997).

The Belt-Purcell basin formed as a branching intracontinental rift basin within a Paleoproterozoic continent. Two arms of the rift system are well defined against the margin of the Paleoproterozoic core of the North American craton (Fig. 5-6b): (1.) an asymmetric east-northeast-trending arm that extends along the Central Montana trough was bounded to the south by an active fault-line scarp along the northern side of the Wyoming Province Archean craton, and (2.) a symmetrical northwest-trending arm that is defined by the rift-axis mafic sill-turbidite complex and adjacent basin slope facies belts. Both rift arms truncate the structural grain outlined by magnetic (Fig. 5-9 and 5-10) and gravity anomalies in the Archean and (?) Paleoproterozoic basement block that lies to the northeast. Relicts of a southwest-trending arm are preserved in the Salmon river arch (Ruppel, 1975; Doughty and Chamberlain, 1996), which lies between the northern and southern lobes of the Idaho batholith (Fig. 5-1).

The east-northeast-trending arm is conspicuously asymmetrical. There was a carbonate shelf on the north side, but the south side was an active fault zone from which the debris flows of the LaHood Formation were shed into the marginal zone of the basin (Fig. 5-6b). The sedimentary fill in the axial zone of the east-northeast-trending arm is like that in the northwest-trending arm. The axis of the northwest-trending branch of the rift abuts the border fault and the debris flows that mark the south side of the east-northeast-trending branch of the rift (Fig. 5-6b). This suggests that the border fault on the south side of the east-northeast-trending branch may have been a right-hand transfer fault. Horizontal stretching appears to have been much greater across the northwest-trending branch of the rift than the east-northeast-trending branch. Some of the stretching across the northwest-trending branch appears to have been transferred, via the fault along the southern border of the east-northeast-trending branch, to the southwest-trending arm of the basin (preserved in the Salmon River arch) that lay to the south. There was also substantial horizontal stretching across the east-northeast-trending rift arm. Post-stretching thermal subsidence of the rift structure is recorded by the overlying thick, shallow-water, siliciclastic rift-sag deposits of the Ravalli Group/Creston Formation and the carbonate deposits of the Wallace/Kitchener Formation (Chandler, 2000).

The Paleoproterozoic and Archean structures are truncated by the rift, and therefore, they have not controlled the large-scale structure of the rift (Fig. 5-10). However, these older structures have influenced smaller scale features of the Belt-Purcell basin. Reactivation of older, northeast-trending basement structures, which are probably related to the Vulcan structure, have influenced the detailed structure within the axial zone of the rift, including the structures that controlled the location of the Sullivan deposit (Höy et al., 2000; Turner et al., 2000, a and b). The detailed configuration of the margin of the basin also may have been controlled by these older structures. For example the northeast-trending, basin-margin ramp that marks the northwest side of the Waterton-Glacier salient is aligned with the southeast boundary of the Vulcan structure (*see* Fig. 5-10 and also the preceding discussion of the Waterton-Glacier salient of the Lewis thrust sheet).

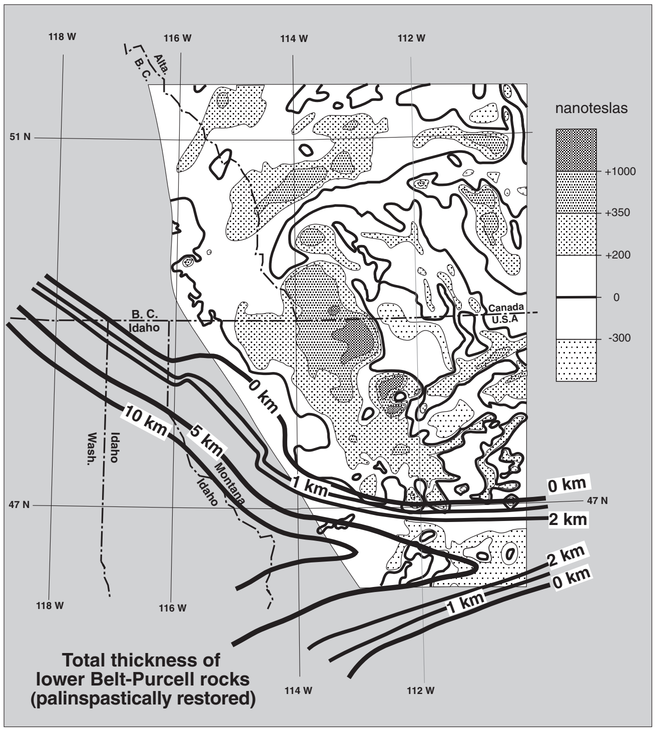


Figure 5-10. Relationships between the northeastern margin of the Belt-Purcell basin and magnetic anomaly patterns in the Precambrian basement of southwestern Alberta, southeastern British Columbia and adjacent parts of northern Montana (magnetic anomaly map from Fig. 5-9a; palinspastically restored isopach map of total thickness of lower Belt-Purcell rocks form Fig. 5-6a).

"East Kootenay orogeny"

The "East Kootenay orogeny" is a Mesoproterozoic episode of deformation, regional metamorphism, and granitic intrusion in the Purcell anticlinorium in southern Canada (White, 1959; Leech, 1962). It has been interpreted as marking the termination of Belt-Purcell sedimentation (McMechan and Price, 1982) at about 1300 Ma, which is the Rb-Sr whole-rock age of the Hellroaring Creek granodiorite (Ryan and Blenkinsop, 1971) that intrudes deformed and foliated lower Belt-Purcell rocks in the Purcell anticlinorium about 20 km west of the Sullivan deposit. Doughty and Chamberlain (1996) have documented an episode of bimodal magmatism, rifting and renewed basin subsidence at about 1370 Ma, in the eastern part of the Salmon River arch (Fig. 5-1), in rocks that have been correlated with the Belt-Purcell Supergroup. They suggested that this tectonic episode should be correlated with the mafic magmatism (Purcell Lava and Nicol Creek Formation) that terminated Middle Belt carbonate deposition, and with the local syndepositional block faulting that is recorded by thickness variations in the Nicol Creek Formation immediately south and east of the Sullivan deposit (McMechan, 1981), and at unconformities below the Sheppard and Gateway Formations immediately north of the Sullivan deposit (Höy, 1993), as well as with the Hellroaring Creek stock. They also suggested that it comprises a regional episode of deep seated magmatism and crustal extension that marked the initiation of the deposition of the shallow-water siliciclastic deposits of the upper part of the Belt-Purcell Supergroup. However, new U-Pb zircon dates (about 1445 Ma) from the magmatic rocks which occur at the top of the middle Belt carbonate rocks in northern Montana (Aleinikoff et al., 1996), and marked the initiation of the deposition of the shallow-water siliciclastic deposits of the upper part of the Belt-Purcell Supergroup, show that they are much older than the "East Kootenay orogeny". The regional tectonic significance of the episode of bimodal magmatism, rifting and renewed basin subsidence in the eastern part of the Salmon River arch, and the nature and significance of the "East Kootenay orogeny", both require clarification.

Grenville-age deformation

An enigmatic episode of Grenville age (1050 -1120 Ma) "burial" metamorphism appears to be relatively widespread in the Belt-Purcell rocks (Anderson and Davis, 1995), but evidence for deformation of this age is elusive. Wooden et al. (1978) reported Rb-Sr dates of 1120-1130 from mafic dikes in the Archean basement in southern Montana, south of the east-northeast-trending arm of the Belt-Purcell basin. Ross et al., (1992) reported that there are detrital zircons of Grenville age (1070 - 1244 Ma) in the Buffalo Hump Formation of northeastern Washington, which has been interpreted as equivalent to the upper part of the Belt-Purcell Supergroup, but may be younger. In either case, the Grenville-age provenance of the Buffalo Hump Formation implies that an exposed basement terrane that was younger than most of the Belt-Purcell Supergroup lay west of the Belt-Purcell basin during, or prior to, the deposition of the Buffalo Hump Formation. The enigmatic Grenville-age bur-

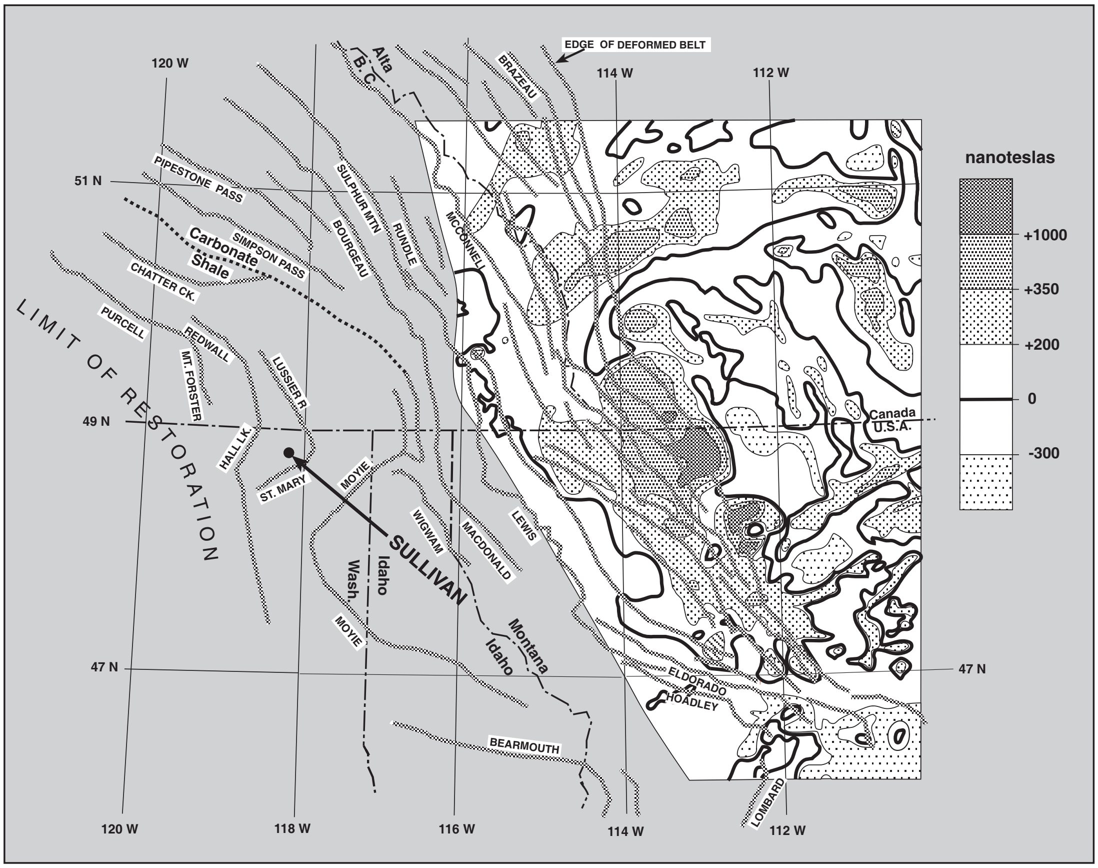


Figure 5-11. Magnetic anomaly map with palinspastically restored hanging wall traces of principal thrust faults (magnetic anomaly map from Fig. 5-9a; palinspastically restored hanging wall traces of principal thrust faults from Fig. 5-2).

ial metamorphism presumably is related to the development of this western belt of Grenville-age basement.

Neoproterozoic deformation

The Neoproterozoic rocks of the Windermere Supergroup and its correlatives extend along the North American Cordillera from east-central Alaska to southern California. They record an episode of rifting and deep subsidence that was co-extensive with the Cordilleran Paleozoic miogeocline, and which was a harbinger of the continental break-up that gave rise to the Cordilleran miogeocline (Stewart, 1976). The widespread occurrence of texturally and mineralogically immature pebble and granule conglomerates ("grits") and related sandstones sets the Windermere Supergroup apart from the underlying Belt-Purcell Supergroup and from the overlying Early Paleozoic strata.

In southern Canada, the northeastern edge of the Windermere basin follows the eastern Main ranges of the Rocky Mountains from northeastern British Columbia almost to the Crowsnest Pass. There, it makes a 200 km right-hand offset across the Purcell anticlinorium into northeastern Washington, passing close to the location of the Sullivan deposit (Fig. 5-12). This offset is due primarily to Neoproterozoic displacement on the antecedent of the St. Mary fault (Lis and Price, 1976). In the western Purcell Mountains the Windermere succession in the structural block on the northwest side of the St. Mary fault is 5 - 10 km thick, and includes conglomerate units at the base, near the middle, and near the top that contain clasts derived from the Belt-Purcell Supergroup. This thick Windermere succession overlies the upper part of the Belt-Purcell Supergroup, and is overlain by Lower Cambrian strata of the Hamill Group. In the structural block on the southeast side of the St. Mary fault, Lower Cambrian strata of the Cranbrook Formation lie unconformably on the middle and lower parts of the Belt-Purcell Supergroup, and more than 5 km of Belt-Purcell strata have been removed by pre-Early Cambrian erosion. Thus, there was more than 10 km of throw on the antecedent of this part of the St. Mary fault. This clearly was a structure of crustal dimensions. However, nearby to the northeast, in the western range of the Rocky Mountains, where the St. Mary fault merges with the Lussier River fault, the Windermere Supergroup is absent, and the stratigraphic separation across the fault beneath the sub-Cambrian unconformity is very small.

The antecedent of the St. Mary fault was a structure that cut across the axial zone of the lower Belt-Purcell rift basin some 10 km south of the Sullivan deposit (Fig. 5-11 and 5-12). It was aligned with the structure in the underlying Archean basement that is marked by the boundary between the "Vulcan low" and the Matzhiwin high. Therefore, it is logical to conclude that it developed as a result of Neoproterozoic reactivation of a structure inherited from the Archean basement, and furthermore, to suggest that the northeast-trending basement structures on the northeast side

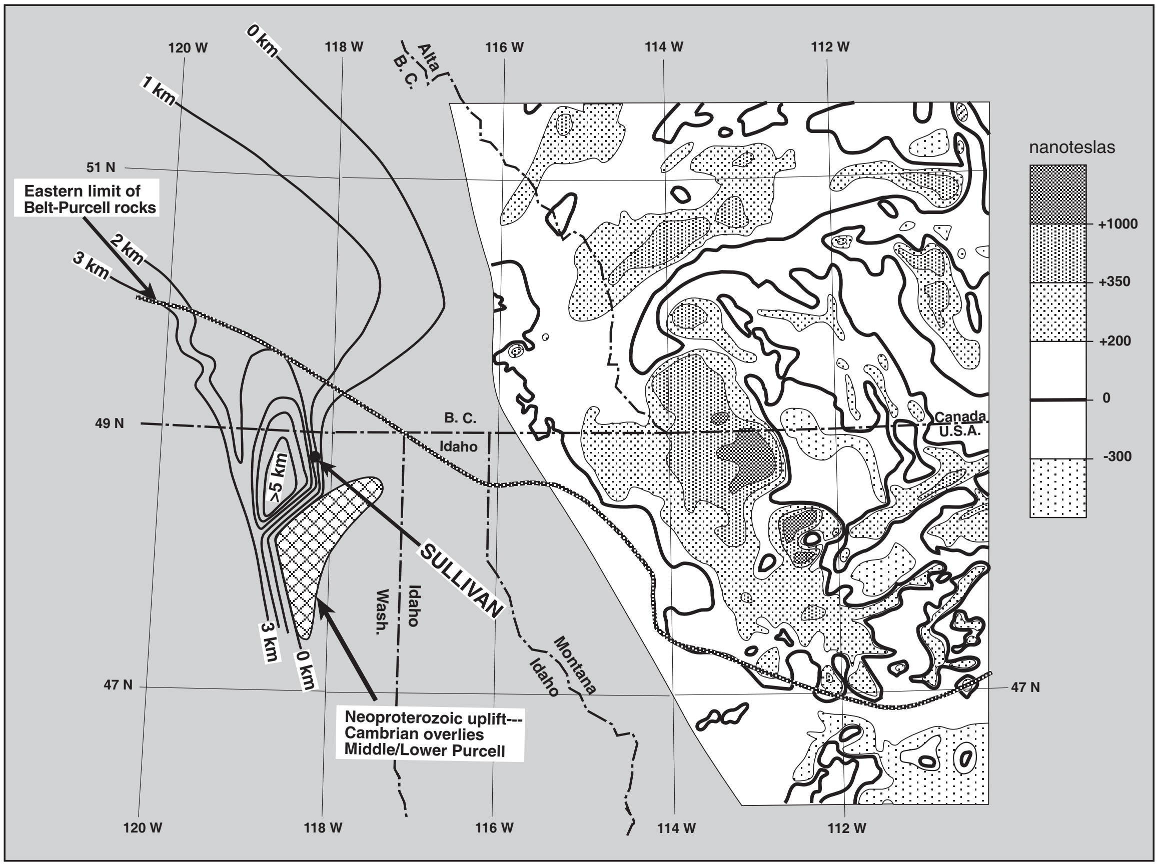


Figure 5-12. Palinspastically restored isopach map of Windermere Supergroup. The cross-hatch pattern identifies the area between the Moyie and St. Mary faults within which the Purcell Supergroup was deeply eroded, and from which conglomerates were shed northward into the Windermere Supergroup (Lis and Price, 1976).

of this arm of the Belt-Purcell rift may have extended across the axial zone into the basement rocks on the southwest side.

Early Paleozoic deformation

The boundary between the Cordilleran miogeocline and the North American cratonic platform follows the east side of the Main Ranges of the Rocky Mountains from northeastern British Columbia to the area just east of the Sullivan deposit, where there is a 200 km right-hand offset that extends across the Belt-Purcell basin into northeastern Washington. In the vicinity of the Sullivan deposit, the right-hand offset coincides with the northeast-trending segment of the Moyie-Dibble Creek fault, a transverse right-hand reverse fault that passes 45 km south of the Sullivan deposit (Fig. 5-11 and 5-13). (The Dibble Creek fault, which occurs in the western Rocky Mountains in the footwall of the Rocky Mountain trench normal fault, is the offset counterpart of the Moyie fault, which occurs in the Purcell Mountains, in the hanging wall of the Rocky Mountain trench normal fault.)

The Moyie-Dibble Creek fault follows the locus of an Early Paleozoic structure across which there was 5 - 10 km of downthrow to the northwest between Early Cambrian and Late Devonian time (Leech, 1960; Price et al., 1972; Benvenuto and Price, 1979). In the western Rocky Mountains, on the northwest of the Dibble Creek fault, the Upper Devonian (Frasnian) carbonate rocks of the Fairholme Group are underlain by up to 7 km of Early Paleozoic (Lower Cambrian, Middle and Upper Cambrian, Ordovician, Silurian, and Middle Devonian) rocks. In contrast, in the region southeast of the Dibble Creek fault, the Fairholme Group is underlain by < 200 m of shallow water Middle Cambrian rocks, and close to the fault, the Fairholme Group unconformably overlaps the Cambrian rocks and lies on the middle part of the Belt-Purcell Supergroup. In the eastern Purcell Mountains, the youngest rocks preserved on the northwest side of the Moyie fault are the Lower Cambrian Cranbrook and Eager Formations, which form a succession > 2 km thick; but on the southeast side of the Moyie fault the Fairholme Group is unconformable on the Belt-Purcell succession, and it cuts downsection northwestward through ~ 2 km of rock from the upper to the middle part of the Belt-Purcell Supergroup.

The Moyie -Dibble Creek fault coincides with the northwestern margin of Montania (Price et al., 1972; Benvenuto and Price, 1979), a westward extension of the North American cratonic platform whose basement consists of Belt-Purcell rocks and older crystalline basement rocks. Montania was overlain by a thin, condensed section of shallow-water Cambrian rocks, and by a relatively thin succession of Devono-Carboniferous rocks, similar to those that extend eastward into eastern Montana, Alberta and Saskatchewan. As the block on the northwest side of the antecedent of the Moyie-Dibble Creek fault was down-dropped, the northwestern margin of Montania was tilted upward.

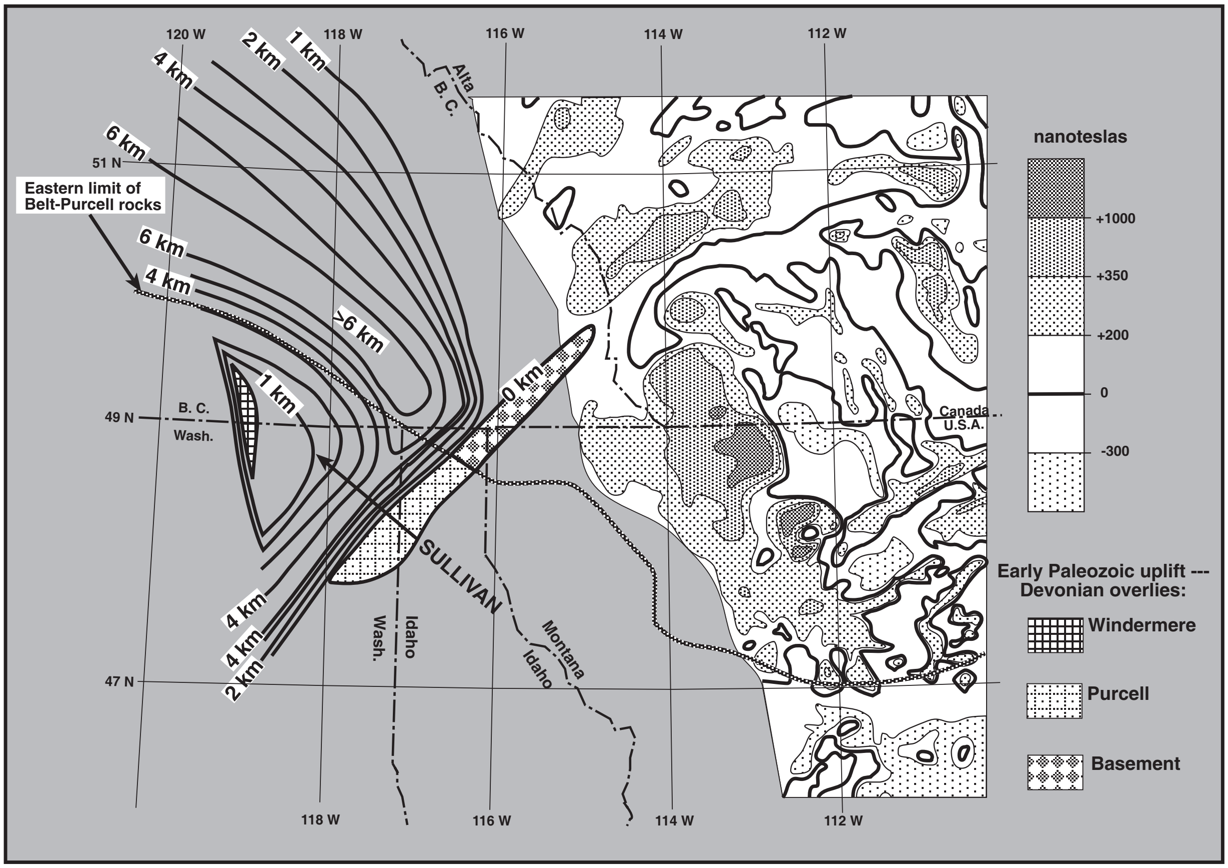


Figure 5-13. Palinspastically restored isopachs of the Lower Paleozoic rocks that are preserved beneath the unconformity at the base of the Upper Devonian (Frasnian) Fairholme Group. Where the Lower Paleozoic rocks have been removed by pre-Upper Devonian (pre-Frasnian) erosion, the underlying Neoproterozoic (Windermere), Mesoproterozoic (Belt-Purcell) and Archean or Paleoproterozoic crystalline basement rocks are identified by different patterns.

The antecedent of the Moyie-Dibble Creek fault was so closely aligned with the suture zone that is outlined by the "Vulcan low" in the Archean basement on the northwestern margin of the Medicine Hat block that (Fig. 5-7) as to leave little doubt that it is an inherited structure that formed by reactivation of the Archean basement structures. This antecedent structure was a feature of crustal dimensions (> 7 km of throw); it passed close to the Sullivan deposit, and it extended across the axis of the Belt-Purcell basin, lending further support to the conclusion that the suture zone in the Archean basement rocks on the northeast side of the northwest arm of the Belt-Purcell rift also extended under the southwest side.

CONCLUSIONS

The Sullivan deposit and most of the other Mesoproterozoic rocks of the Belt-Purcell Supergroup form the lower part of the northeastward-tapering "accretionary wedge" of supracrustal rocks that were scraped off the under-riding North American plate and accreted to the over-riding tectonic collage of Cordilleran terranes that "collided" obliquely with North America. The accretionary wedge was compressed and thickened as it was displaced eastward and northeastward, first during a Late Jurassic-Early Cretaceous episode of left-lateral transpression, and then during a Late Cretaceous-Paleocene episode of right-lateral transpression. It also was locally fragmented and stretched during an early Tertiary episode of crustal extension and right-lateral shear. The net shortening across the Rocky Mountain foreland thrust and fold belt decreases progressively southward from > 250 km in the vicinity of the North Saskatchewan and Athabasca Rivers, to about 40 km northeast of Missoula, and to < 20 km in the Little Belt Mountains of west-central Montana, near Helena, Montana. This observation is tantamount to describing the net horizontal displacement across this part of the thrust and fold belt as a homogeneous ("rigid block") rotation of about 30^o around an Euler pole near Helena, Montana. Our balanced palinspastic map, which is based on twelve published palinspastically restored, balanced, regional structural sections of the foreland thrust and fold belt, portrays the distribution of the rocks as they existed in the Middle Jurassic, prior to the displacements that were associated with the two episodes of transpressional deformation, and with the ensuing early Tertiary crustal extension. It shows the restored configuration and location of the Belt-Purcell basin in relation to the structures of the Precambrian basement of western North America that have been outlined by aeromagnetic and gravity maps.

The Belt-Purcell basin formed as a branching intracontinental rift within an Archean and Paleoproterozoic craton. The main, northwest-trending rift branch was oriented at a high angle to the dominant northeast-trending tectonic grain of the Archean and Paleoproterozoic basement along the northeast side of the basin. It was roughly symmetrical and is distinguished by the absence of evidence of syn-rift uplift and erosion of the rift flanks, by voluminous syn-rift mafic gabbroic sills, and by a very thick syn-rift fill of relatively fine-grained basin-plain turbidites that were of distant provenance and entered the basin from the southwest in a large fan delta that that must have been fed by a very large river system. The smaller, east-northeast-trending rift branch was strongly asymmetric. The north side included a shallow carbonate shelf and adjacent broad slope; but the south side was a steep, active fault-line scarp from which coarse debris flows were shed into the axial zone of the basin. The main, northwest-trending rift branch abuts the steep, uplifted south flank of the east-northeast-trending branch; but swarms of northwest-trending Mesoproterozoic mafic dykes in the Archean basement to the south show that the zone of magmatic upwelling associated with the axis of the northwest-trending rift branch continues beyond the southern termination of the northwest-trending rift branch.

There were two major episodes of rifting in the evolution of the Belt-Purcell basin. The first, which was the most important, was underway at about 1470 Ma when the Sullivan deposit formed, but it may have commenced prior to 1497 Ma (Anderson and Parrish, 2000). It involved the accumulation of about 10 km of relatively fine-grained basin-plain turbidites and intercalated mafic sills of the lower part of the Belt-Purcell Supergroup; and it was followed by a period of thermal relaxation during which about 6 km of shallow water sediment accumulated above and along the flanks of the rift zone. The Sullivan deposit formed during first episode of rifting. The second episode of rifting occurred at about 1445 Ma. It was associated with increased subsidence, but no deep-water rift basin; with local mafic volcanism, and with local syndepositional block faulting in a shallow shelf environment. The Belt-Purcell rocks also were affected by the enigmatic “East Kootenay orogenay” and by an enigmatic episode of Grenville-age (1050 - 1120 Ma) “burial metamorphism” that presumably is related to the development of a Grenville-age orogenic belt in the region west of the basin.

The Sullivan deposit formed in the axial zone of the northwest branch of the rift where structures that controlled this branch were intersected by the Vulcan structure. The Vulcan structure is a major northeast-trending Paleoproterozoic structure in the Alberta basement that is outlined by a conspicuous negative magnetic anomaly (the “Vulcan low”). It truncates the northwest-trending Archean structures of the Medicine Hat block. Seismic reflection imaging suggests that the it is a depressed block that is overlain by Precambrian strata and is bounded by steep fault zones. It marks the northern boundary of Montania, a long-lived tectonically positive block that coincides with a 200 km right-hand offset in the eastern boundary of the Cordilleran miogeocline, and a major cross-strike discontinuity in the foreland thrust and fold belt.

Neoproterozoic and Early Paleozoic northeast-trending crustal scale faults (throw $\geq$ 10 km), which displaced the Belt-Purcell basin in the region immediately south of the Sullivan deposit, developed by reactivation of Archean structures in the underlying basement. They are related to a 200 km right-hand offset in the faulting that controlled both the eastern margin of the Cordilleran miogeocline and the eastern limit of the syn-rifting deposits of the Windermere Supergroup. The Sullivan deposit is situated in a northwest-trending arm of a branching intracontinental rift system that cuts across the grain of the underlying Archean basement, but it is located in a zone in which Archean basement structures associated with the suture that defines the northwestern margin of the Medicine Hat block have been reactivated repeatedly in Mesoproterozoic, Neoproterozoic, Early Paleozoic, and Mesozoic time.

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