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The Cordilleran Foreland Thrust Belt in Northwestern Montana and Northern Idaho From COCORP and Industry Seismic Reflection Data[1]

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ABSTRACT

COCORP and petroleum industry seismic reflection profiles in northwestern Montana reveal the structure of the Cordilleran foreland thrust belt. The Front Ranges consist of thick thrust sheets containing Precambrian Belt Supergroup and Paleozoic miogeoclinal shelf rocks above a thin remnant of Paleozoic rocks and gently westward-dipping North American basement. Interpretation of the seismic data and results from a recent petroleum exploration well suggest that 15–22 km of Precambrian Belt Supergroup sedimentary rocks are present in several thrust plates beneath the eastern Purcell anticlinorium. Previous hypotheses of a large mass of Paleozoic miogeoclinal sedimentary rocks or slices of crystalline basement located beneath the eastern Purcell anticlinorium do not appear to be supported by the data. The easternmost occurrence of allochthonous basement is interpreted to be in the western part of the anticlinorium near the Montana–Idaho border. Comparison of the Cordilleran foreland thrust belt in northwestern Montana and southern Canada suggests that a change in the deep structure of the Purcell anticlinorium occurs along strike. The anticlinorium in southern Canada has been interpreted as a hanging-wall anticline that was thrust over the western edge of thick Proterozoic North American basement, whereas in northwestern Montana the anticlinorium appears to consist of a complex series of thrust sheets above highly attenuated North American basement.

INTRODUCTION

The foreland thrust belt in northwestern Montana displays two characteristics that differ from other parts of the Cordilleran foreland thrust belt of western North America: (1) an extremely thick section of Proterozoic Belt Supergroup rocks and (2) a virtual lack of evidence at the surface for a well-developed Paleozoic miogeoclinal wedge. Early geologic mapping did not reveal major evidence for thrusting west of the Lewis thrust in Glacier National Park, resulting in hypotheses that the Belt Supergroup was autochthonous or parautochthonous (Mudge, 1970; Harrison, 1972) and that the Cordilleran foreland thrust belt had been deflected eastward around a rigid block containing the "Belt basin" (Harrison, 1972; Harrison et al., 1974). Subsequent geologic mapping in northwestern Montana (Harrison et al., 1980; Harrison et al., 1983) identified major thrusts within the Belt Supergroup, leading to the conclusion that the Cordilleran foreland thrust belt is continuous through northwestern Montana within Belt Supergroup rocks.

As part of a major regional transect of the Cordillera in the northwestern United States (Potter et al., 1987), the Consortium for Continental Reflection Profiling (COCORP) collected deep seismic reflection profiles in northwestern Montana and northern Idaho during 1985 to examine the deep structure of the foreland thrust belt. These profiles were augmented with an industry profile farther east so that structures near the leading edge of the foreland thrust belt could be traced westward to the vicinity of the COCORP lines. These seismic profiles were instrumental in addressing the following questions in this study. To what extent do thrust plates beneath the Purcell anticlinorium contain Paleozoic rocks or

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crystalline basement? What is the westward extent of potentially hydrocarbon-bearing Paleozoic rocks in the subsurface? What is the geometry of major thrust structures at depth and toward the interior parts of the mountain belt? How does the structure of the foreland thrust belt in northwestern Montana compare with that of the more extensively studied foreland thrust belt in southern Canada?

In this paper, we present detailed interpretations of the seismic data and a new interpretation of the regional structure of the foreland thrust belt in northwestern Montana and northern Idaho. Our analysis suggests that the Purcell anticlinorium consists of several thrust plates containing Precambrian Belt Supergroup rocks, with the basal decollement 20–22 km beneath the western part of the anticlinorium. Only a thin remnant of autochthonous Paleozoic rocks is interpreted to be present beneath the easternmost part of the Purcell anticlinorium and allochthonous crystalline basement is interpreted only in the western part of the anticlinorium. The data also suggest that changes in the internal structure of the Purcell anticlinorium and the location of the western edge of thick Proterozoic North American basement occur along strike from southern Canada to northwestern Montana.

REGIONAL GEOLOGIC SETTING

The Cordilleran foreland thrust belt in northwestern Montana and southernmost Canada (Figure 1) has been divided into four major regions (see Bally et al., 1966): the Foothills belt, the Front Ranges, the Rocky Mountain trench, and the Purcell anticlinorium. The Foothills belt, located east of the Lewis thrust (Figure 2) in the vicinity of the United States–Canada border, consists of closely spaced folds and imbricate thrust faults involving Mesozoic synorogenic sedimentary rocks at the surface and Paleozoic miogeoclinal shelf rocks at depth (Gordy et al., 1977). The Front Ranges in Montana consist predominantly of Proterozoic Belt Supergroup rocks within large thrust plates (Figure 2). These thrust sheets were deformed and transported east–northeastward during the Cretaceous and early Tertiary (Hoffman et al., 1976) along widely spaced thrust faults. The Rocky Mountain trench is a topographic low bounded on the east by normal faults. The trench separates the Front Ranges from the Purcell anticlinorium (Figure 1), a structural high consisting of Belt Supergroup rocks deformed by a series of north–northwest-trending folds and faults (Harrison et al., 1980). In this paper, the Purcell anticlinorium south of the international border is used in a geographic sense to describe the area between the Rocky Mountain trench and the Purcell trench (Figures 1, 2). The area between the Rocky Mountain trench and the lead thrust in the Libby thrust belt is referred to as the eastern part of the Purcell anticlinorium, and the western part includes the area from the Libby thrust belt west to the Purcell trench (Figure 2). The Purcell trench forms the westward limit of the foreland thrust belt in Idaho, separating relatively unmetamorphosed sedimentary rocks exhibiting thin-skinned deformation in the Purcell anticlinorium from highly deformed upper greenschist to amphibolite facies metamorphic rocks and plutons exposed in the Priest River Complex in the hinterland of the mountain belt (Figure 2) (Harrison et al., 1972; Miller and Engels, 1975; Rhodes and Hyndman, 1984).

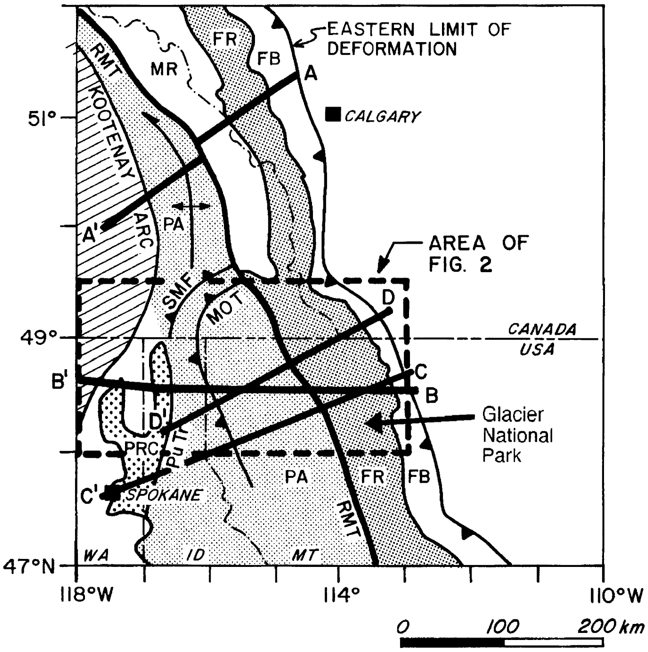


Figure 1—Map illustrating major tectonic and selected structural features of the Cordilleran foreland thrust belt from 47°–52°N and location of cross sections illustrated in Figure 3. FB = Foothills belt, FR = Front Ranges, MR = Main Ranges, RMT = Rocky Mountain trench, PA = Purcell anticlinorium, MOT = Moyie thrust, SMF = St. Mary faults, PuTr = Purcell trench, PRC = Priest River Complex. Data compiled from Bally et al. (1966), Mudge (1982), and Price (1981).

In southern Canada, the Purcell anticlinorium was interpreted by Price (1981) as a crustal-scale hanging-wall anticline located between the Rocky Mountain trench and the Kootenay arc (Figures 1, 3a). In Price's hypothesis for the origin of the anticlinorium, a miogeoclinal wedge of Proterozoic and Paleozoic sedimentary rocks was thrust over the western edge of Proterozoic North American basement located beneath the Kootenay arc. South of 49°45'N (Figure 1), however, the northeasterly-trending St. Mary and Moyie thrusts cut across the trend of the anticlinorium, the Kootenay arc becomes south and southwest trending, Belt Supergroup strata are exposed over a much wider area in northwestern Montana than in southern Canada, and gravity values increase along the anticlinorium (Price, 1981). These observations suggest that a change in the

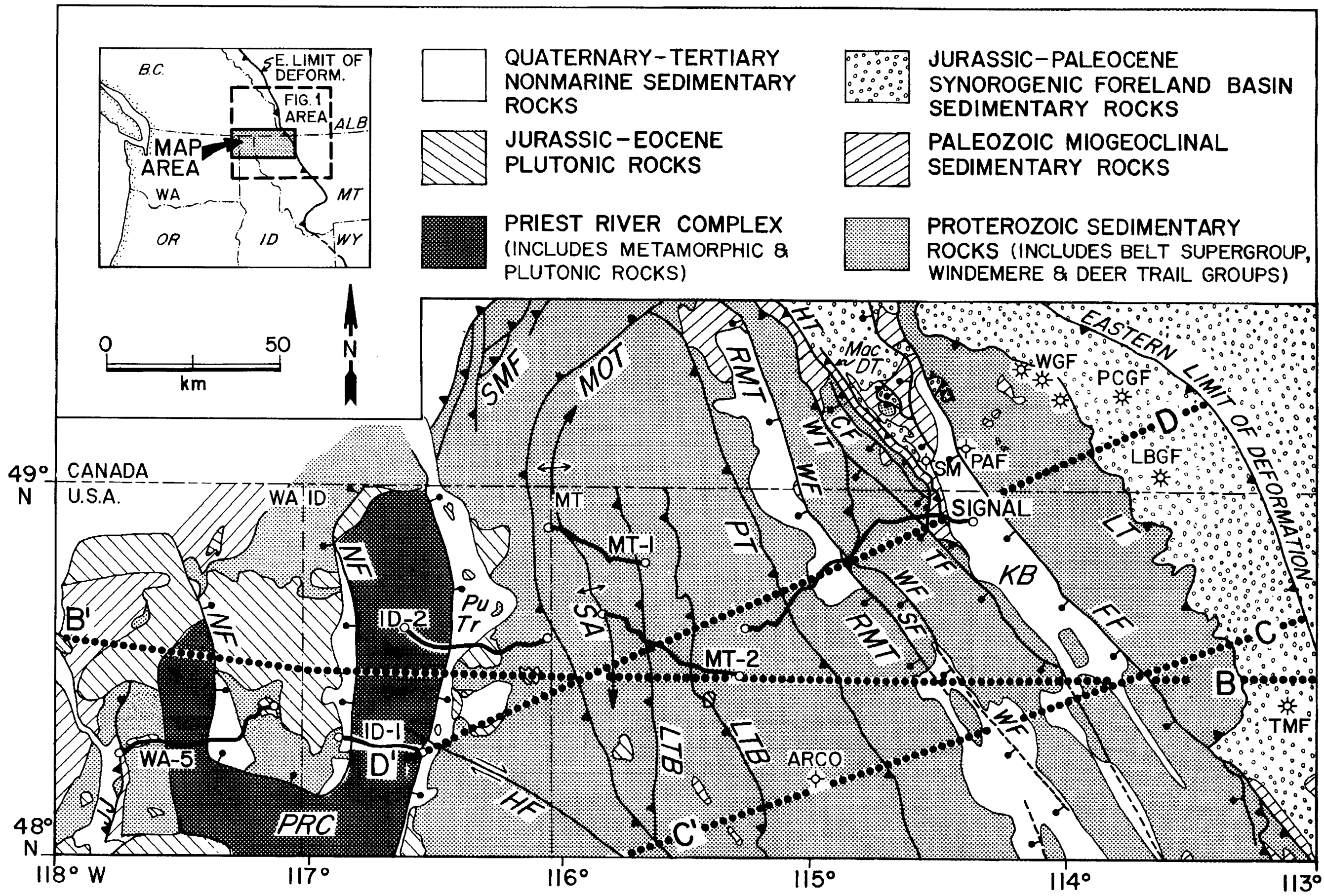
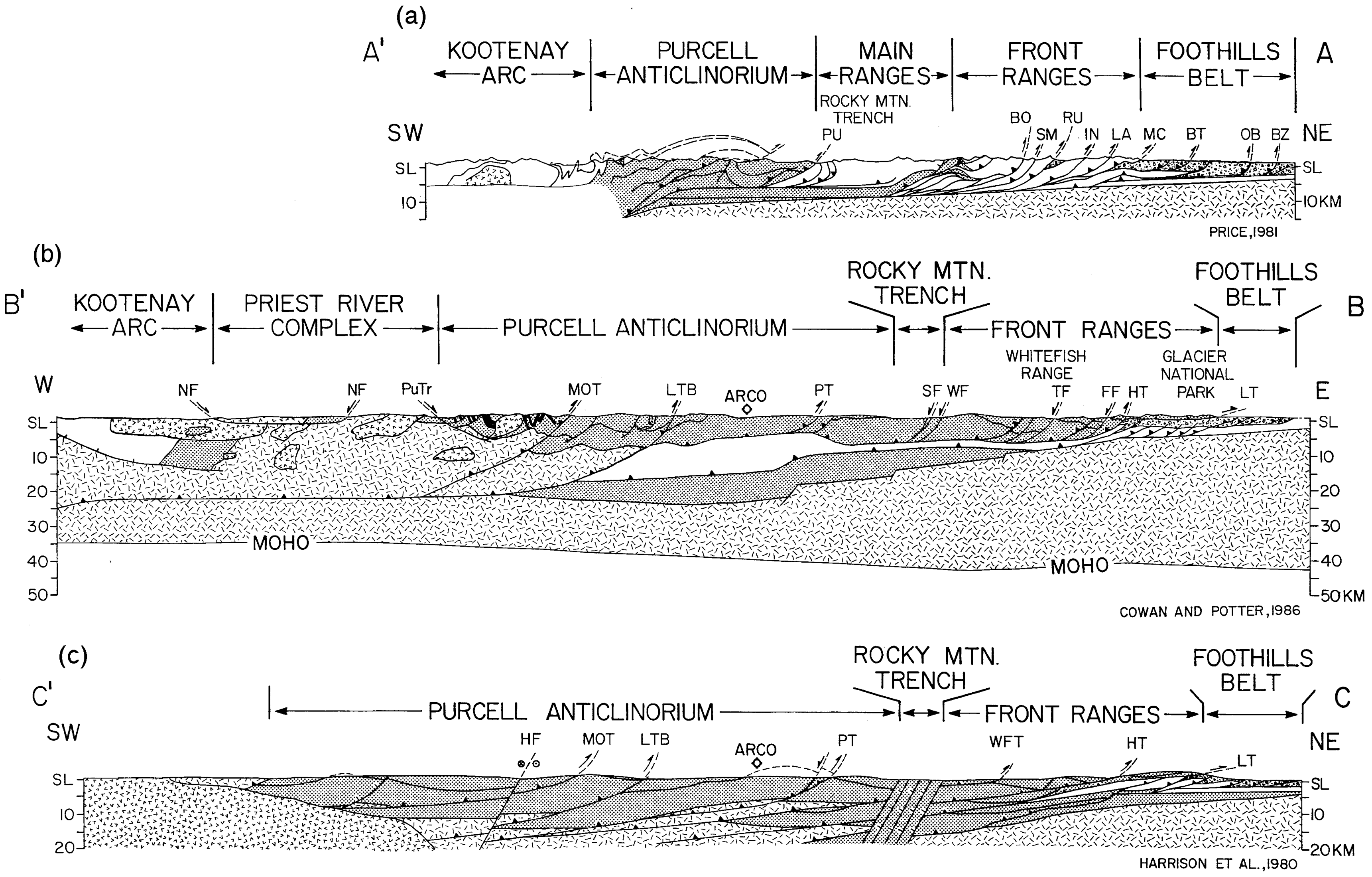


Figure 2—Generalized geologic map and location of seismic reflection lines and regional cross sections used or referenced in this study. SIGNAL = Signal of Montana line WTF-82-1; MT-1, MT-2, ID-1, ID-2, and WA-5 = COCORP Montana lines 1 and 2, Idaho lines 1 and 2, and Washington line 5, respectively. Major geologic features and structures from east to west: LT = Lewis thrust, FF = Flathead fault, KB = Kishenehn basin, MacDT = MacDonald thrust, HT = Hefty thrust, CF = Couldrey fault, TF = Tuchuck fault, WT = Wigwam thrust, WF = Whitefish fault, SF = Stryker fault, RMT = Rocky Mountain trench, PT = Pinkham thrust, LTB = Libby thrust belt, SA = Sylvanite anticline, MOT = Moyie thrust, SMF = St. Mary faults, HF = Hope fault, PuTr = Purcell trench, PRC = Priest River Complex, NF = Newport fault, JJ = Jumpoff Joe fault. Petroleum exploration wells and fields: WGF = Waterton gas field, PCGF = Pincher Creek gas field, LBGF = Lookout Butte gas field, TMF = Two Medicine oil and gas field, PAF = Pacific-Atlantic flathead well, SM = Shell MacDonald well, ARCO = ARCO-Marathon 1 Paul Gibbs well. Lines of section for cross sections: BB' = Continent-Ocean transect B-3 (Cowan and Potter, 1986; see Figure 3b); CC' from Harrison et al. (1980) (see Figure 3c); DD' = new regional cross section interpreted from this study (see Figure 3d). Data complied from Harrison et al. (1983), Mudge (1982), Aadland and Bennett (1979), Gordy et al. (1977), Miller and Yates (1976), Miller and Engels (1975), Johns (1970), Dahlstrom (1970), Price (1962), Ross (1959), and Okulitch and Woodsworth.

structure of the foreland thrust belt may occur along strike.

Three contrasting views of the structure of the Purcell anticlinorium south of the United States–Canada border were published prior to the COCORP surveys. Cowan and Potter (1986) (Figure 3b) interpreted a 10-km-thick mass of Paleozoic miogeoclinal shelf rocks (perhaps structurally thickened) beneath the eastern part of the anticlinorium and allochthonous North American basement beneath the western part of the anticlinorium. In contrast, Harrison et al. (1980) suggested that Paleozoic rocks were absent but that several slices of allochthonous crystalline basement were present beneath the anticlinorium (Figure 3c). Fountain and McDonough (1984) used gravity modeling to propose the presence a basement-cored hanging-wall anticline beneath the anticlinorium.

The Proterozoic Belt Supergroup is an important element in the regional geology of northwestern Montana. Harrison (1972) divided the Belt into four groups. From



PRICE,1981

COWAN AND POTTER,1986

HARRISON ET AL.,1980

Figure 3. See caption on facing page.

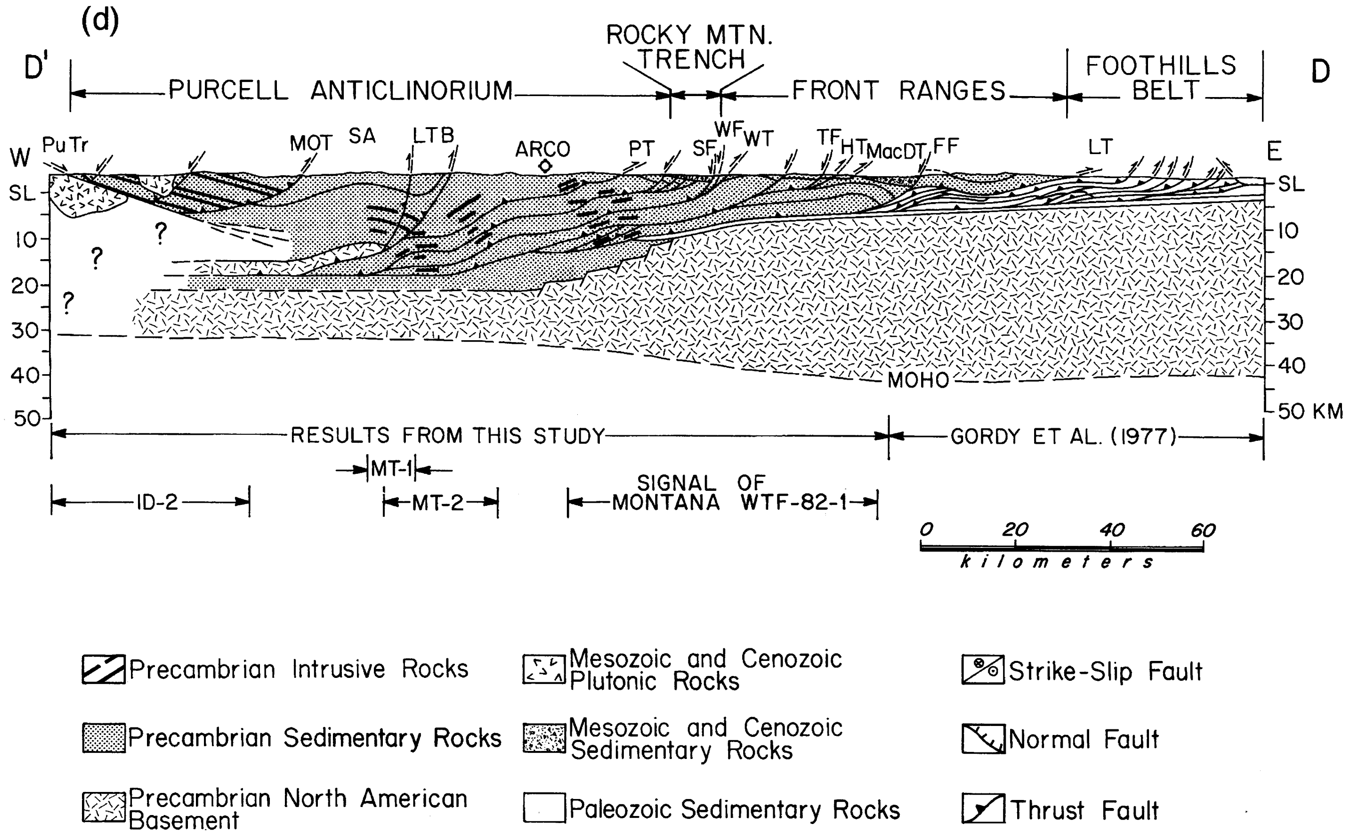


Figure 3—Three previously published cross sections of the Cordilleran foreland thrust belt in southern Canada (AA') and northwestern Montana (BB' and CC') and a new regional cross section based on this study (DD'). See Figures 1 and 2 for the locations of the lines of section. Abbreviations used are identical to those for structures shown on the geologic map in Figure 2 except as noted below. The thin solid line within the Proterozoic sedimentary rocks (Belt Supergroup) in sections BB', CC', and DD' represents the stratigraphic boundary between the Prichard Formation and Ravalli Group below, and the Helena-Wallace Formations and the Missoula Group above. The projected location of the ARCO-Marathon 1 Paul Gibbs well is shown above the sections in Montana. (a) Balanced cross section AA' of the southern Canadian foreland thrust belt (Price, 1981). Faults not shown in Figure 2: BZ = Brazeau, OB = Old Baldy, BT = Burnt Timber, MC = McConnell, LA = Lac des Arcs, IN = Inglismaldie, RU = Rundle, SM = Sulphur Mountain, BO = Bourgeau, PU = Purcell. (b) Crustal cross section BB' from Continent-Ocean Transect B-3 (Cowan and Potter, 1986). Note the interpretation of a 10-km-thick section of Paleozoic carbonate rocks beneath the Purcell anticlinorium. Cowan and Potter (1986) stated that there may be a number of thrust slices within this mass. (c) Cross section CC' from Harrison et al. (1980). Note thrust slices of crystalline basement beneath the Purcell anticlinorium and normal faults within the Rocky Mountain trench. These faults are shown offsetting thrusts within the foreland thrust belt. Faults not shown in Figure 2: WFT = Whitefish thrust. (d) New regional geologic cross section DD' constructed from the interpretation of the seismic reflection data, petroleum exploration wells, and geologic maps within the study area. The subsurface locations of Precambrian intrusive rocks (sills) are based on the interpretation of seismic reflection data, results of the ARCO-Marathon 1 Paul Gibbs well, and the downdip projection of surface outcrops. The depth to the Moho is based on interpreted seismic refraction data (Hales and Nation, 1973; Crosby, 1974).

Table 1. Seismic Data Acquisition Parameters

	Signal of Montana Line WTF-82-1	COCORP Lines MT-2, MT-1, ID-2
Station Spacing	50.3 m	100.6 m
Source Spacing	100.6 m	100.6 m
Group Spacing	50.3 m	100.6 m
Common Midpoint Spacing	25.1 m	50.3 m
Recording Configuration	Split-dip spread	Off-end spread
Nominal Spread Dimensions	2565-201.2-VP-201.2-2565 m	VP-402.3-9958 m
Number of Channels	96	96
Nominal Stacking Fold	24	48
Energy Source	4 Vibrators	4 or 5 Vibrators
Sweep Frequencies	56–14 Hz	10–32 Hz
Sweep Length	15 s	32 s
Field Record Length	20 s	48 s
Correlated Record Length	5 s	16 s
Sampling Rate	2 ms	8 ms

base to top they are (1) the lower Belt or Prichard Formation, (2) the Ravalli Group, (3) the Helena and Wallace formations (sometimes referred to as the middle Belt carbonate), and (4) the Missoula Group. The Prichard Formation, Ravalli Group, and Missoula Group consist of argillite, siltite, and quartzite, and the Helena and Wallace formations are primarily limestones or dolostones, and quartzites (see various papers in Hobbs, 1984). Scattered gabbroic sills and dikes intrude the Helena and Wallace formations in Glacier National Park (Ross, 1959) and gabbroic to dioritic intrusives are prevalent within the lower and middle parts of the Prichard Formation in northwesternmost Montana and the adjacent Idaho panhandle (Aadland and Bennett, 1979; Harrison et al., 1983).

From 1983 to 1984, a deep petroleum exploration well, the ARCO–Marathon 1 Paul Gibbs (Figure 2), was drilled to test the hypothesis of Paleozoic rocks beneath Belt Supergroup rocks exposed across the Purcell anticlinorium (Boberg, 1985). The well drilled a total of 5417 m of lower Belt Supergroup rocks and established a correlation between high-amplitude reflections on seismic reflection lines from the Purcell anticlinorium and diabase intrusives within the Belt Supergroup, but did not encounter any Paleozoic rocks (Boberg, 1985).

SEISMIC DATA

Four seismic reflection lines, WTF-82-1 acquired as part of a petroleum industry survey by Signal of Montana, Inc., and Montana line 1, Montana line 2, and Idaho line 2 acquired by COCORP, form a nearly continuous traverse across the foreland thrust belt in northwestern Montana and northern Idaho (Figure 2). All of the data were collected on crooked roads using a Vibroseis® source and the common midpoint method of reflection profiling. Cross lines within the survey area are not yet available, limiting the three-dimensional control of reflections and structures within the foreland thrust belt.

The data acquisition parameters for the two data sets are similar in many respects, but differences are noted in Table 1. Data processing for all of the lines used standard industry techniques.

The term "reflection sequence," or "sequence," is used in this paper to describe a group of relatively continuous reflections that may have an igneous, sedimentary, metamorphic, or structural origin. A sequence may be bounded by surfaces of discordance or concordance. These surfaces may have a depositional (angular unconformity, disconformity) or tectonic (fault) origin.

DATA DESCRIPTION AND INTERPRETATION

Western Front Ranges

The eastern half of Signal of Montana line WTF-82-1 begins at the western edge of Glacier National Park in the Kishenehn basin (Figure 2), crosses the western part of the Front Ranges, and enters the Rocky Mountain trench at VP (vibration point) 930. Reflections labeled A (Figure 4a) can be traced continuously across the seismic line and occur at 4.2 s two-way traveltime (approximately 11.5 km) beneath the eastern edge of the Rocky Mountain trench at VP 1000. On a depth section, the apparent dip measured along the base of sequence A from VP 250–640 is 2.4–2.7°SW. Projecting this trend northeastward beneath Glacier National Park, these reflections would appear at the base of autochthonous and parautochthonous Paleozoic miogeoclinal shelf rocks encountered in scattered petroleum exploration wells in the Foothills belt north and east of the park (Figure 2) (Gordy et al., 1977; Mudge, 1982). In addition, this calculated dip is similar to the regional dip of a prominent Middle Cambrian reflection mapped on seismic reflection profiles in the undeformed foreland and traced beneath the southern Canadian foreland thrust belt (Bally et al., 1966; P. L. Gordy, 1986, personal communication). Therefore, reflections within sequence A are interpreted as the basal part of the autochthonous or parautochthonous Paleozoic miogeoclinal shelf rocks (Figure 4b). The top of the Proterozoic crystalline basement is inferred to lie just beneath sequence A, and appears relatively unreflective down to the bottom of the data at 5.0 s. Proterozoic Belt Supergroup rocks are not interpreted to be beneath Paleozoic strata here as was suggested by Cowan and Potter (1986) and Harri-

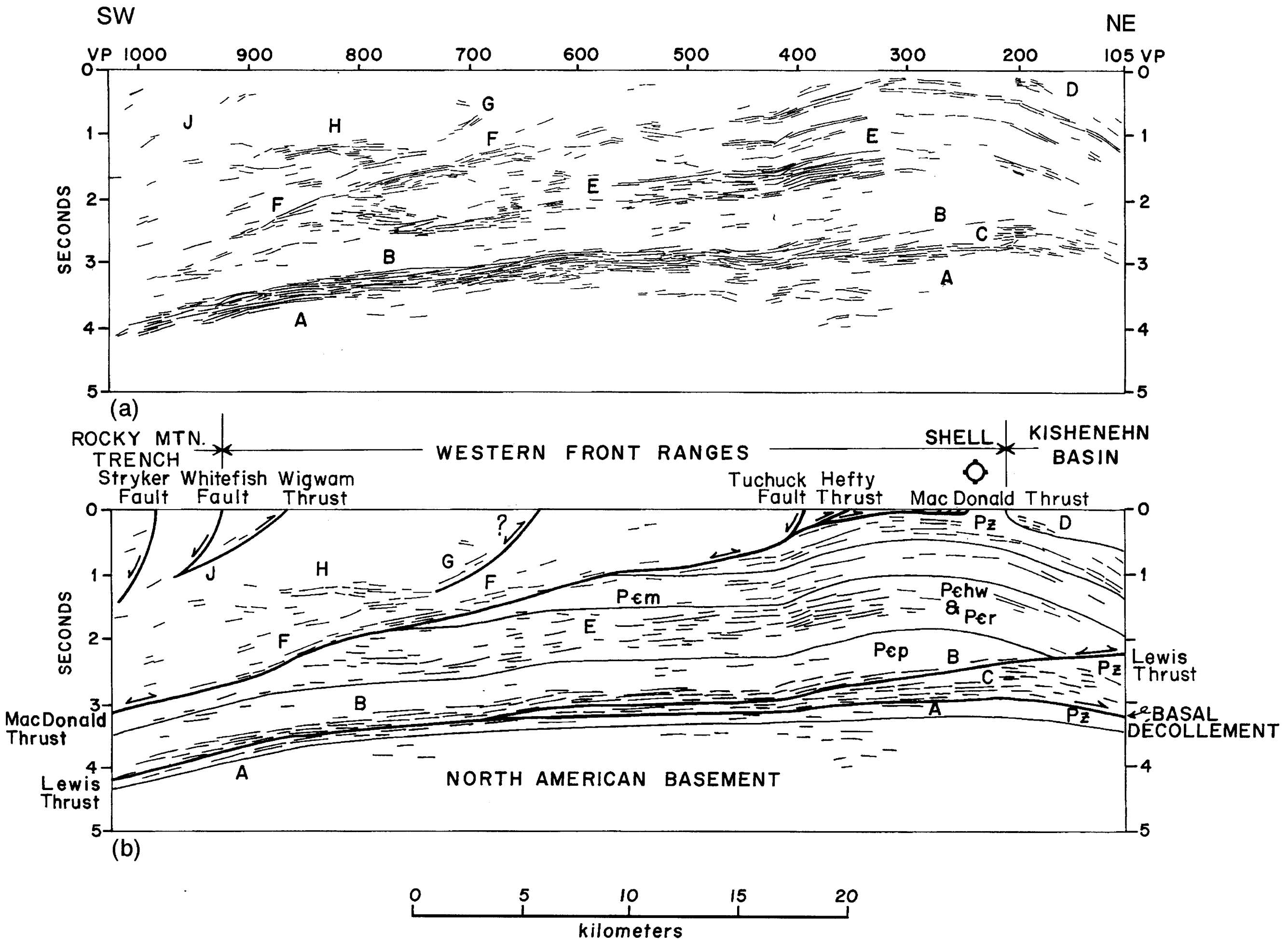


Figure 4—(a) Unmigrated line drawing of the eastern half of Signal of Montana line WTF-82-1 crossing the western Front Ranges; (b) Generalized line drawing and structural interpretation. Drawings are displayed so that vertical and horizontal scales are equal at a velocity of 6.0 km/s. Letters refer to reflection sequences discussed in the text. Stratigraphy shown in the Lewis thrust plate: Pz = Paleozoic strata, P€m = Precambrian Missoula Group, P€hw = Precambrian Helena Formation, P€r = Precambrian Ravalli Group, P€p = Precambrian Prichard Formation.

son et al. (1980) (Figure 3b, c) because (1) regional petroleum exploration wells in southern Alberta did not encounter Belt Supergroup rocks beneath Paleozoic rocks (Bally et al., 1966; P. L. Gordy, 1986, personal communication) and (2) Belt Supergroup rocks generally are reflective within the Lewis thrust plate and the western Front Ranges, which contrasts with the unreflective character of the data beneath sequence A.

A large anticline outlined by reflections from VP 200–400 (Figure 4a) requires at least one fault between it and horizontal reflections at the base of sequence A. Westward-dipping reflections B (Figure 4a) are the only major discordant reflections between these two features. Assuming a constant dip, these reflections would project updip to a position approximately 3–4 km beneath the surface trace of the Flathead fault (Figure 2), a major normal fault that bounds the eastern edge of the Kishenehn basin. This fault has been interpreted from field evidence and drilling as a Tertiary listric normal fault, which reactivated a major footwall ramp along the Lewis thrust (Bally et al., 1966; Constenius, 1982). Therefore, reflections B are interpreted as the Lewis thrust, or rocks in the hanging wall immediately above the thrust. Calculations based on seismic reflection data, drilling results, and outcrop measurements yield very similar estimates for the thickness of Belt Supergroup rocks within the Lewis thrust plate both east and west of the Flathead fault. The similarity of thickness estimates suggests that the discordance between the Lewis thrust and the eastern limb of the anticline is due to rotation of the strata in the hanging wall of the Flathead fault and not a hanging-wall cutoff along the Lewis thrust.

The subsurface location of the Lewis thrust is identified based on surfaces of discordance, interpreted as thrust ramps, between sequences A, B, and C (Figure 4b). Thrusts mapped within the Foothills belt and encountered in wells in the Waterton gas field and Pacific–Atlantic Flathead well to the north in Canada (Figure 2) all indicate that the basal decollement of the foreland thrust belt is located beneath the Lewis thrust east of the Flathead fault (Gordy et al., 1977). Although the precise position of the basal decollement and the location where it meets the Lewis thrust are not evident from the data, our preferred interpretation is shown in Figure 4b.

Reflections within sequence C (Figure 4a) immediately beneath the Lewis thrust are interpreted to be from allochthonous Paleozoic miogeoclinal shelf sedimentary rocks encountered beneath the Lewis thrust in the Pacific–Atlantic Flathead well (Figure 2) (Gordy et al., 1977). Although sequences A and C have apparent eastward dips from VP 105–210, as contrasted with horizontal or apparent westward dips from VP 240–640, this change in dip is interpreted to be a velocity effect due to low-velocity Tertiary (Kishenehn Formation) and Quaternary sedimentary rocks in the Kishenehn basin east of VP 215 (sequence D, Figure 4a).

A normal sequence of Paleozoic rocks is interpreted within the upper 0.5 s of the Lewis plate (Figure 4b) because Paleozoic rocks are mapped at the surface west of the Kishenehn basin in the Lewis plate (Figure 2) (Johns, 1970) and the Shell MacDonald well located 20 km along strike to the northwest (Figure 2) drilled a normal sequence of Paleozoic and Precambrian Belt Supergroup sedimentary rocks within the upper part of the Lewis plate (P. L. Gordy, 1986, personal communication). A minimum thickness of 4500 m of Belt strata is exposed in the Lewis plate in Glacier and Waterton Lakes national parks (Ross, 1959; Gordy et al., 1977), and requires at least 4.5 km, or approximately 1.6 s two-way traveltime equivalent, of Belt Supergroup strata below the Paleozoic rocks and above the Lewis thrust after accounting for rotation of strata in the hanging wall of the Flathead fault. Reflections within sequence E (Figure 4a), outlining the western flank of the anticline and traceable to at least VP 850, and reflections within sequence B located immediately above the interpreted position of the Lewis thrust from VP 320–1000 (Figure 4a), must correspond to Belt Supergroup strata, indicating that the Belt Supergroup is moderately reflective within the Lewis plate.

The seismic line crosses the MacDonald and Hefty thrusts and a normal fault from VP 245–390 (Johns, 1970). Immediately along strike to the north in Canada, the Hefty thrust is the trailing thrust of an imbricate fan whose sole thrust is the MacDonald thrust (Price, 1962). Because of a lack of offsets or discordances in shallow reflections from VP 250–340, this imbricate fan is interpreted to be listric, becoming horizontal a few hundred meters below the seismic datum and merging with the Hefty thrust near VP 380–400 (Figure 4b). The Tuchuck fault, a normal fault at VP 390 (Johns, 1970), probably soles into the MacDonald thrust (Figure 4b).

The location of the MacDonald thrust in the subsurface (Figure 4b) is defined principally by discordances between gently westward-dipping reflections in the underlying Lewis plate and scattered, more steeply westward-dipping reflections in the overlying MacDonald plate (0.9–1.3 s, VP 580–640; sequence F, VP 700–890). Above the inferred position of the MacDonald thrust, sequence G projects toward the surface at VP 630 and across the trend of horizontal reflections H. Sequence G may represent a minor normal fault mapped at VP 690 (Johns, 1970), a thrust splay above the MacDonald thrust, or a thrust reactivated as a normal fault. This structure may sole into the base of sequence H, separating H from westward-dipping sequence F. Alternatively, sequence G may be off-line reflected energy. Discontinuous westward-dipping reflections J (Figure 4a) project toward the mapped location of the Wigwam thrust at VP 860–870 (Johns, 1970), and are interpreted as this thrust or rocks in the hanging wall just above the thrust (Figure 4b).

A noticeable change in the dip of reflections within sequences A and B, from approximately 5.1°SW (VP 650–860) to 14–15°SW (VP 870–1000), occurs at VP 870 (Figure 4a). This change in dip is interpreted to be real basement geometry because low-velocity sedimentary deposits within the Rocky Mountain trench are not present east of VP 990, Belt Supergroup rocks with similar seismic velocities are exposed at the surface in this area, reflections from 1.0–2.0 s do not show a systematic increase in dip west of VP 870, and the seismic line is relatively straight in this area. From VP 720–1020, no major offsets are observed within the inferred Paleozoic sequence or the top of basement surface, suggesting that the Lewis thrust remains in a decollement zone a few tens or hundreds of meters above crystalline basement east of the Rocky Mountain trench.

Rocky Mountain Trench

As the seismic line crosses the Whitefish and Stryker normal faults and enters the Rocky Mountain trench (Figure 2), the data quality deteriorates markedly below 1.0 s (Figure 5a). This change in data quality coincides with the presence of Quaternary glacial deposits at the surface (Johns, 1970). A group of short, chaotic reflections, sequence K (Figure 5a), outline a northeastward-thickening wedge interpreted as Quaternary (and Tertiary?) sedimentary rocks within the Rocky Mountain trench. These reflections terminate near VP 1000 against the downdip projection of the Stryker fault, which is consistent with geologic observations of motion on the Stryker fault 17.7 km south of the seismic line (Johns, 1970). Thus, the Rocky Mountain trench appears to be a half-graben bounded on the northeast by a series of normal faults (Figure 5b).

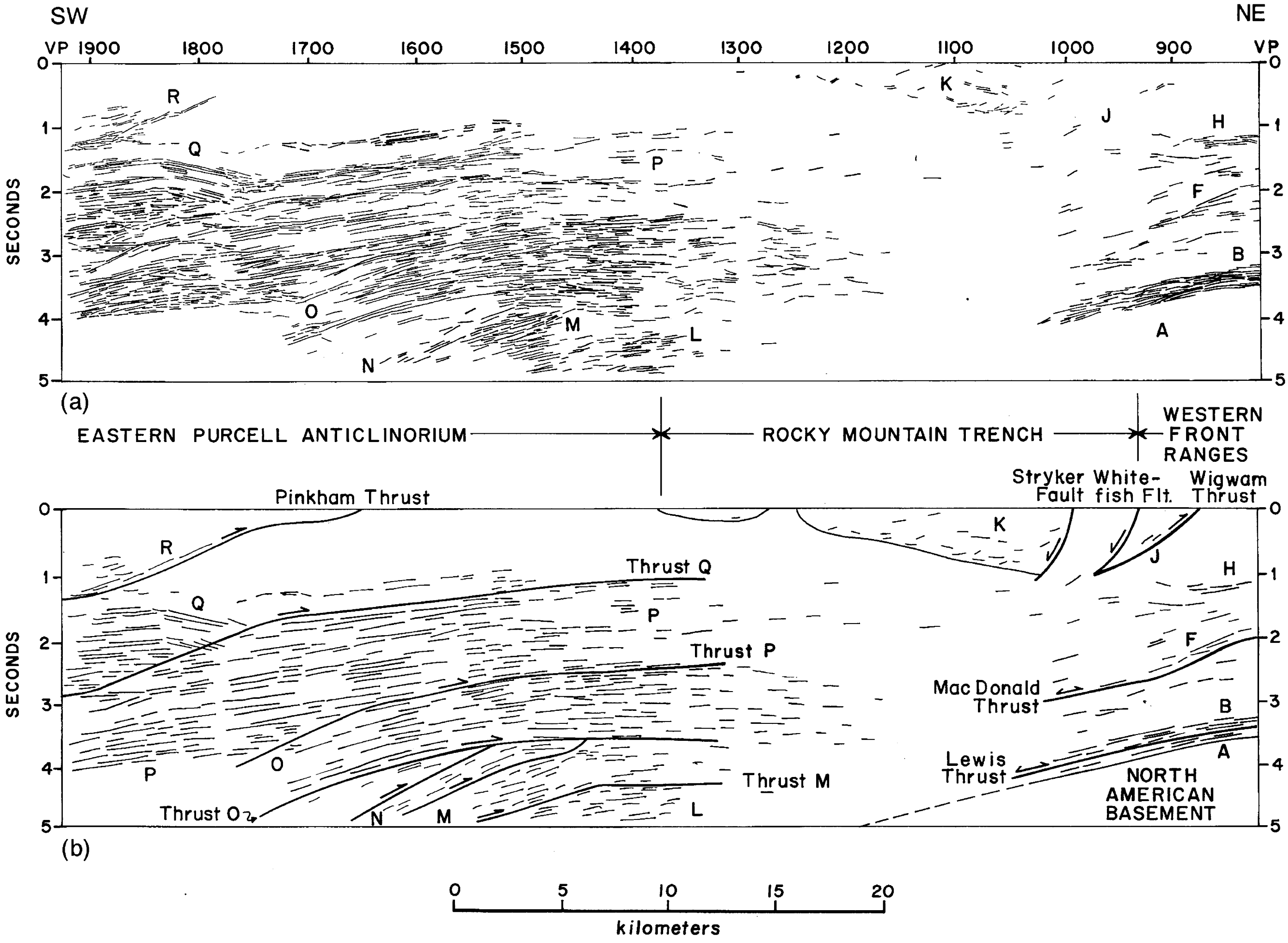


Figure 5—(a) Unmigrated line drawing of the western half of Signal of Montana line WTF-82-1 crossing the Rocky Mountain trench and the eastern Purcell anticlinorium. (b) Generalized line drawing and structural interpretation. Drawings are displayed so that vertical and horizontal scales are equal at a velocity of 6.0 km/s. Letters refer to reflection sequences discussed in the text.

Unfortunately, the absence of reflections below sequence K does not allow specific structures to be traced westward beneath the trench. In addition, the relationship between the Wigwam thrust and the Whitefish and Stryker faults is not constrained by the data: one or both of the normal faults may sole into the Wigwam thrust or may offset it. If these normal faults are similar to other normal faults encountered in foreland thrust belts (Royse et al., 1975), then they probably sole into the underlying Wigwam thrust at depth.

Eastern Purcell Anticlinorium

Of reflection sequences L through R identified on Signal of Montana line WTF-82-1 beneath the eastern part of the Purcell anticlinorium (Figure 5a), only westward-dipping sequence R can be related to a known structure. Sequence R projects toward the mapped trace of the Pinkham thrust at VP 1655 (Harrison et al., 1983). The five discordances between sequences L through Q are also interpreted as thrusts because (1) widespread angular unconformities with high angles of discordance have not been documented within the Belt Supergroup or between the Belt and overlying Paleozoic strata based on geologic mapping and (2) the recognition of thrust belt structures on both sides of the Rocky Mountain trench from geologic mapping (Johns, 1970; Harrison et al., 1980; Price, 1981; Harrison et al., 1983) and the interpretation of seismic reflection data near the international border (Bally et al., 1966; Cook et al., 1987) suggest that a structural style exists within the Purcell anticlinorium similar to that interpreted east of the Rocky Mountain trench in the Front Ranges.

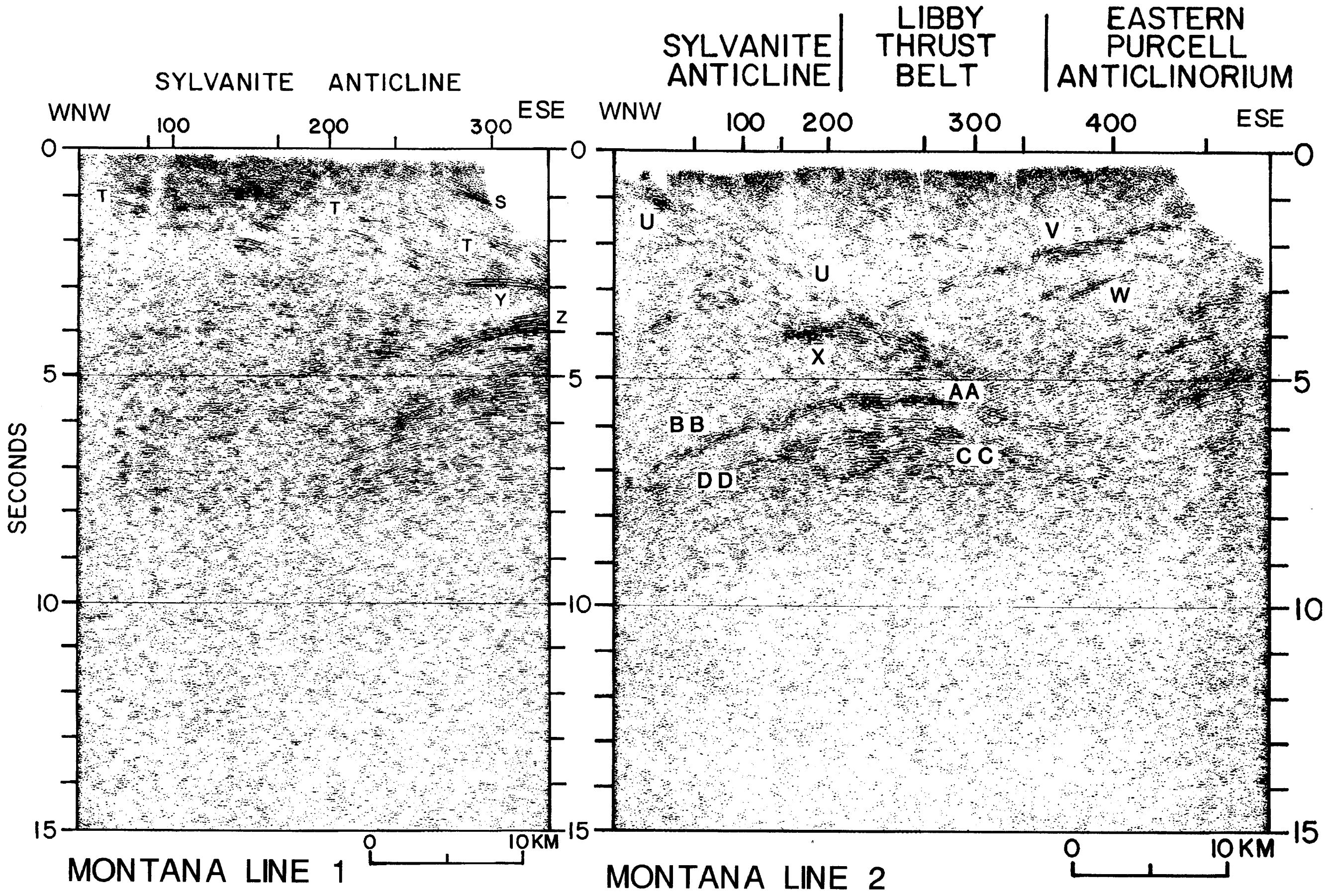


Figure 6—Unmigrated time sections of COCORP Montana lines 1 and 2. Sections are displayed so that vertical and horizontal scales are equal at a velocity of 6.0 km/s. Letters refer to reflection sequences discussed in the text. Note high-amplitude reflections from 1.0–8.0 s, which are interpreted as intrusives within the Prichard Formation, and the lack of reflections below approximately 8.5 s.

Surfaces of discordance between sequences L through Q from VP 1500–1900 are interpreted as footwall and hanging-wall ramps along thrusts separating these sequences (Figure 5b). Tracing of inferred thrusts M, O, P, and Q (which carry sequences M, O, P, and Q, respectively, in their upper plates) northeast of VP 1450 becomes difficult due to a lack of discordances in the dominantly horizontal reflection pattern from VP 1340–1450. Northeast of VP 1450, therefore, these thrusts are interpreted as flats (Figure 5b). Specific correlation of thrusts L–Q with the Lewis, Hefty, or Wigwam thrusts on the east side of the Rocky Mountain trench is speculative. The ramp and flat geometry shown by thrust M (Figure 5b, VP 1350–1550) suggests a footwall ramp, eliminating parts of sequence L. If thrust M is correlative with the Lewis thrust, then sequence L would represent autochthonous Paleozoic miogeoclinal shelf and Precambrian Belt Supergroup sedimentary rocks.

The unique correlation of structures on the western end of Signal of Montana Line WTF-82-1 with structures on the eastern end of COCORP Montana line 2 (Figure 6) is not possible due to a large 14.9-km downdip data gap (Figure 2) and a lack of three-dimensional control in the area, but some general relations can be inferred. The Pinkham thrust and thrust Q dip approximately 23–24°SW near the western end of the Signal line (Figure 5b). If these thrusts were projected across the data gap with this constant dip, they would be located at about 3.4 s and 4.9 s, respectively, on the eastern end of Montana line 2 (Figure 6), where reflections have similar unmigrated apparent dips of about 21–23°W. Faint, low-amplitude reflections from 5.0–7.0 s at VP 420–480 on Montana line 2 have shallower unmigrated apparent dips (about 15°W), suggesting they are from one or more separate thrust plates.

Western Purcell Anticlinorium

COCORP Montana lines 1 and 2 cross the eastern limb of the Sylvanite anticline, a south–southeastward-plunging structure exposing a nearly complete section of Belt Supergroup rocks at the surface (Harrison et al., 1983; Harrison and Cressman, 1985). Line 2 continues to the east across the Libby thrust belt, a syncline disrupted by several steeply dipping north-south–trending reverse and normal faults (Harrison et al., 1983; J. E. Harrison, 1986, personal communication) and part of the eastern Purcell anticlinorium (Figure 2).

High-amplitude reflections S on Montana line 1 (Figure 6) project to surface outcrops of a group of gabbroic to dioritic sills mapped within the Prichard Formation (Johns, 1970; Harrison et al., 1983). Extensive outcrops of similar sills in a stratigraphically lower position within the Prichard Formation were also mapped just north of Montana line 1 (Johns, 1970; Harrison et al., 1983) and may be correlative with reflection sequence T (Figure 6). Sequence U on Montana line 2 (Figure 6) is also interpreted as mafic intrusives within the lower to middle Prichard Formation based on updip projection of these reflections to outcrops mapped by Harrison et al. (1983).

Reflection sequences V and W on Montana line 2 (Figure 6) probably also represent mafic sills and dikes based on their similar high-amplitude character and stratigraphic position compared with diabase sills encountered in the ARCO–Marathon 1 Paul Gibbs well. Located 40 km along strike southeast of the data gap between Signal of Montana line WTF-82-1 and COCORP Montana line 2 (Figure 2), the well drilled several diabase sills within the lower and middle Prichard Formation (Boberg, 1985). Sonic and density logs from the well (Figure 7) show a substantially higher velocity and density for the sills compared with the argillite of the Prichard Formation. The large acoustic impedance contrasts associated with the sills can be correlated with high-amplitude reflections on seismic lines in the vicinity of the well and are interpreted as the source of high-amplitude reflections seen on industry seismic data throughout the Purcell anticlinorium (Boberg, 1985; P. L. Gordy, 1986, personal communication). Sequences V and W appear to be in a stratigraphic position similar to that of the diabase sills encountered in the ARCO–Marathon well.

Very high-amplitude reflections from 3.5–7.5 s on Montana line 2 and reflections and diffractions from 2.8–7.5 s on the eastern end of Montana line 1 are also interpreted to be from mafic intrusives within the Prichard Formation for four reasons. (1) The high-amplitude character of these reflections is very similar to high-amplitude reflections S and U, which project to outcrops of mafic intrusives within the Prichard Formation. (2) Results from the ARCO–Marathon well indicate that high-amplitude reflections observed on seismic lines from the Purcell anticlinorium are the result of mafic sills in the Prichard Formation (Boberg, 1985). (3) Where they are known to occur in outcrop across the anticlinorium, Belt Supergroup rocks stratigraphically above the Prichard Formation are not highly reflective, as observed on the upper 1.0 s of the western half of the Signal of Montana line and COCORP Montana line 2. (4) Allochthonous and autochthonous crystalline basement within the foreland thrust belt is relatively unreflective as was noted on the eastern half of Signal of Montana line WTF-82-1 and as will be shown in following paragraphs.

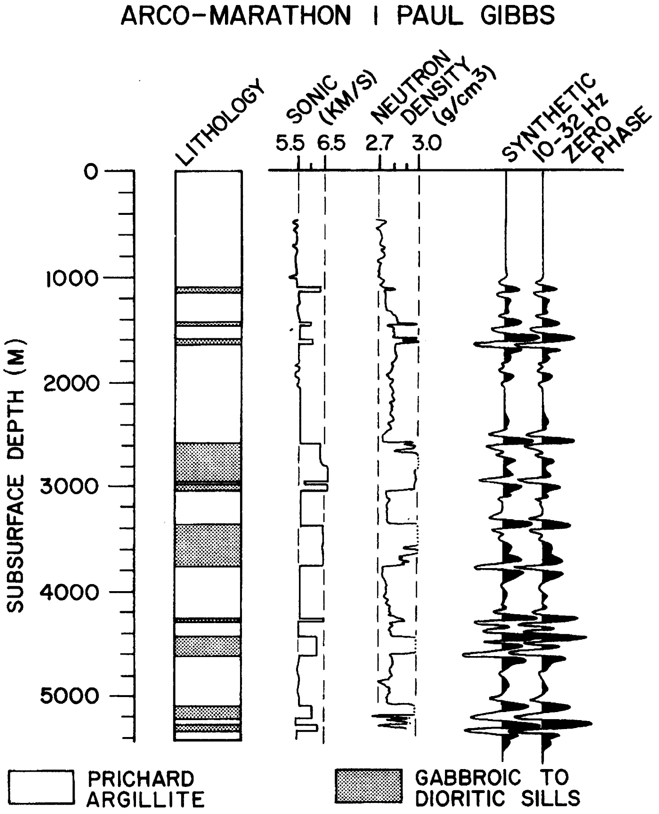


Figure 7—Lithologic, sonic, and neutron density logs from the ARCO-Marathon 1 Paul Gibbs well (modified from Harrison et al., 1985), and corresponding synthetic seismogram generated from the sonic log. The gabbroic to dioritic sills have a much higher velocity and density than argillite of the Prichard Formation and are interpreted as the source of high-amplitude reflections on seismic data throughout the Purcell anticlinorium.

Due to the steep dips of reflections on Montana lines 1 and 2, data migration is necessary to properly locate and interpret geologic structures. Because two-dimensional migration yields only a rough approximation of the location of reflectors in the subsurface in this area of complex three-dimensional geology, the migrated data do not clearly image the subsurface locations of faults within the Libby thrust belt. The migrated data, however, help constrain interpretations of structures in the area and suggest that faults within the Libby thrust belt remain steeply dipping to at least 3.0 s, or a depth of at least 8.5 km.

Migration of Montana line 2 separates sequences U and V, outlining the flanks of the Libby syncline, and moves sequence U almost completely above sequence

X (compare Figures 6 and 8a). The discordance between sequences U and X after migration could be interpreted either as the subsurface location of one or more faults of the Libby thrust belt, a sharp kink within the Libby syncline, or both. Our preferred interpretation is shown in Figure 8b. Reflections Y on Montana line 1 (Figure 6) appear to truncate eastward-dipping reflections within sequence T. After migration (Figure 9a), reflections within sequence T move above and west of sequence Y. This discordance may represent the subsurface location of the trailing fault of the Libby thrust belt, which crops out 6.2 km east of the eastern end of Montana line 1 (Harrison et al., 1983), or it may merely represent a sharp kink in the Libby syncline.

Reflections from 4.0–8.0 s on Montana line 2 (Figure 6) are alternately dipping (sequences BB and DD) and horizontal (sequences AA and CC) suggesting that the Pinkham thrust and structurally lower thrusts have a ramp and flat geometry beneath the Sylvanite anticline, Libby thrust belt, and the eastern Purcell anticlinorium. After migration (Figure 8a), sequence BB appears to define a footwall ramp that changes to a flat at the base of sequence AA (Figure 8b), whereas sequence DD may define an additional footwall ramp passing into a flat at sequence CC. Reflections within sequence BB are the deepest westward-dipping reflections on Montana line 2 and are interpreted as a footwall ramp cutting up from the basal decollement at 7.0–7.5 s, or a depth of 20–22 km (Figure 8b). Although it is difficult to trace structures to the east, faint, low-amplitude westward-dipping reflections from 5.0–7.0 s at VP 420–480 (Figure 8a) suggest that the basal decollement is located at 6.0–7.0 s at the eastern end of Montana line 2. Horizontal reflections within sequence CC suggest the basal decollement becomes horizontal somewhere to the west of VP 400, perhaps near the base of sequence CC (Figure 8b).

Two relatively unreflective zones, one underlying sequence T on Montana line 1 (Figures 6, 9) and the other from 2.8–6.0 s at the eastern end of Montana line 2 (Figures 6, 8), could be interpreted as either allochthonous crystalline basement or as poorly reflective Belt Supergroup strata. If these areas do not contain thrust plates of unreflective Belt rocks, they are probably crystalline basement because no stratigraphically lower rocks are known below the Prichard and above basement. We favor an interpretation of these unreflective zones as crystalline basement for the following reasons. (1) There is no evidence from geologic mapping of rocks located stratigraphically below the Prichard Formation and above basement. (2) A similarly unreflective area on the eastern part of Signal of Montana line WTF-82-1 was interpreted as crystalline basement. Thus, we interpret the easternmost occurrence of allochthonous basement to be within the core of the Sylvanite anticline.

However, a lack of reflections alone is not sufficient evidence to interpret the presence of crystalline basement. Relatively unreflective areas at 4.0–5.0 s from VP 1700–1925 on Signal of Montana line WTF-82-1 (Figure 5a) and 6.0–7.5 s from VP 400–480 on COCORP Montana line 2 (Figure 6) are interpreted as unreflective Belt Supergroup rocks because these areas correlate downdip within thrust plates with sequences AA and CC, which include high-amplitude reflections interpreted as sills within the Prichard Formation (Figure 8b). Thus, we interpret the easternmost occurrence of allochthonous basement to be within the core of the Sylvanite anticline.

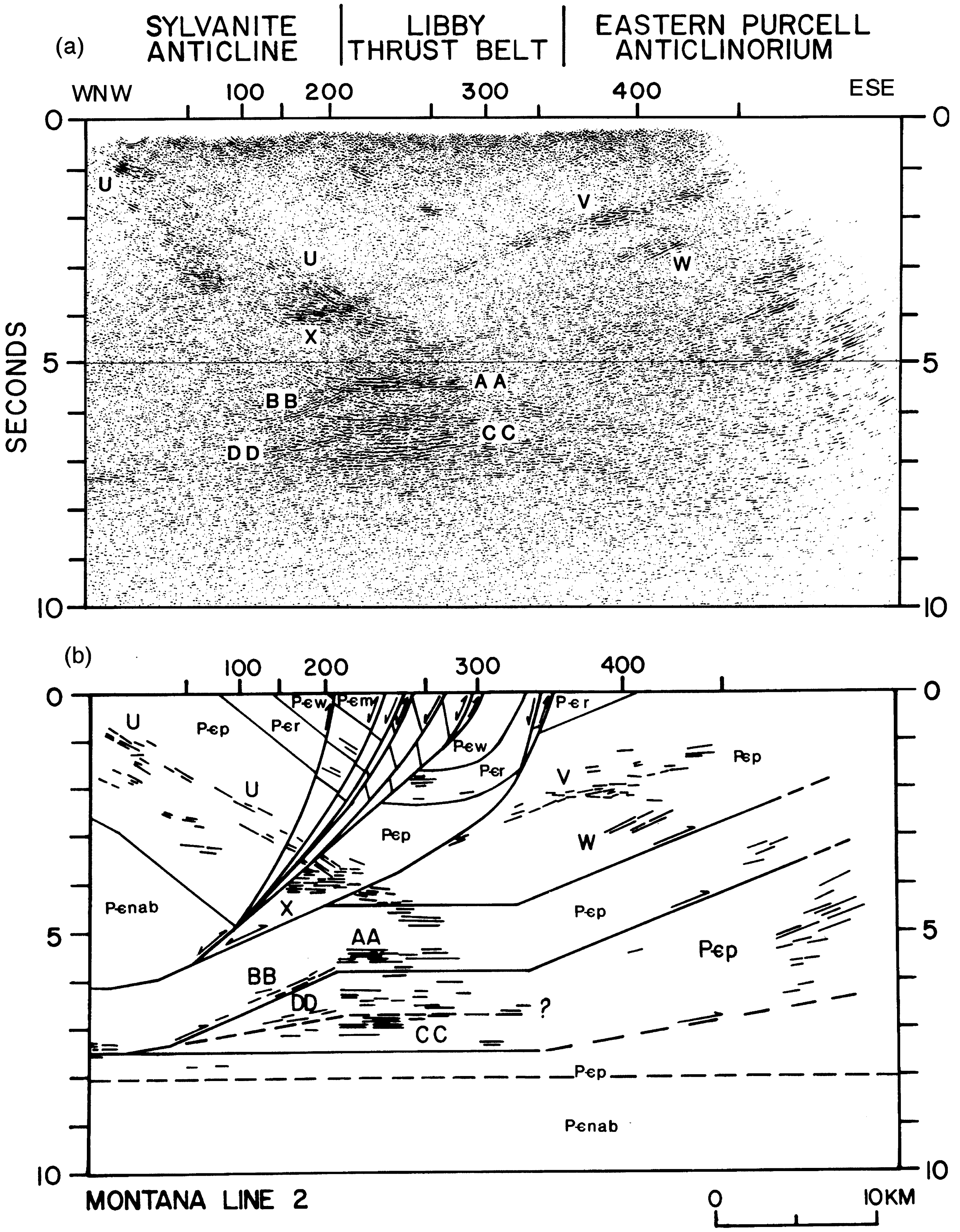
Autochthonous crust on Montana lines 1 and 2 also appears relatively unreflective. Only scattered reflections are observed below 8.0 s on Montana lines 1 and 2 (Figure 6). Unreflective areas on the eastern half of Signal of Montana line WTF-82-1, interpreted as autochthonous North American basement, and unreflective areas on Montana lines 1 and 2 interpreted as allochthonous basement, suggest by analogy that the crust below 8.0 s on Montana lines 1 and 2 may also be basement. Autochthonous Prichard Formation would occupy the sparsely reflective region beneath the basal decollement and above basement.

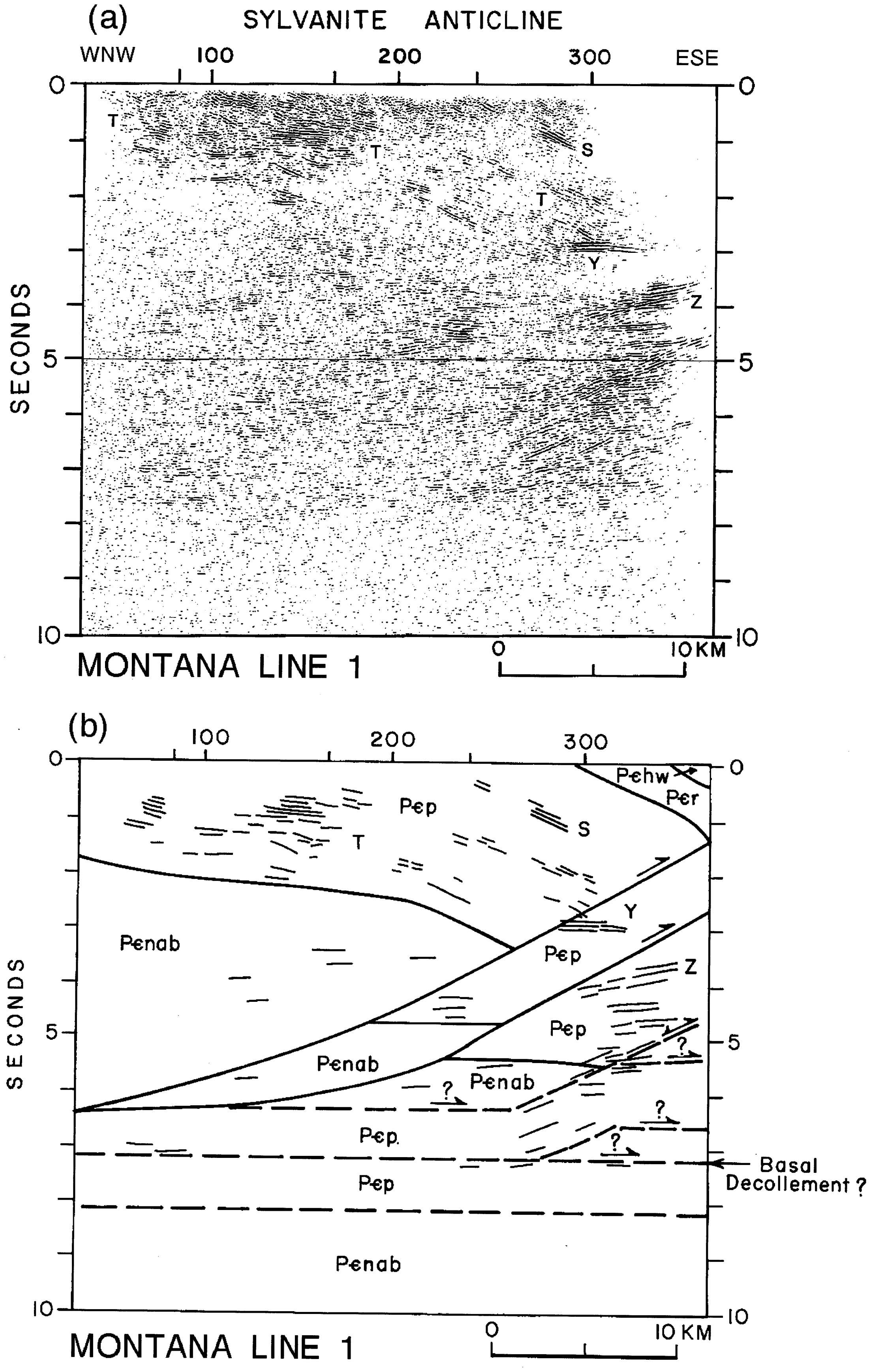
Purcell Trench and Moyie Thrust Plate

COCORP Idaho line 2 crosses the Purcell trench, where an inferred eastward-dipping normal fault at approximately VP 145 (the Purcell trench fault) separates gneisses and granitic plutons of the Priest River Complex on the west from the lower Prichard Formation on the east (Figure 2). The Prichard Formation is intruded by numerous gabbroic to dioritic sills and dikes (Moyie or Purcell sills) and small, scattered granitic plutons.

The data quality on Idaho line 2 is only fair and the data are not included here. Although the Purcell trench fault is not imaged, a group of arcuate reflections can be traced across the data. These reflections restrict the Purcell trench fault to the upper 12–14 km of the crust

Figure 8—(a) Wave equation migration of COCORP Montana line 2. (b) Geological and structural interpretation of COCORP Montana line 2. Note the ramp and flat thrust geometry suggested by sequences AA and BB and that most reflections within sequence U have moved above horizontal reflections X after migration (compare with Figure 6). Data are displayed so that vertical and horizontal scales are equal at a velocity of 6.0 km/s. Letters refer to reflection sequences discussed in the text. P€m = Precambrian Missoula Group, P€w = Precambrian Wallace Formation, P€r = Precambrian Ravalli Group, P€p = Precambrian Prichard Formation, P€nab = Precambrian North American basement.


(a)
SYLVANITE ANTICLINE
LIBBY THRUST BELT
EASTERN PURCELL ANTICLINORIUM
WNW
100
200
300
400
ESE
SECONDS
0
5
10
U
U
V
W
X
AA
BB
CC
DD
(b)
100
200
300
400
0
5
10
P€w
P€m
P€r
P€p
P€r
P€w
P€r
P€p
P€p
P€nab
U
U
V
W
X
P€p
AA
BB
DD
?
CC
P€p
P€p
P€nab
MONTANA LINE 2
0
10KM


(a)
SYLVANITE ANTICLINE
WNW
100
200
300
ESE
0
5
10
SECONDS
T
T
T
S
Y
Z
MONTANA LINE 1
0
10KM
(b)
100
200
300
0
5
10
SECONDS
P€hw
P€r
P€p
S
T
Y
P€nab
P€p
Z
P€p
P€nab
P€nab
?
?
?
?
P€p.
P€p
P€nab
Basal Decollement ?
MONTANA LINE 1
0
10 KM

beneath the eastern end of Idaho line 2. In addition, the Moyie thrust and deeper structures were not clearly imaged making any interpretation of thrust structure in this area speculative.

The Moyie or Purcell sills, which crop out near the end of the line and which are extensively exposed south and west of the line, were also not imaged. This may be due to their steeper eastward dips of 50–80°E at the surface in the vicinity of Idaho line 2 (Aadland and Bennet, 1979) compared to dips of 10–40°E for the sills on Montana lines 1 and 2.

DISCUSSION

A new regional cross section spanning the Cordilleran foreland thrust belt from southern Alberta, across northwestern Montana, and into northern Idaho has been constructed (DD', Figure 3d) based on the interpretation of the seismic reflection profiles discussed and previous results from petroleum industry profiles and exploration wells in the eastern Front Ranges of southern Canada (Gordy et al., 1977). The section was constructed using as guidelines the observations in foreland thrust belts that (1) thrusts typically exhibit ramp and flat geometries, cutting stratigraphically up section in the direction of tectonic transport, (2) thrusts place older strata over younger strata, and (3) later normal faults tend to have a listric geometry, soling into thrusts at relatively shallow depths (Dahlstrom, 1970; Royse et al., 1975). The section is not balanced west of the MacDonald thrust due to uncertainties in the mapping and correlation of Belt Supergroup strata across the Kishenehn basin and Rocky Mountain trench, the erosion of Belt Supergroup strata that formed the hanging-wall ramp along the Lewis thrust east of Glacier National Park, and the uncertain location and shape of the autochthonous Belt basin at depth. In addition, we have illustrated only macroscopic structures such as the ramp and flat geometry of thrusts and large-scale folds that can be resolved by the seismic reflection data.

Structure and Stratigraphy of the Foreland Thrust Belt

Undeformed North American basement dips 2.5–5.0°SW toward the interior of the mountain belt beneath the Foothills belt and Front Ranges, with the basal decollement of the foreland thrust belt located above Paleozoic miogeoclinal shelf rocks and perhaps a few tens or hundreds of meters above crystalline basement. The Lewis thrust most likely ramps downsection into Belt Supergroup rocks beneath or just west of the Rocky Mountain trench because autochthonous Belt rocks are not interpreted to be present east of the trench (Figure 3d). The autochthonous edge of the Belt basin thus would be located beneath the Rocky Mountain trench just north of the international border as was suggested by Bally et al. (1966). The easternmost part of the Purcell anticlinorium, therefore, is the site of the western edge of thick Proterozoic North American basement, with thinner continental crust beneath the anticlinorium (Figure 3d).

Significant thicknesses of Paleozoic rocks are not interpreted beneath the Purcell anticlinorium along the line of section for five reasons. (1) Paleozoic rocks exposed in the Lewis and MacDonald thrust plates are cut out by footwall ramps along the MacDonald and Hefty thrusts, respectively (Figure 4b, VP 350–600). Similarly, Paleozoic rocks interpreted beneath the Lewis thrust (sequence C, Figure 4a) are cut out by footwall ramps along the Lewis thrust (Figure 4b). (2) Autochthonous Paleozoic rocks below the basal decollement and above basement east of the Rocky Mountain trench must be eliminated where the Lewis thrust ramps down into Belt Supergroup strata. As discussed, this scenario most likely occurs beneath or immediately west of the Rocky Mountain trench. (3) Beneath the eastern part of the Purcell anticlinorium, only sequence P (Figure 5a) can include Paleozoic strata because all of the other thrust plates beneath the anticlinorium either expose Belt Supergroup rocks at the surface or are interpreted to correlate with thrust plates exposing Belt strata in the Front Ranges, eliminating the possibility of Paleozoic rocks at depth. (4) Cambrian strata within the Libby thrust belt south of 48°15'N (Figure 2) are most likely local occurrences within the core of the Libby syncline, and probably do not extend westward in the subsurface (Harrison and Cressman, 1985). (5) High-amplitude reflections on seismic lines throughout the Purcell anticlinorium are interpreted to be mafic sills within the Prichard Formation based on the results of the ARCO–Marathon 1 Paul Gibbs well and the tracing of high-amplitude reflections to outcrops of mafic sills.

Although the base of the Prichard Formation is not exposed, a minimum thickness of 5800 m, including sills, is known from surface exposures in the core of the Sylvanite anticline (J. E. Harrison, 1986, personal com-

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Figure 9—(a) Wave equation migration of COCORP Montana line 1. (b) Geological and structural interpretation of COCORP Montana line 1. Note that dipping reflections within sequence T have moved above and west of horizontal reflections Y after migration (compare with Figure 6). Data are displayed so that vertical and horizontal scales are equal at a velocity of 6.0 km/s. Letters refer to reflection sequences discussed in the text. P€m = Precambrian Missoula Group, P€w = Precambrian Wallace Formation, P€r = Precambrian Ravalli Group, P€p = Precambrian Prichard Formation, P€nab = Precambrian North American basement.

munication). If the reflections within sequence T on Montana line 1 are assumed to be from sills and dikes within the lower and middle Prichard Formation, and if the base of these reflections is assumed to delineate the base of the Prichard Formation, then a thickness of 10,000 ± 500 m is indicated for the Prichard Formation in this area. Together with estimates of the thicknesses of Belt Supergroup rocks that overlie the Prichard Formation on the flanks of the Sylvanite anticline (Cressman and Harrison, 1986), a minimum stratigraphic thickness of 18 km is indicated for the Belt Supergroup in the vicinity of the Sylvanite anticline. This thickness of strata suggests that the Belt Supergroup exposed on the Sylvanite anticline originally was deposited on highly stretched continental crust or oceanic crust.

The Purcell anticlinorium consists of several large thrust plates containing Belt Supergroup rocks intruded by mafic sills and dikes. These thrusts are folded above a major ramp in the basal decollement and above an interpreted duplex near the Proterozoic hingeline of western North America (Figure 3d). Previous hypotheses that crystalline basement is involved in thrusting beneath the eastern part of the Purcell anticlinorium are not supported by the seismic data. Across the width of the foreland thrust belt, autochthonous and allochthonous basement are relatively unreflective. Data from the eastern Purcell anticlinorium, in contrast, show numerous, high-amplitude reflections. As previously discussed, the easternmost location of allochthonous crystalline basement is interpreted to be within the core of the Sylvanite anticline (Figures 3d, 8b).

The crustal structure from the Moyie thrust to the Purcell trench (Figure 3d) is speculative due to the lack of reflections on Idaho line 2. The only constraint on the geometry of the Purcell trench fault from the data is that it is restricted to the upper 12–14 km of the crust beneath Idaho line 2. If the Purcell trench fault penetrates to mid-crustal levels to the east, then it is apparently unreflective because no prominent eastward-dipping reflections are observed on Montana lines 1 or 2 that can be related to the fault. The Purcell trench fault, therefore, has been drawn as a low-angle planar fault similar to normal faults bounding other metamorphic core complexes in the hinterland of the northwestern United States Cordillera.

The extent to which basement is involved in thrusting in the panhandle of Idaho east of the Purcell trench is also not known. Basement probably is present in one or more thrust plates because allochthonous basement is interpreted beneath the Sylvanite anticline. Potter et al. (1986) suggested that thrust structures probably continue westward beneath the Priest River Complex and may contain crystalline basement. Correlation of interpreted thrust structures in Montana with those beneath the Priest River Complex is not possible, however, due to a large north-south offset in the seismic lines (Figure 2) and an unknown amount of extension on the Purcell trench fault.

Petroleum Geology

The conclusion that substantial thicknesses of Paleozoic rocks are not present beneath the Purcell anticlinorium suggests that subthrust Paleozoic rocks similar to those containing hydrocarbon reservoirs in southern Canada are restricted to the Front Ranges east of the Rocky Mountain trench. This conclusion is in agreement with conclusions reached by Harrison et al. (1985). The greatest potential for Paleozoic discoveries along the line of section is within the Foothills belt and the eastern Front Ranges, east of the footwall ramp in the Lewis thrust (VP 400 on Signal of Montana line WTF-82-1, Figure 4), which provides room for significant thicknesses of Paleozoic strata in imbricate thrust plates or duplexes beneath the Lewis thrust (see also Fritts and Klipping, 1987). Because Glacier National Park covers a large part of the eastern Front Ranges in northwestern Montana, exploration will be restricted to areas south and east of the park. The Two Medicine field (Figure 2) is an example of hydrocarbon-bearing Paleozoic rocks within the Foothills belt southeast of Glacier National Park (Mudge, 1982).

Although Paleozoic source and reservoir rocks are interpreted to be limited in geographic extent, the possibility of source and reservoir rocks within the Belt Supergroup across most of the foreland thrust belt was suggested by data from the ARCO–Marathon 1 Paul Gibbs well. Gas shows were encountered within the Prichard Formation in the well, and studies of the well cuttings indicate that the Prichard Formation contains sufficient organic carbon to have been a hydrocarbon source rock (Boberg, 1985). In addition, stromatolite zones have been identified in the Missoula Group, Helena and Wallace formations, and the Altyn Formation (possible equivalent of the Prichard Formation?) in Glacier National Park and the Whitefish Range (Ross, 1959; Whipple et al., 1984). Fracture porosity within the Belt Supergroup may be sufficient in certain areas to have created hydrocarbon reservoirs (Boberg, 1985). Finally, wells drilled in the Kishenehn basin have encountered oil shales and hydrocarbons within Tertiary rocks (Boberg, 1984), suggesting that hydrocarbons might be present in Tertiary (and Mesozoic?) sedimentary rocks in the Kishenehn basin and Rocky Mountain trench.

Comparison with the Southern Canadian Foreland Thrust Belt

Comparison of the structure of the Cordilleran foreland thrust belt in northwestern Montana (Figure 3d) and southern Canada (Figure 3a) confirms the suggestion that a change in the deep structure of the foreland thrust belt occurs along strike. Balanced sections constructed by Price (1981) suggest that the western edge of thick Proterozoic North American basement is located beneath the Kootenay arc from 49°45'N to 50°30'N, with thinner continental crust beneath and west of the Kootenay arc. This appears to change to the southeast, with the western edge of thick Proterozoic North American basement interpreted to be beneath the easternmost part of the Purcell anticlinorium in northwestern Montana, and attenuated continental crust beneath most of the anticlinorium (Figure 3d). As a result, Belt Supergroup rocks currently within the Purcell anticlinorium have not been thrust over the Proterozoic hingeline and onto thick continental crust in northwestern Montana as shown in Price's model for southern Canada (compare Figure 3a, d).

Finally, Belt Supergroup strata within the Purcell anticlinorium in northwestern Montana appear to be imbricated to a greater degree than in southern Canada. Four or five major thrust plates containing 15–22 km of Belt Supergroup strata (Figures 5b, 8b) are imaged within the anticlinorium in northwestern Montana as compared with three major thrust plates with 12–20 km of Belt Supergroup and Windemere Group rocks in southern Canada (Figure 3a) (Price, 1981; Cook et al., 1987).

The Front Ranges in northwestern Montana consist of thick thrust plates containing predominantly Proterozoic Belt Supergroup rocks (Figures 2, 4b), as contrasted with smaller thrust plates containing mostly Paleozoic miogeoclinal shelf strata in the Front Ranges of southern Canada at 50–52°N latitude (Figure 3a) (Price, 1981). This difference can be attributed to the autochthonous position of the Belt basin. A thick section of Proterozoic Belt Supergroup and Paleozoic miogeoclinal shelf sedimentary rocks that accumulated along the western edge of the North American craton in Montana, where the present-day Purcell anticlinorium is located, were subsequently thrust over the edge of the craton and into their current position within the Front Ranges. The Paleozoic strata were then extensively eroded leaving mostly Belt Supergroup rocks exposed in the Front Ranges of Montana. In contrast, Paleozoic miogeoclinal shelf rocks deposited on the North American craton in southern Canada were thrust into their current position within the Front Ranges (Price, 1981). Because the autochthonous Belt basin in southern Canada was located further west beneath the present-day location of the Kootenay arc, Belt Supergroup rocks were not thrust as far east in southern Canada as in Montana.

CONCLUSION

COCORP and industry seismic reflection profiles, spanning most of the Cordilleran foreland thrust belt in northwestern Montana, image the structure of the thrust belt. Recognition of reflection sequences and their boundaries permits the identification and tracing of thrust faults from the Front Ranges to the western part of the Purcell anticlinorium. The interpretation of high-amplitude reflections beneath the Purcell anticlinorium as intrusives within the Prichard Formation suggests that 15–22 km of allochthonous Precambrian Belt Supergroup sedimentary rocks are present beneath the eastern part of the anticlinorium. The data do not appear to support models that include a large mass of Paleozoic miogeoclinal sedimentary rocks or slices of crystalline basement beneath the eastern part of the anticlinorium. Based on the unreflective character of autochthonous crystalline basement and regional geologic considerations, the easternmost location of allochthonous basement is interpreted to be within the core of the Sylvanite anticline near the Montana–Idaho border. Comparison of cross sections of the Cordilleran foreland thrust belt in southern Canada and northwestern Montana suggests that the western edge of thick Proterozoic crust is located farther east, and the basal decollement is located at a greater depth in northwestern Montana than in southern Canada.

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