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Regional structure, the Atlantic Richfield-Marathon Oil No. 1 Gibbs borehole, and hydrocarbon resource potential west of the Rocky Mountain trench in northwestern Montana

by

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Introduction

The U.S. Geological Survey has maintained since 1970 a program of systematic geological and geophysical study of terrane exposing the Middle Proterozoic Belt Supergroup. Belt rocks are exposed over an area of about 50,000 mi^2 in northwestern Montana, northern Idaho, and eastern Washington. Geologic mapping has been done primarily on $1^o \times 2^o$ quadrangles at 1:250,000, although small areas have been mapped at 1:62,500 or larger scales for metallic mineral resource appraisal of Wilderness areas or to study particular scientific problems related to the Belt. Geophysical studies include preparation of aeromagnetic and gravity maps of the entire Belt terrane as well as local audio-magnetotelluric surveys for specific problems.

The following brief report interprets some of that geologic and geophysical data with reference to the ARCO-Marathon deep borehole and the oil and gas potential of the area west of the Rocky Mountain trench in northwestern Montana. The hole was drilled from September 1983 to August 1984, in the NE1/4 sec. 2 T. 28 N., R. 27 W. in Flathead County, Montana. Drilling data required by Montana State law were released on April 5, 1985.

Our interpretations are presented by analyzing data and concepts shown in two geologic cross sections and in a group of selected logs from the deep hole.

Regional geology

Figure 1 is a diagrammatic cross section showing an interpretation of structure and stratigraphy updated from a section along the same line published by Harrison, Kleinkopf, and Wells in 1980. Surface geology is controlled by geologic mapping at 1:250,000 by the U.S. Geological Survey and includes published data on the Kalispell $1^o \times 2^o$ quadrangle (Harrison, Cressman, and Whipple, 1983) as well as mapping accomplished during the field seasons of 1983 and 1984.

Key concepts portrayed in the section include the cut out of the Paleozoic section at the Rocky Mountain trench by the Lewis (Le) thrust, basement at an elevated level beneath the Purcell anticlinorium, and Cambrian strata at shallow depth in the highly thrusted syncline (the Libby thrust belt) just west of the Purcell Anticlinorium. The Lewis cuts down through the Phanerozoic section, which we suggest had been thinned due to erosion prior to thrusting. A restored section would show little or no Paleozoic rocks west of the present position of the Purcell anticlinorium. An alternative is to balance the section by requiring more than 200 km of movement on the Lewis and associated thrust faults which would leave a very thin slice of Lower

Paleozoic beneath the Purcell anticlinorium that balances with rocks exposed in the Kootenai arc in eastern Washington as suggested by Price (1981). In either case, the Paleozoic section is extremely thin or missing in Belt terrane west of the Rocky Mountain trench. The diagram is not intended to make a conceptual statement about the main surface of detachment where it contacts crystalline basement. The decollement may go into basement and become a zone of shears or mylonitic layers. It has been projected here as a surface in the manner used by Price (1981), in part to emphasize that the known thickness of Belt strata combined with a reasonable projection of the decollement leaves no room for thick sections of Phanerozoic rocks to be intercalated with Belt as inferred by some geologists (Cavanaugh and Cavanaugh, 1984; Moulton, 1984; Potter, 1984). Current seismic data are not of sufficient resolution at depth to permit identification of the decollement west of the Rocky Mountain trench.

A pronounced high gravity anomaly beneath the Purcell anticlinorium was interpreted by Harrison, Kleinkopf, and Wells (1980) as caused by basement slices stacked beneath the anticlinorium. An alternative hypothesis expressed here is that the basement may be folded. In either case, the high gravity anomaly is still interpreted as caused by basement rather than by stacks of dense Phanerozoic carbonate rocks.

Recent geologic mapping by Harrison in the Libby thrust belt has demonstrated that all exposures of Cambrian rocks are in a syncline (the Libby trough) that is paired with the Purcell anticlinorium. Mapping on the Kalispell quadrangle shows that broad, open, north-trending folds of the Purcell anticlinorium are cut at a low angle by thrust faults. This demonstration of broad folding at an unspecified time prior to thrusting is important to an understanding of the Cambrian rocks in the Libby trough. The Libby trough existed as a syncline with Cambrian strata at the top and at least 46,000 feet of Belt rocks below the Cambrian prior to thrusting. Cambrian strata are in normal stratigraphic position resting disconformably on the eroded top of the uppermost unit (the Libby Formation) of the Belt Supergroup or are caught up in thrust splays that dissect the syncline (Harrison and Cressman, 1985). Although the Cambrian strata in the syncline are overridden on the west by thrusts, the Cambrian rocks do not extend to great depths but instead remain at shallow depths in the upper part of the overridden syncline.

Data from the Atlantic Richfield-Marathon Oil No. 1 Gibbs borehole

The data displayed on Figure 2 are from the Gibbs No. 1 borehole drilled on the Purcell anticlinorium about 40 miles west of Kalispell, Montana, in the NE1/4 sec. 2, T. 28 N., R. 27 W. These data were generously supplied by ARCO-Marathon, and we gratefully acknowledge this cooperation. The hole was collared at an elevation of 3,537 feet, about 2,000 feet stratigraphically below the top of the Prichard Formation, and reached a total drilling depth of 17,774 feet. The hole is nearly vertical.

Sonic, gamma-ray, and neutron density logs on Figure 2 were generalized from detailed logs by estimating averages at 50 foot intervals. The lithologic log is derived from the original mud log and includes our interpretation of stratigraphy and structure.

Correlation of the dioritic to gabbroic sills among the four logs is obvious. These Proterozoic sills are characterized by high density, low radioactivity, and high sonic properties. The sills, which total about 3,300 feet of the drilled rocks, form the seismic reflectors seen on most seismic lines west of the Rocky Mountain trench. The reflectors occur consistently starting about 8,000 feet below the top of the Prichard and persist for several thousand feet to a depth below which available seismic data loses definition (about 25,000 feet below ground surface).

Although these logs do not show the conductive zone in the upper Prichard formation, other logs do. This zone, caused by abundant films and disseminated pyrite and pyrrhotite in a black laminated argillite, has been drilled by Cominco American, Inc. and Molycorp, Inc. within a few miles both north and east of the ARCO borehole. These holes were to test for possible stratabound lead-zinc ore bodies and were based on known favorable stratigraphy plus a pronounced audio-magnetotelluric anomaly first reported by the U.S. Geological Survey (Wynn, Kleinkopf, and Harrison, 1977). The core from the boreholes showed abundant pyrite and pyrrhotite but disappointingly small amounts of lead and zinc.

The general stratigraphic section displayed in the Gibbs No. 1 is similar to that measured on the surface in the Plains area about 60 miles to the south where about 22,000 feet of Prichard plus sills is exposed (Cressman, 1985). The ARCO mud log identifies various kinds of "quartzite" in the lower Prichard. Extensive studies of cuttings and logs will be required to make a more positive correlation, if possible, with the seven slightly but distinctly different clastic units identified in the Plains section by Cressman.

Possible thrust faults shown on the lithologic log are our interpretation. The Pinkham thrust, mapped on the surface about 15 miles east of the borehole, is probably at a depth of about 7,800 feet in the hole. The thrusts are essentially bedding-plane thrusts (see Figures 1 and 3) where encountered in the borehole, and most of the tectonic shortening on the Pinkham at its outcrop has been taken up by the large vertical-to-overturned anticline formed where the Pinkham ramps up through the Belt strata (Figure 3). Consequently, little disruption of the stratigraphic section should be caused by the thrusts.

Schistose zones in the lower part of the borehole are subject to multiple interpretations. The zones may be splays from the main detachment surface at depth below the bottom of the hole, or they may reflect slippage along bedding due to folding in the lower Prichard near its contact with folded crystalline basement.

Differences in seismic reflectors across the Rocky Mountain trench

Figure 3 is an enlargement of part of Figure 1 and is designed to show our concept of the problems in interpreting seismic data across the Rocky Mountain trench. As in Figure 1, the position of the basal surface of detachment and its true relation to crystalline basement are uncertain.

Causes for seismic reflectors are different across the Rocky Mountain trench. East of the trench, low-dipping thrust faults and duplex structures stack Phanerozoic strata beneath the upper plate of the Lewis thrust and above the basal surface of detachment. The Lewis cuts down through the Phanerozoic section and, at the Rocky Mountain trench, joins the basal decollement at a depth of about 23,000 feet below sea level (about -7 km). East of the trench the flat thrust faults and some reflectors within the Phanerozoic strata can be seen clearly in the seismic data and are well controlled both by surface exposures and by bore holes east of the outcrop of the Lewis. At about 25,000 feet, available seismic data become increasingly incoherent, and the contact with crystalline basement as well as the position and habit of the basal decollement are unclear.

The quality of seismic data within the Rocky Mountain trench is poor. Energy attenuation in the thick fill of Tertiary, Pleistocene, and Holocene sediments leaves a gap in continuity of all seismic reflectors that we have seen.

West of the rocky Mountain trench, a zone of strong seismic reflectors is evident and nicely outlines a series of broad open structures that have significant vertical closure on anticlines. These reflectors are the diorite sills in the lower Prichard. The top of the zone of sills is at about 23,000 feet below sea level at the wedge edge of the zone at the west side of the trench. Even though the character of the seismic reflections west of the trench is somewhat different from those east of the trench, most workers have connected the two zones across the gap at the trench and thus have suggested that thick sections of Phanerozoic rocks were interleaved with Belt rocks west of the trench. Such would be possible only if Belt strata west of the trench were as thin (about 10,000 feet or less) as the thinned shoreward facies displayed east of the trench. The Gibbs No. 1 hole plus the geologic mapping and stratigraphic measurements on the Kalispell quadrangle demonstrate a minimum thickness of 46,000 feet for Belt strata in that area. In addition, the depth to the zone of strong seismic reflectors in the Prichard Formation can be readily calculated by using known stratigraphic thicknesses of Belt strata at any point west of the Rocky Mountain trench. The zone of reflectors mimics the surface geologic structure in the Kalispell quadrangle and thus is identifying a useful marker zone in the Proterozoic stratigraphic section rather than identifying a thrust wedge of Phanerozoic strata.

Conclusions

New data from the Libby thrust belt and the Gibbs No. 1 borehole, when combined with extensive seismic data west of the Rocky Mountain trench seem to confirm our original appraisal (Harrison, Kleinkopf, and Wells, 1980) that some oil and gas potential exists east of the trench in the United States part of Belt terrane, but that little potential exists west of the trench.

Acknowledgements

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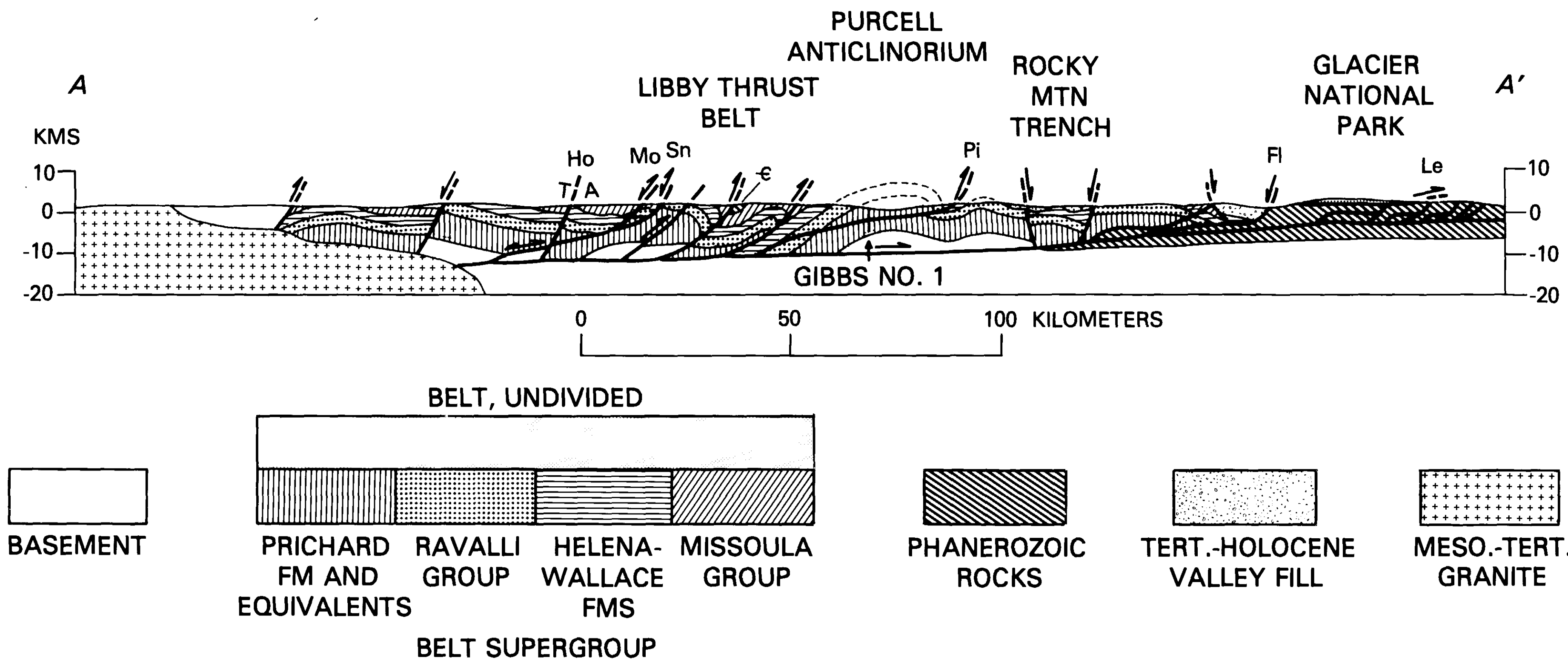

Figure 1. Diagrammatic structure section, Glacier National Park through Gibbs No. 1 borehole. (A-A' same as shown in Figure 2, Harrison, and others, 1980.) Ho, Hope fault; Mo, Moyie thrust; Sn, Snowshoe thrust; Pi, Pinkham thrust; Fl, Flathead fault; Le, Lewis thrust.

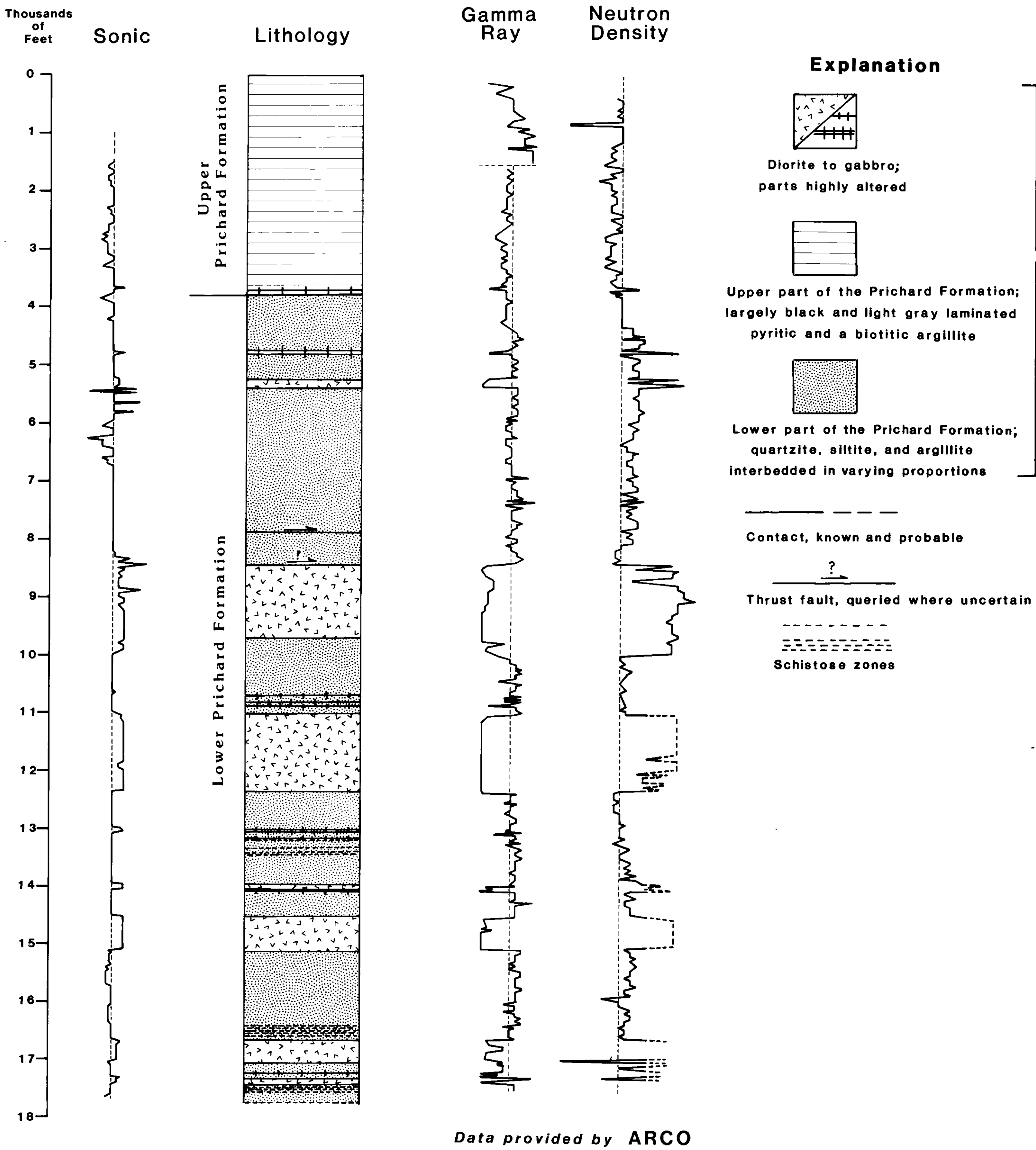

Figure 2.--Generalized lithologic and geophysical logs, Gibbs No. 1 borehole

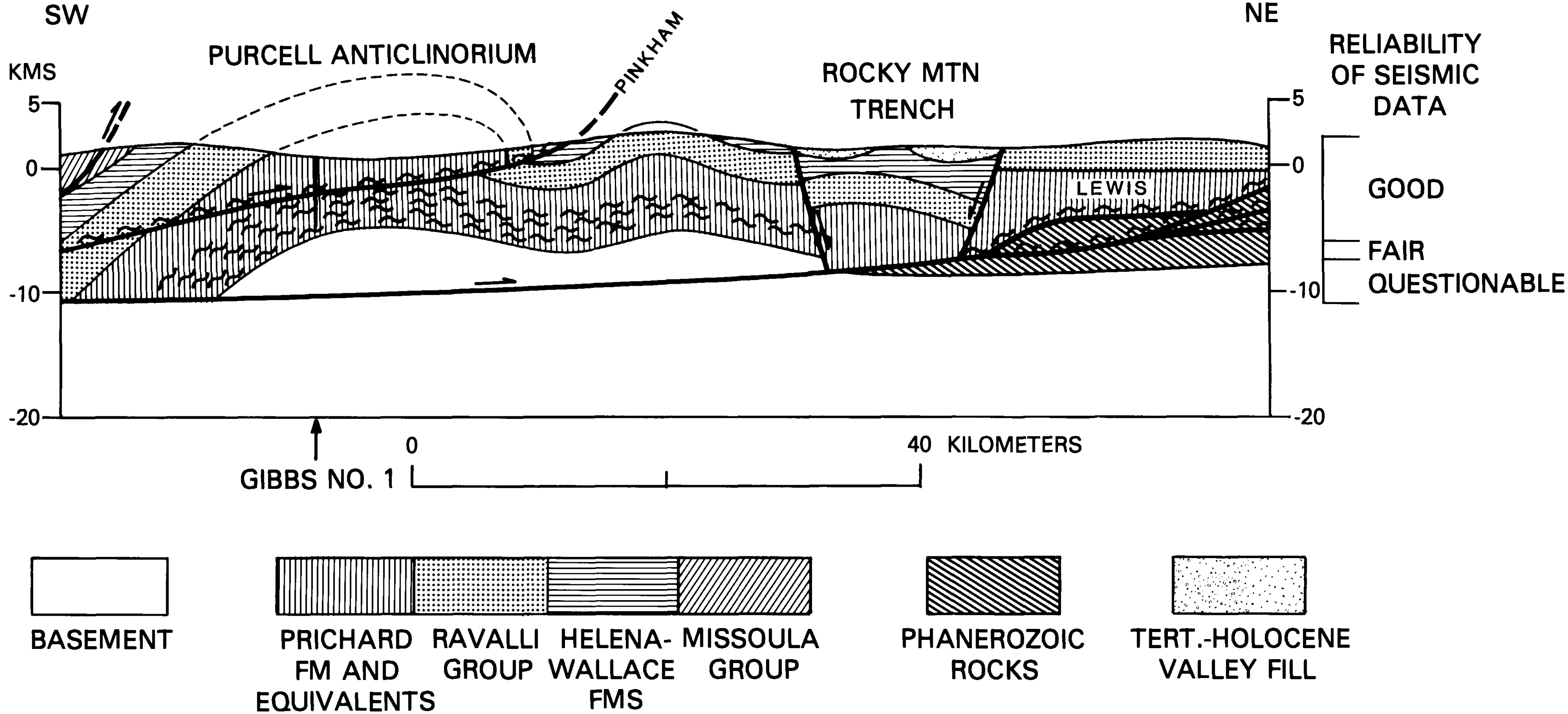

Figure 3. Seismic reflectors (dashed wavey lines) east and west of the Rocky Mountain trench.