Cambrian(?), Middle Proterozoic, and Archean Rocks Penetrated in a Borehole near Argenta, Beaverhead County, Montana, and Some Paleogeographic and Structural Implications

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By Robert C. Pearson

BELT SUPERGROUP IN THE HIGHLAND MOUNTAINS AND PROBABLE EQUIVALENT ROCKS IN THE PIONEER AND ANACONDA RANGES, SOUTHWESTERN MONTANA

J. Michael O'Neill *and* Robert C. Pearson, *Editors*

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By Robert C. Pearson

ABSTRACT

The Middle Proterozoic Belt Supergroup is only 220 m thick where it is penetrated by a borehole in the Argenta mining district about 20 km northwest of Dillon, Mont. This unusually thin sequence of Belt strata is assigned to the Garnet Range Formation (Missoula Group), the youngest widespread formation of the Belt. A conglomeratic base may indicate a depositional contact on Archean schist at a depth of 285 m. The Garnet Range is overlain by 55 m of quartzarenite that is probably the Middle Cambrian Flathead(?) Quartzite. The Garnet Range consists of thin-bedded, poorly sorted, ferruginous, argillaceous, micaceous, feldspathic quartzite; red and green sandy and silty argillite; and thick-bedded coarse-grained to very coarse grained feldspathic quartzite. The upper two-thirds of the unit is mostly interlayered, poorly sorted, argillaceous quartzite and argillite, and the lower third is mostly thick-bedded, feldspathic quartzite. Archean rocks, penetrated from a depth of 285 m to the bottom of the hole at 336 m, are mostly coarse-grained biotite–quartz–plagioclase–potassium feldspar–garnet schist and a few thin layers of amphibolite.

Belt strata near Argenta are comparable in thickness and rock type to Missoula Group strata in the Highland Mountains, 50 km to the north. However, a much thicker Missoula Group (about 7 km thick) forms the Grasshopper thrust plate 6 km to the west; this sequence has been transported tens of kilometers eastward with respect to that at Argenta. No Belt strata are present between Archean and Cambrian rocks to the east and south of Argenta. These relations suggest that an onlap margin of the Belt Basin is probably within a few kilometers of the drill site.

The seemingly unfaulted sequence of Flathead(?) Quartzite, Belt Supergroup, and Archean crystalline basement is clear evidence that previously proposed structures such as the Argenta and Ermont thrust faults do not exist in this area. The Humbolt Mountain anticline, on which the hole was drilled, may be considered a basement-cored anticline similar to the Armstead and Biltmore anticlines and numerous other anticlines in the foreland to the east.

INTRODUCTION

The southern margin of the Belt Basin in much of southwestern Montana is obscure because Belt Supergroup rocks are covered by younger rocks or are absent above pre-Belt rocks where they may have been eroded. Inferences that the Belt Basin extended far to the south of their present remnant were based solely on tenuous facies relations and thickness trends (Reynolds, 1984). On the Grasshopper thrust plate, Missoula Group (upper part of the Belt Supergroup) rocks are widespread and more than 7 km thick (Ruppel and Lopez, 1984), but, east of the Grasshopper decollement, outcropping Belt strata, which are also Missoula Group, are restricted to a small area in the core of an anticline near Argenta, Mont. (fig. 1). After Ruppel and Lopez (1984) correlated the outcropping rocks near Argenta with Garnet Range Formation, the youngest widespread Belt unit, the rocks could reasonably be assumed to represent only the uppermost part of a very thick Belt sequence, such as that on the Grasshopper plate, or they could be interpreted as part of a thin thrust-fault sliver (Brandon, 1984).

Thus, a mineral-exploration borehole in the Argenta mining district is significant for several reasons: (1) the Belt sequence penetrated in the borehole is only 220 m thick; (2) the Belt strata are conglomeratic at the base; and (3) the Belt strata overlie Archean schist and gneiss at a depth of less than 300 m in an area where such shallow depth had not been suspected. The conglomeratic base of the Belt suggests

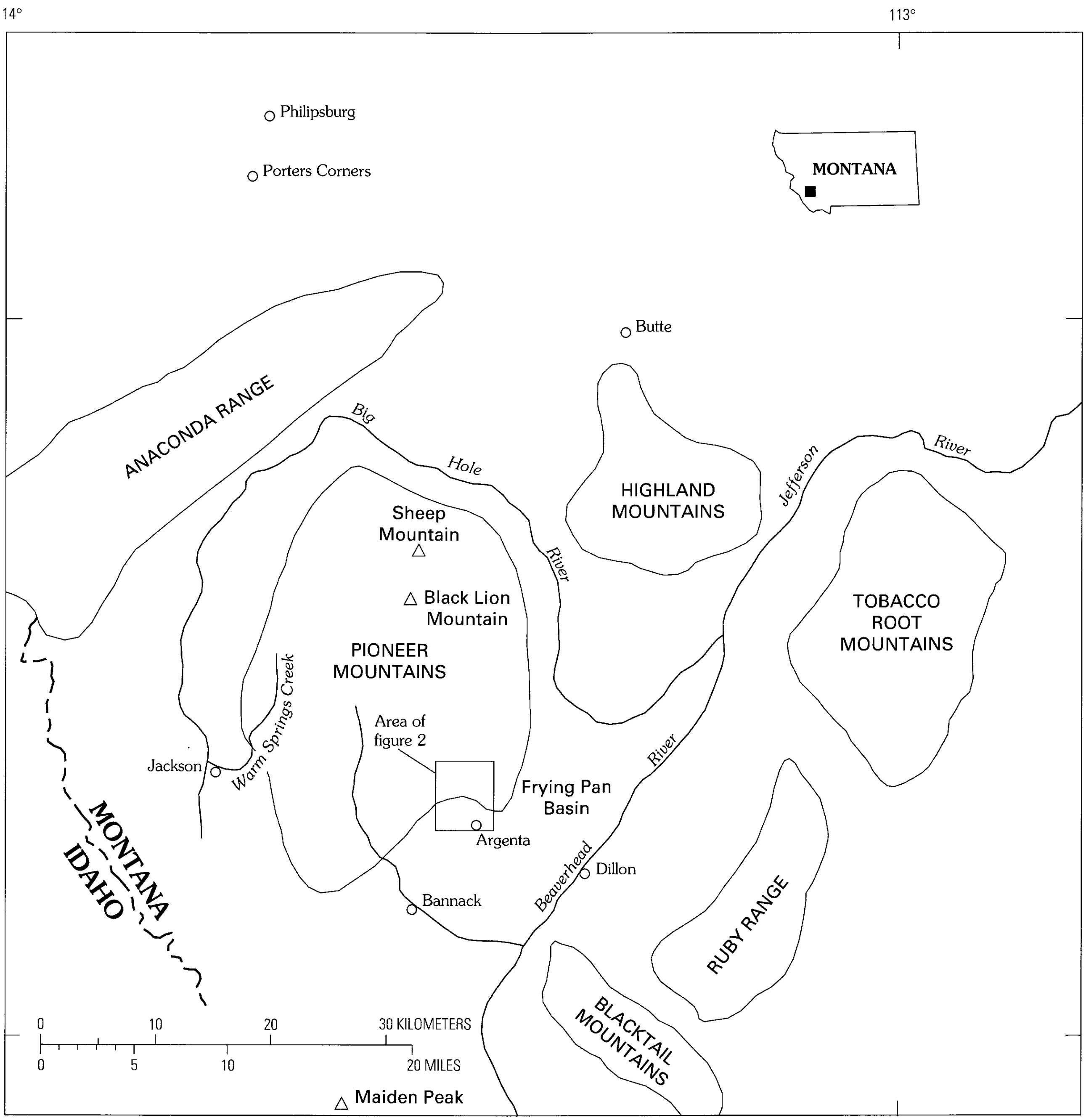


Figure 1. Index map of southwestern Montana.

strongly that the base is depositional and not a fault. This rare find coupled with other information from other drill holes and outcrops nearby provide a basis for inferring the edge of the Belt Basin in this area. The borehole near Argenta also provides important information for the structural interpretation of the eastern margin of the Cordilleran thrust belt.

The borehole was drilled in 1968 to a depth of 336 m and was cored the entire length. The core has a diameter of 6 cm (NC size) from the surface to a depth of 115.5 m, and the remainder is 4.7-cm in diameter (NX size). This hole was drilled by Copper Range Corporation on property controlled by the William Hand family of Dillon, Mont., who have custody of the core, made it available for study, and supplied a copy of the driller's log. Prior to examination in 1992, the core had been split, portions removed for tests and analyses, and numerous boxes of core were missing or in disarray; however, a comparison of the extant core with the driller's log indicates that the portions not available for examination did not contain any unusual or significant intervals. About 80 percent of the core was present when I examined it and collected small samples for petrographic and mineralogic study in August and September 1992. The borehole is located about 3.2 km north-northwest of the village of Argenta (fig. 1) in NE$^1/_4$ SW$^1/_4$ sec. 18, T. 6 S., R. 10 W., and near the east side of the Ermont 7$^1/_2$-minute quadrangle. According to the driller's log, the drill collar is at an altitude of 6,962 ft (2,122 m).

The drill site is near the Groundhog mine, and hence the hole will be referred to as the Groundhog drill hole. (It was called "CRX-4" by the mining company that drilled it.) This report describes the rocks from the Groundhog drill hole, with emphasis on the Belt strata, interprets their stratigraphic position and structural relationships, and compares this sequence of Belt rocks with other Belt successions in the region.

ACKNOWLEDGMENTS

William Hand very graciously permitted access to the drill core and provided a copy of the lithologic log. In addition, William and Donald Hand have been helpful in supplying information on the geology and mineral deposits in the Argenta area. William Hand died in 1994 before seeing the results of this work, in which he took a great interest. Phyllis Denton, U.S. Forest Service, arranged for facilities in Dillon, Mont., to examine the core. For all of these courtesies, I am very grateful. Elizabeth Youngren recognized the significance of crystalline rocks in the drill core to interpretation of the local geology and called my attention to the drill hole a few years ago.

GEOLOGIC SETTING OF THE ARGENTA AREA

The Argenta mining district is in a north-trending segment of the Cordilleran thrust belt that was referred to by Ruppel and Lopez (1984) as the "frontal fold and thrust zone," a structural belt characterized by parallel anticlines, synclines, and minor thrust faults. The belt is transitional between the Rocky Mountain foreland to the east and the region of major thrust faults to the west. The district is about 6 km east of the Kelley thrust (fig. 2), a segment of the Grasshopper decollement, which is one of the major thrust faults of southwestern Montana (Ruppel and Lopez, 1984). The upper plate of this thrust, now called the Grasshopper plate (figs. 2 and 3), consists of at least 7 km of upper Belt (Missoula Group) strata (Ruppel and Lopez, 1984) and local thin remnants of overlying lower Paleozoic rocks.

Terminology of Belt rocks in this report is that currently in common use and defined first by Harrison and Grimes (1970). The terms argillite, siltite, and quartzite reflect the widespread low-grade metamorphism that Belt rocks have undergone. Other rock names are used in petrographic descriptions such as arkose, subarkose, and quartzarenite (Pettijohn, 1957); these terms reflect more precisely variations in mineral composition.

The mines of the Argenta district are on the crest and both flanks of the Humbolt Mountain anticline (Myers, 1952), a major northerly trending sinuous structure that is at least 15 km long. For part of its length, this anticline has also been called the Argenta anticline (Hobbs, 1967), but the older name, Humbolt Mountain (Myers, 1952), is used here. In the vicinity of Argenta, the Humbolt Mountain anticline is broken by steep faults that have mostly small, probably mostly dip-slip, displacement (Myers, 1952). Most steep faults strike northwest and north. Various interpretations of the structure of the east flank of the Humbolt Mountain anticline, discussed in a later section of this report, involve a steep reverse fault, a low-angle thrust fault, or unconformities to account for local relationships.

West of Argenta, where the valley of Rattlesnake Creek cuts across the Humbolt Mountain anticline, the oldest rocks exposed are quartzite, feldspathic quartzite, and argillite of the Middle Proterozoic Garnet Range Formation (fig. 2), the uppermost formation of the Missoula Group at most places in west-central Montana. These rocks have been recognized as Proterozoic since a study by Shenon (1931) but were first correlated with the Garnet Range by Ruppel and Lopez (1984). The Garnet Range is overlain on the crest of the anticline by a quartzite unit that Shenon (1931) and Myers (1952) assigned partly to the Middle Cambrian Flathead Quartzite, an assignment adopted tentatively here. Others considered all of the quartzite, in addition to the underlying beds, to be parts of the Belt Supergroup (Hobbs, 1967; Ruppel and Lopez, 1984; Brandon, 1984). To the north, near Humbolt Mountain (fig. 2), the Garnet Range also underlies quartzite on the crest of the anticline. These quartzite beds were interpreted by most previous workers to be Belt and to be thrust over the Garnet Range (Myers, 1952; Brandon, 1984; Ruppel and others, 1993), but here these rocks also are regarded as Flathead(?) in normal stratigraphic position above the Garnet Range.

Strata above the Flathead(?) Quartzite are of unquestioned Middle Cambrian and younger age. These units have been correlated with cratonic Cambrian units to the east, such as Wolsey Shale, Meagher Limestone, Park Shale, and Pilgrim Dolomite, or with units to the north in the Philipsburg, Mont., area, such as Silver Hill Formation and Hasmark Dolomite. Regardless of which stratigraphic assignment is best, these rocks were not encountered in the drill hole, and they will receive little attention in this report.

The correct interpretation of the stratigraphy and paleogeography of the rocks penetrated in the Groundhog drill hole depends on their structural relations and whether these rocks represent an unfaulted stratigraphic succession. If this thin sequence of the Belt Supergroup is not thinned tectonically, such as by thrust faulting, the sequence could represent basin-margin deposits and thus be important to the

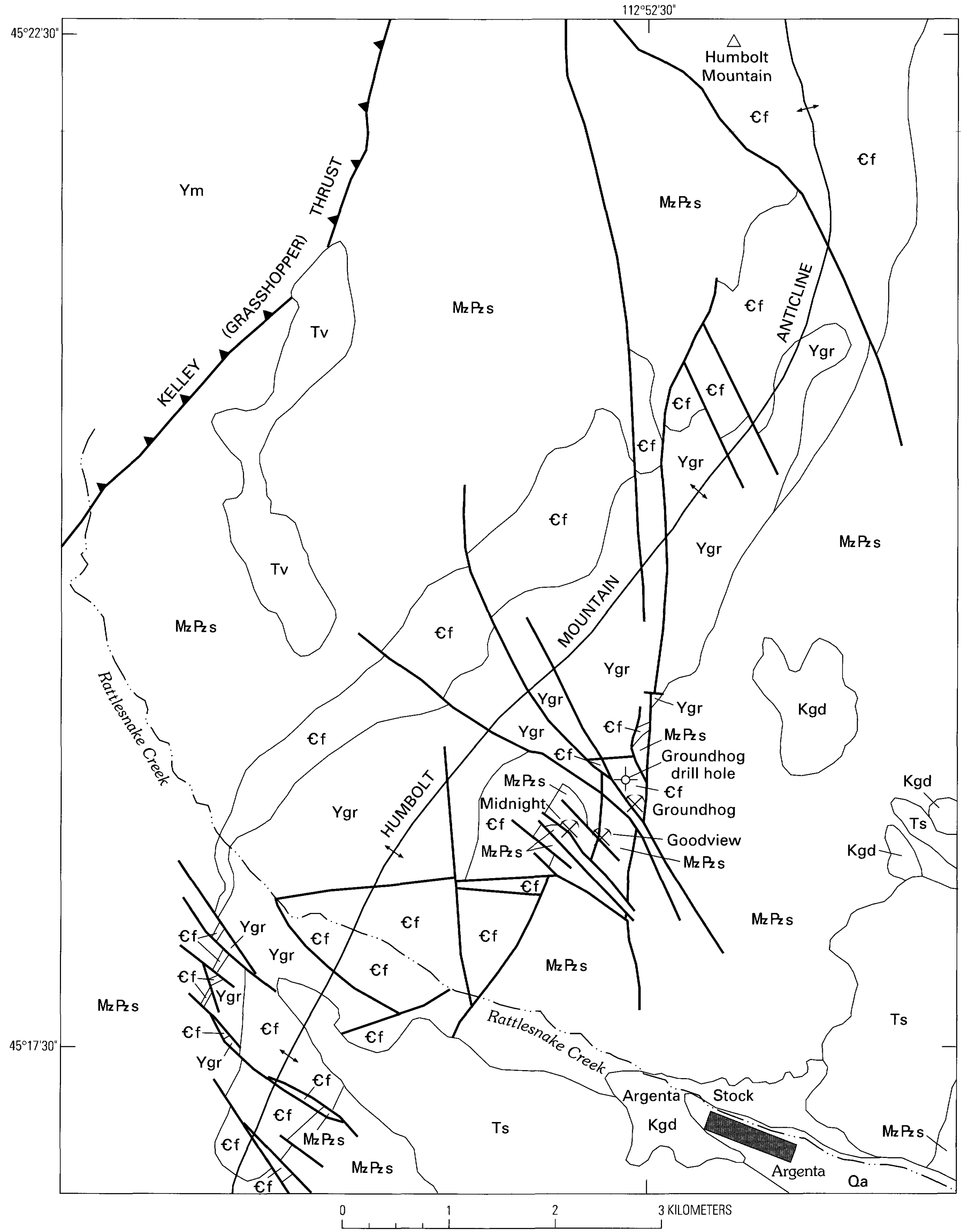
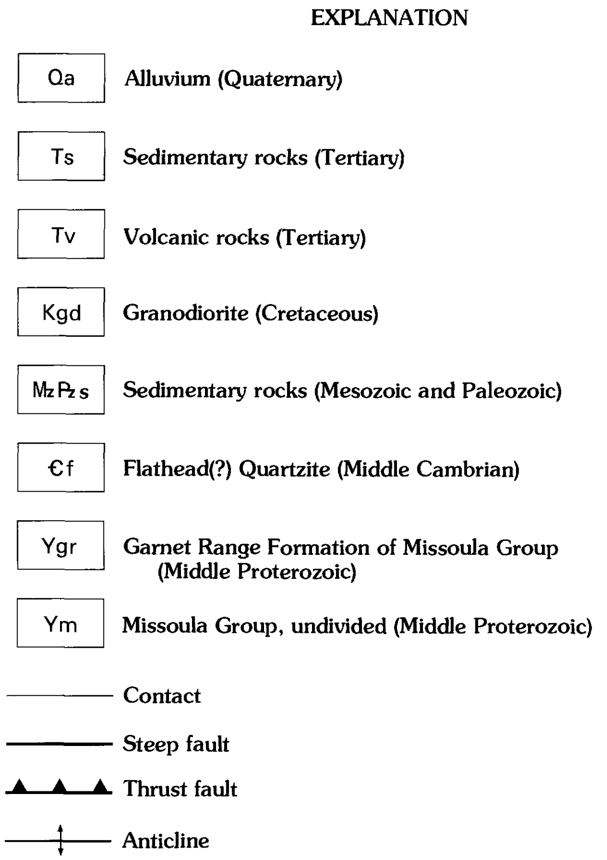


Figure 2 (above and facing column). Geologic map of the Argenta area, Beaverhead County, Montana. Geology generalized and modified from Myers (1952).



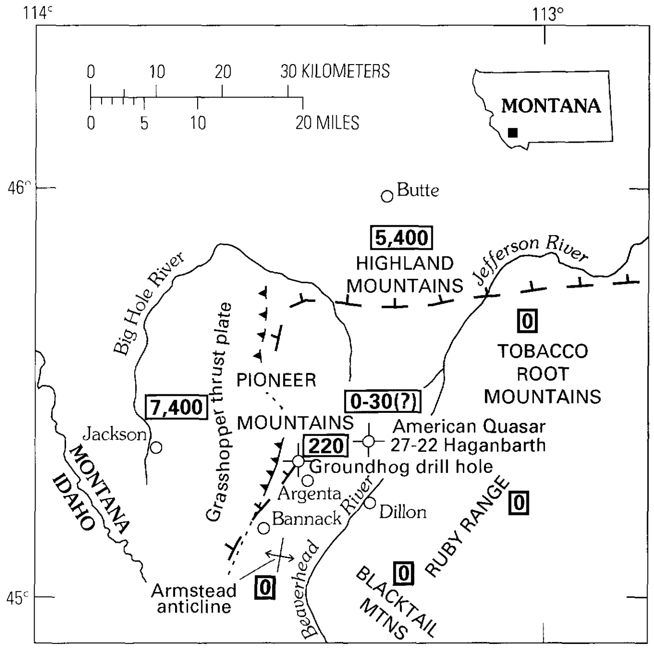


Figure 3. Major structural features, limit of exposed Belt Supergroup rocks, and thickness (in meters, shown in boxes) of Belt in southwestern Montana. Hachured line shows limit of Belt strata—modified in Pioneer Mountains from Harrison (1972).

regional relationships. Previous interpretations of structure in the area of the drill hole include: (1) thrust faulting (Shenon, 1931; Ruppel and Lopez, 1984; Brandon, 1984), (2) high-angle reverse faulting (Hobbs, 1967), and (3) high-angle normal faulting (Myers, 1952). Clearly, the rocks have been broken by numerous steep faults, as shown by Myers (1952) and documented in detail in and around mines by Geach (1972). Evidence for thrust faulting or high-angle reverse faulting has not been found during my recent (1994) field studies, in former studies of the mines (Geach, 1972), or in the drill core from the Groundhog drill hole. Although the drill core contains several zones of gouge and breccia and slickensided surfaces (commensurate with the proximity to known steep faults), many of these zones are steeply dipping, and none of them coincide with abrupt lithologic changes or change in dip. Dip of bedding in both the Flathead(?) Quartzite and Garnet Range Formation is within 10° of horizontal throughout the length of the core. Furthermore, no repetitions or deletions of strata or inversions of age sequence were recognized in the core. If repetitions or deletions are present, they are believed to be minor. The sequence represented by the drill core, therefore, is considered to be essentially intact structurally.

The drill hole was spudded in Flathead(?) Quartzite probably only several meters below the top of the unit. Several hundred meters west and southwest of the drill hole, the Flathead(?) is in depositional contact with Garnet Range Formation. Elsewhere in the area of the drill hole, especially several hundred meters to the north, the Flathead(?) is missing, probably owing to Cambrian erosion, and Cambrian or Devonian dolostone is in apparent depositional contact with Garnet Range. These relationships, which convinced Myers (1952) of faulting and erosion during Cambrian time, have also been explained by high-angle reverse faults (Hobbs, 1967) and low-angle thrust faults (Brandon, 1984; Sears and others, 1988) that slipped during Mesozoic to early Tertiary time.

DESCRIPTION OF ROCKS IN THE GROUNDHOG DRILL CORE

Strata represented in the drill core are divided into three parts: (1) an upper unit of light-gray to nearly white quartzite (Flathead? Quartzite); (2) a middle unit of argillaceous, feldspathic, and micaceous quartzite; argillite; and feldspathic quartzite that are mostly grayish red (Garnet Range Formation); and (3) a lower unit of mostly biotite-feldspar-quartz schist (Archean basement) (fig. 4). The correlation of the upper quartzite unit is tentative because its thickness is greater than that of Flathead in nearby areas, and no direct evidence of its age has been found.

Two small bodies of fine-grained igneous rock, each about 4 m thick, are contained in the drill core (fig. 4) and are probably sills that intrude the sedimentary rocks. The top

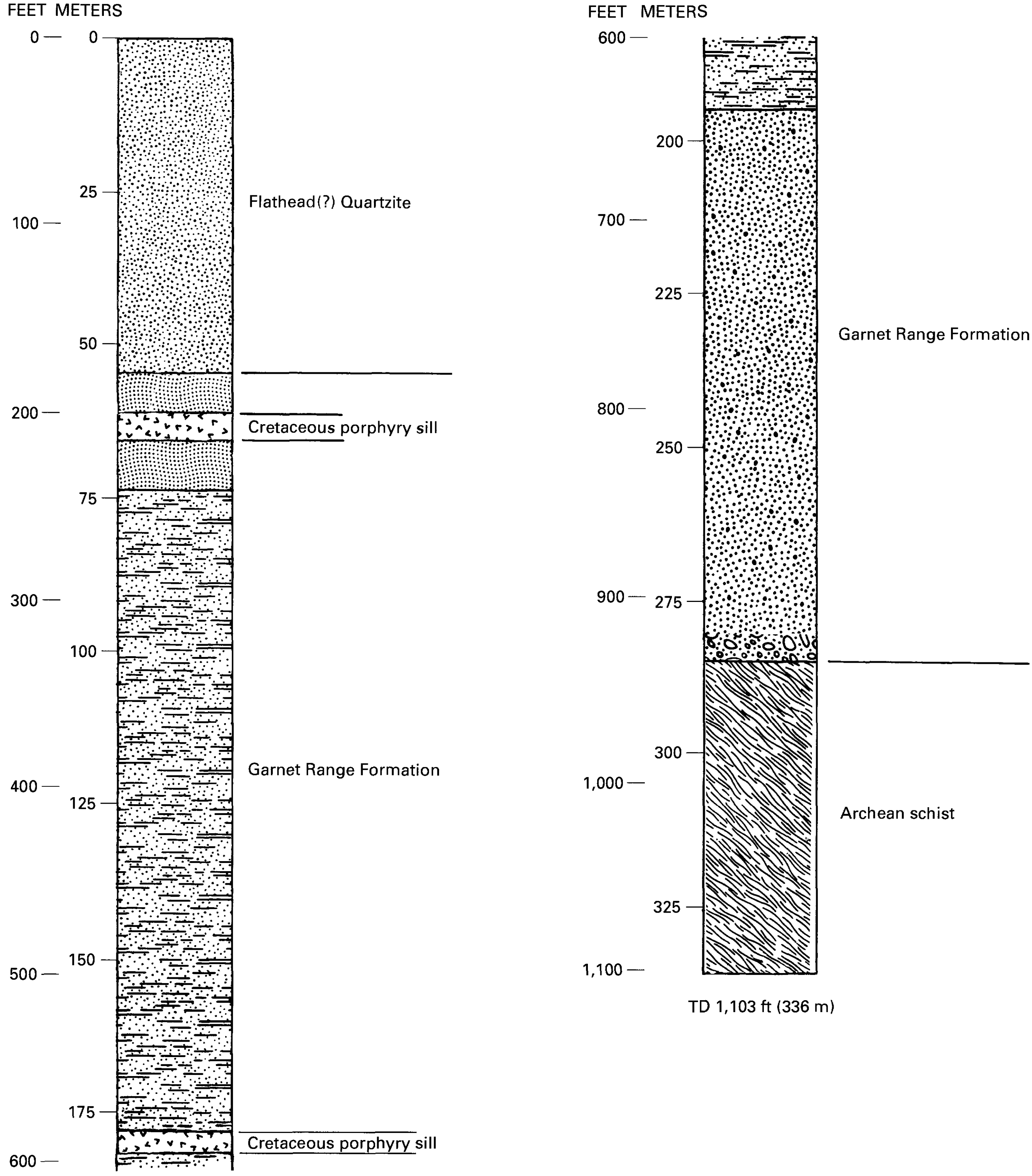
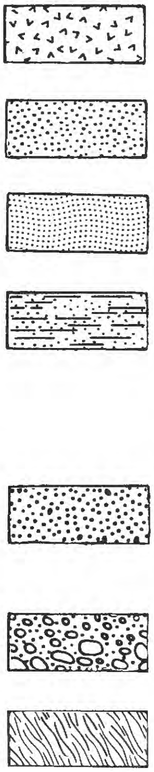


Figure 4 (above and facing column). Stratigraphic columnar section showing rocks in Groundhog drill hole.

of the upper sill is at a depth of 61.2 m and near the Flathead(?) Quartzite–Garnet Range Formation contact, and the top of the lower one is at a depth of 177.9 m and within the Garnet Range. The sills are probably apophyses from the Argenta granodiorite stock at the village of Argenta (fig. 2) or from other intrusive bodies 2–4 km east of the drill site.

Although most of the rocks in the core are fresh, evidence of hydrothermal alteration is present sporadically,

EXPLANATION



Altered fine-grained porphyry

White to light-gray, fine- to coarse-grained quartzarenite

Coarse-grained cross laminated quartzarenite

Interbedded, poorly sorted, red, feldspathic, micaceous quartzite; red and green silty and sandy argillite; and minor arkosic quartzite that increases in abundance downward

Coarse-grained to very coarse grained feldspathic quartzite and minor poorly sorted quartzite and argillite mainly in upper part

Pebble conglomerate and feldspathic quartzite

Biotite-quartz-feldspar-garnet schist and minor amphibolite

mostly along and adjacent to fractures and fracture zones. Pyrite is the most conspicuous product of hydrothermal alteration, but some pyrite that is disseminated in green and gray beds may be sedimentary or diagenetic. Pyrite appears first in the core at a depth of 132 m; above that depth all pyrite has been converted to limonite by weathering, probably in Quaternary or late Tertiary time. From 132 m downward, pyrite increases in abundance and limonite decreases. Below 205 m, pyrite coats nearly all fracture surfaces and is disseminated in gouge and in nearly all rocks that are shades of green, gray, and pale red; pyrite is not disseminated in rocks that are moderate red or dark red. A few quartz veinlets, one of which contains base-metal sulfide minerals, are present in the Archean rocks. The upper 10 m of the Archean rocks are partly pale green and slightly friable, possibly as a result of weathering prior to deposition of Garnet Range Formation in Middle Proterozoic time.

FLATHEAD(?) QUARTZITE

Flathead(?) Quartzite extends from the surface to a depth of 55.1 m (fig. 4). The lower contact is placed above the highest quartzarenite bed that contains red cross-laminae. This contact is not as prominent as might be expected at an unconformity spanning several hundred million years, although, at other places in southwestern Montana, the contact is very similar to this one (Campbell, 1960; Nelson and Dobell, 1961; Winston and Lonn, 1988; Winston and Wallace, 1983). Several beds of prominently cross-laminated rocks, totaling several meters (the precise thickness cannot be determined because of missing core), are between the quartzite of the overlying Flathead(?) and the highest red argillite bed that typifies, and is definitely a part of, the underlying Garnet Range Formation.

Bedding thickness is obscure in the core, but in outcrops nearby (fig. 5), the Flathead(?) is mostly in beds 0.5–1.5 m thick. Much of the rock in the core is massive, except for faint to conspicuous, mostly planar, laminations, which are marked by changes in grain size (fig. 6).

Grain size ranges from fine grained to very coarse grained (fig. 6). The coarser rocks contain sparse granules, typically a few millimeters in diameter and, rarely, small pebbles as much as 1 cm in diameter. The coarser beds are erratically distributed in the formation and are not present at the base. Most grains are well rounded; sorting is poor to good. Color of the quartzarenite is light gray, medium light gray, and where disseminated limonite is present, pinkish gray to very pale orange.

The composition of the Flathead(?) is uniform quartzarenite that consists of about 97 to >99 percent quartz grains and overgrowths and trace amounts of microcrystalline chert or jasperoid grains. The rest of the rock (<1–3 percent) is very fine grained white mica or clay and traces of heavy minerals; attempts to identify the micaceous mineral by X-ray to compare it with the matrix of the Belt rocks were unsuccessful because of its paucity. No feldspar or detrital mica was observed in thin section or on X-ray diffraction patterns, although detrital white mica is fairly common in nearby outcrop.

GARNET RANGE FORMATION

Rocks assigned to the Garnet Range Formation extend from 55.1 m to 284.8 m in the drill hole (fig. 4), but that thickness includes 8.2 m of igneous rock in the two sills. Thus, the thickness of the Garnet Range is 221.5 m. Rocks comprising the Garnet Range are chiefly of three types, in order of decreasing abundance: (1) poorly sorted, argillaceous, feldspathic, micaceous quartzite, (2) coarse-grained to very coarse grained feldspathic quartzite; and (3) micaceous argillite. The term "argillaceous" is used for the fine-grained matrix that is now mica but was originally probably clay. Although these principal rock types are interbedded throughout, poorly sorted quartzite and argillite are most abundant in the upper and middle parts of the unit, and feldspathic quartzite is most abundant in the lower part. In addition to these principal rock types, several meters of cross-laminated quartzarenite are at the top of the Garnet Range, and poorly sorted conglomerate is a minor constituent confined to the base of the unit. Mineralogically, the

Figure 5. Photograph of Flathead(?) Quartzite (upper cliff) and Garnet Range Formation (outcrops on slope) at mouth of Clarks Canyon, Ermont $7^1/_2$-minute quadrangle. Flathead(?) is thick-bedded to massive quartzarenite; Garnet Range is thin- to thick-bedded feldspathic quartzite and argillite.

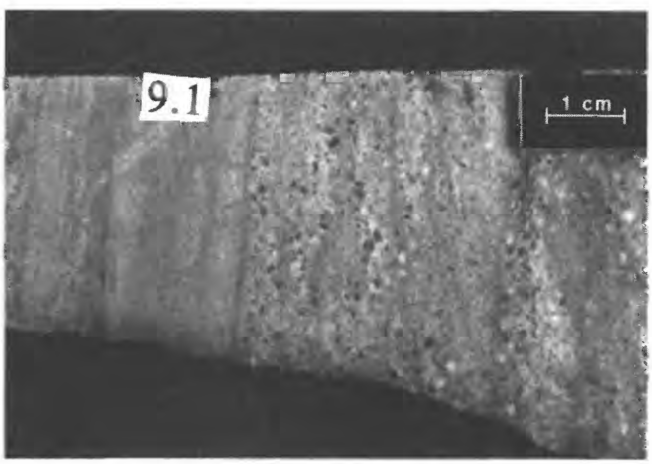


Figure 6. Photograph of Flathead(?) Quartzite from Groundhog drill core: sawn surface of core from depth of 9.1 m. Fine- to coarse-grained quartzarenite.

most noteworthy feature of these rocks is the abundance of detrital and authigenic potassium feldspar, detrital mica, and authigenic hematite; plagioclase is absent or present in only trace amounts.

The poorly sorted argillaceous quartzite, the most abundant rock of the Garnet Range Formation, is mostly grayish red to dusky red, laminated to cross-laminated, and fine to coarse grained (figs. 7 and 8 illustrate typical examples); a few beds are light greenish gray. Although bedding, aside from lamination, is not clearly evident in the core because of fracturing, incomplete core recovery, and splitting of the core lengthwise, the beds are typically on the order of 1–4 decimeters thick where exposed at the surface south of the drill hole. In core of quartzite from the middle part of the unit, red mud chips are widely scattered.

Grain size and, to some extent, mineral composition vary from one lamina to another within the poorly sorted quartzite. Fine- and medium-grained laminae tend to be more feldspathic than coarse-grained laminae, which are more quartzose and tend to contain a higher percentage of matrix. As estimated from thin sections, potassium feldspar comprises about 20–70 percent of the rock, of which about 80 percent is detrital and the rest authigenic. Most detrital feldspar grains show microcline twinning, although some twinning is faint. The authigenic feldspar is a clear or slightly turbid rim on detrital grains or is intergranular cement. A few grains composed entirely of fine-grained, felted mica may represent altered plagioclase. Quartz comprises about 25–60 percent of the rock and detrital mica as much as 10 percent. The matrix, commonly 10–30 percent of the rock, consists of very fine grained micaceous material, silt-size and smaller detrital grains, disseminated hematite flakes and "dust," and opaque mineral grains. Rock fragments, most of them quartz rich and of metamorphic origin, are very sparse. Detrital mica flakes are mostly 0.5–3.0 mm in diameter, are oriented parallel to bedding, and are commonly concentrated on the tops of laminae or beds. Some laminae consist almost entirely of detrital mica (fig. 8). The detrital mica ranges from colorless to amber colored in hand

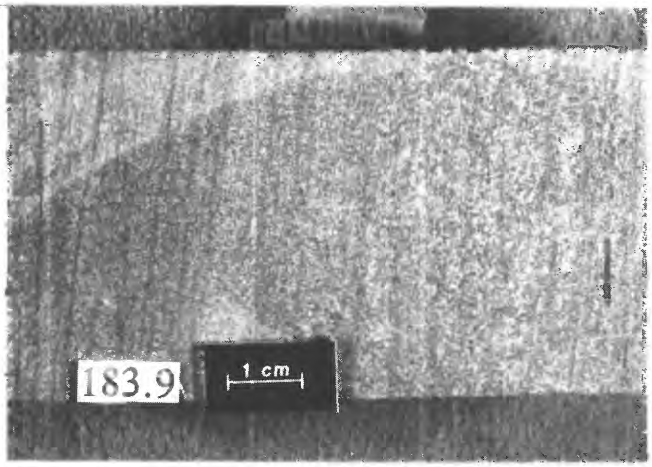


Figure 7. Photograph of Garnet Range Formation at depth of 183.9 m in Groundhog drill core: sawn surface of thinly laminated, very feldspathic, slightly micaceous quartzite. Surface stained for potassium feldspar, which shows up as light grains; dark grains are mostly quartz. Dark bar at right is red mud chip. Arcuate marks in upper left are from saw.

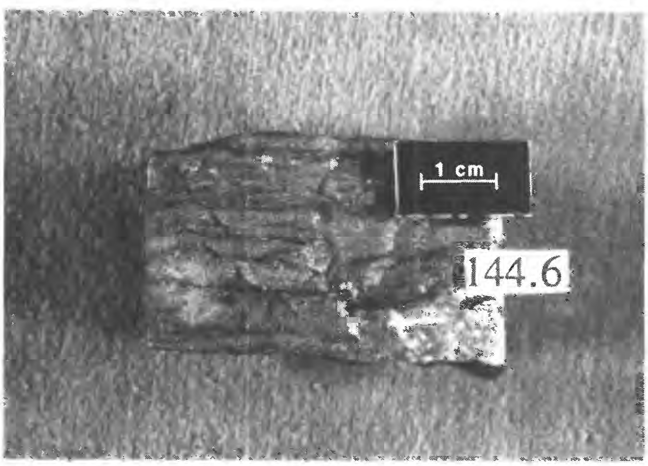


Figure 8. Photograph of fractured surface of very micaceous feldspathic quartzite in upper part of Garnet Range Formation at depth of 144.6 m in Groundhog drill core. Thin, dark laminae are composed mostly of detrital mica.

specimen but in thin section appears to be entirely muscovite. The amber-colored muscovite has inclusions of hematite and possibly other minerals and may be detrital biotite that has been altered.

The feldspathic quartzite is medium to very coarse grained, pale red to pale reddish orange and grayish red, and slightly micaceous. Petrographically, the rocks are arkose and subarkose (fig. 9). They consist of about 55–85 percent quartz grains and overgrowths, 15–35 percent potassium feldspar grains and overgrowths, and 5–15 percent micaceous matrix. Some of the micaceous material appears to be altered feldspar. The amount of matrix is definitely less than

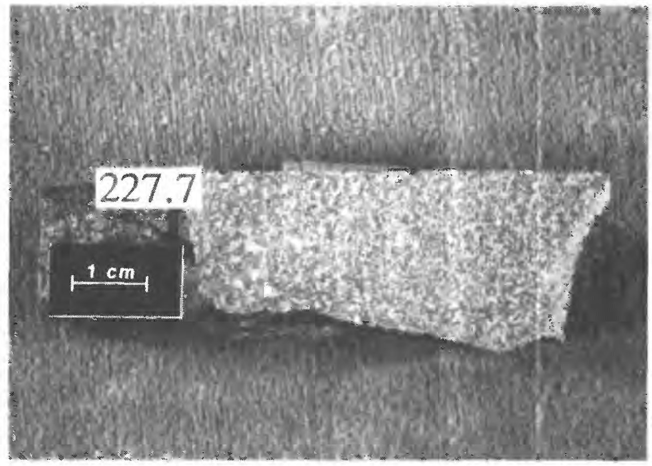


Figure 9. Photograph of Garnet Range Formation at depth of 227.7 m in Groundhog drill core: sawn surface of coarse-grained feldspathic quartzite (arkose). Surface stained for potassium feldspar (light grains); dark grains are nearly all quartz.

in the poorly sorted quartzite, although gradations seem to exist between poorly sorted quartzite and feldspathic quartzite. Tourmaline, zircon, detrital muscovite, sphene, and opaque minerals are common heavy minerals. Some of the muscovite is crowded with dark inclusions of hematite and other minerals and probably represents altered biotite.

The argillite is mostly grayish red to dusky red, sandy and silty, and rich in detrital mica. Some beds or parts of beds are yellowish gray or light greenish gray. Core recovery of argillite was poor, and most that was recovered is in thin partings or laminae between poorly sorted quartzite or feldspathic quartzite beds, although some argillite sequences (beds?) are as much as a few meters thick. Detrital mica flakes that are parallel to bedding produce a pronounced fissility. A dull, submetallic film of gray hematite that coats many bedding planes and other splitting surfaces seems to become more abundant with depth. Green argillite commonly contains pyrite, and red argillite contains hematite but no pyrite. Unaltered brown to green biotite was found in one sample of argillite from 25 m below the top of the Garnet Range. This biotite, in addition to the more abundant white mica, is in thin flakes 0.1–0.3 mm in diameter that appear to be detrital.

The quartzite beds at the top of the Garnet Range Formation (as here defined), which may total about 14 m thick, differ from the overlying Flathead(?) Quartzite only in containing prominent cross-laminae 2–3 mm thick, some of which are red and alternate with thicker (3–6 mm thick) light-gray and very light gray laminae (fig. 10). The mineral composition and grain size are not noticeably different from the overlying Flathead(?). The highest sill encountered in the core intruded this sequence of quartzite beds at the top of the Garnet Range. These several meters of quartzite are assigned to the Garnet Range rather than the Flathead(?)

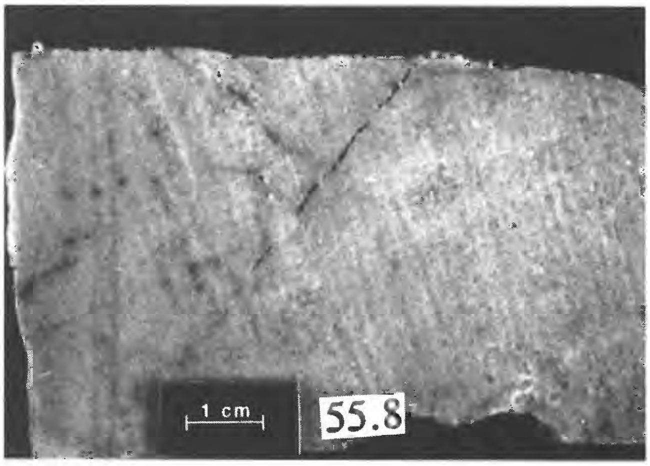


Figure 10. Photograph of core from near top of Garnet Range Formation at depth of 55.8 m in Groundhog drill hole: sawn surface of quartzarenite. Note prominent cross-laminae and horizontal laminae.

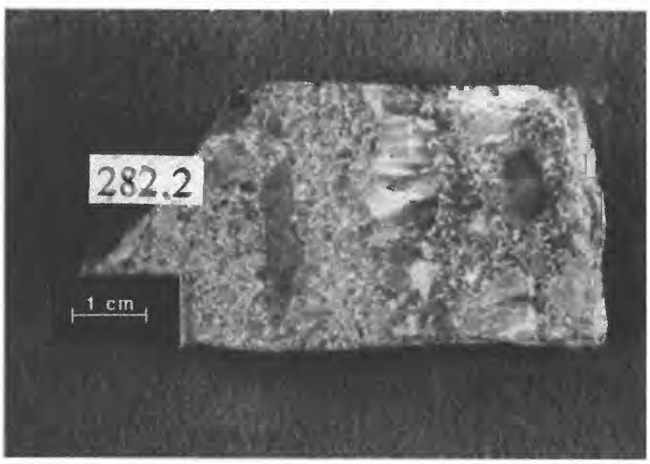


Figure 11. Photograph of core from Garnet Range Formation at depth of 282.2 m in Groundhog drill hole: sawn surface of conglomerate. Surface stained for potassium feldspar, which comprises about 15 percent of rock. Large pebble in center is fractured white crystalline quartz; dark pebble on right is ferruginous jasperoid.

partly because of the very similar sequence in the Anaconda Range (Wallace and others, 1992) and at Porters Corners near Philipsburg, Mont., about 120 km to the north (fig. 1) (Winston and Wallace, 1983).

Several beds of pebble conglomerate are interlayered with poorly sorted coarse-grained to very coarse grained feldspathic sandstone in the lower 4 m of core, directly above the contact with Archean schist. Although core recovery was poor in this interval, it was sufficient to show that the conglomerate consists of pebbles of crystalline quartz and jasperoid as much as 5 cm long, pink feldspar as much as 2 cm long, and a rock consisting of quartz and pink microcline and resembling pegmatite or possibly the pink granite that comprises most of the Archean terrane in the Maiden Peak area about 50 km south-southwest of Argenta (fig. 1). The pebbles are rounded to subangular and supported by a more abundant coarse-grained and very coarse grained sand matrix (fig. 11) composed of quartz, metaquartzite, jasperoid, pink feldspar, muscovite, altered biotite, and locally, disseminated pyrite. Some jasperoid grains and pebbles contain disseminated hematite and resemble ferruginous jasperoid associated with iron formation in Archean rocks in the Ruby Range to the east (James, 1990).

The contact between Garnet Range Formation and Archean rocks is marked by about 2 cm of light greenish-gray gouge or regolith. This layer consists of the same minerals as the sandstone and arkose and also minor amounts of chlorite and disseminated pyrite.

X-ray diffraction analysis of bulk-rock samples of the various rock types gives information on mineralogy of the rocks beyond that determinable optically. The X-ray data confirm the petrographic determination of the abundance of potassium feldspar and the absence in most specimens of plagioclase; a trace of plagioclase was detected definitely in only one specimen. The X-ray data also indicate that, in most specimens, the potassium feldspar is orthoclase rather than microcline despite the grid twinning visible in many of the grains. Other specimens contain mixtures of microcline and orthoclase, resulting from either detrital microcline and authigenic orthoclase or microcline partially converted to orthoclase during or since diagenesis. Hematite was detected by X-ray in most of the red rocks, and in some, the amount probably exceeds five percent. The argillite and the fine-grained matrix of sandstone consist largely of mica, and no chlorite or clay minerals were found.

ARCHEAN SCHIST

From a depth of 285 m to the bottom of the drill hole at 336 m, the rock penetrated is coarsely crystalline schist. Quartz-plagioclase-garnet-biotite schist is the most abundant, and hornblende-clinopyroxene-plagioclase schist is present in a few thin layers. Much of the biotite-rich schist contains augen of feldspar (both plagioclase and potassium feldspar) as much as 1 cm long and crystals of red garnet typically 0.3–0.5 cm in diameter and rarely as much as 2 cm in diameter. The well-defined foliation in the schist is approximately horizontal throughout.

CORRELATION AND PALEOGEOGRAPHY

The quartzarenite penetrated in the upper part of the drill hole, as well as exposed at the surface on the crest and both flanks of the Humbolt Mountain anticline, is here correlated with Flathead(?) Quartzite because its stratigraphic position and composition are similar to the Flathead elsewhere. The greater thickness (about 60 m) of the quartzarenite exposed locally on the Humbolt Mountain anticline compared with that in exposures in mountain ranges to the north, east, and south is the only reason that this correlation may be questionable. In those areas, the unit typically is 0–30 m thick, but Ruppel and others (1993) report nearly as great a thickness (43 m) locally in the Tobacco Root Mountains. The quartzarenite, in whole or in part, was previously thought to be Proterozoic. Hobbs (1965) assigned all of the quartzarenite to the Proterozoic because of intercalated argillite, which he claimed is not present in the Flathead in western Montana. In fact, the argillite that he described is in very small amount and is not unlike shale partings on quartzite beds in Flathead in the region. He may also have confused argillite interbedded with quartzarenite beds near the top of the Garnet Range Formation with the overlying quartzarenite unit. Others (Myers, 1952, and Ruppel and others, 1993, for example) assigned southern outcrops on the anticline to the Flathead but more northerly outcrops to the Missoula Group. Indeed, the characteristics of the rock do change from south to north: outcrops become rare; bedding becomes obscure; the rock progressively weathers into more angular blocks and piles of rubble; the rock becomes a more vitreous quartzite that fractures across the grains; and it loses its brown to red colors and becomes white to light gray. All of these characteristics are the result of bleaching and recrystallization caused by heating effects of the Pioneer batholith, which crops out 3 km northeast and 5 km northwest of Humbolt Mountain. The poor outcrop, the weathering into angular blocks, and the tendency of the blocks to move downslope as sheets of surficial debris masking adjacent units all cause the unit to resemble the Missoula Group in many areas in the Pioneer Mountains. Further studies will be needed to confirm or deny that the unit is all or partly Cambrian.

Proterozoic strata in the Argenta area are correlated with the upper part of the Missoula Group on the basis of lithologic similarity with rocks extensively exposed in the Anaconda Range (fig. 1) (Wallace and others, 1992) and in other parts of the Butte 1°×2° quadrangle (Wallace, 1987). The upper part of the sequence, which is exposed at the surface and continuously cored in the drill hole, is here confidently assigned to the Garnet Range Formation, as was done for the exposed portion by Ruppel and Lopez (1984). In the drill hole, the increase downward in coarse-grained arkose and the presence of red mud chips in quartzite in the middle part of the sequence suggest further the possibility that the middle and lower parts are correlative with the McNamara Formation and Bonner Quartzite, respectively. Such correlations would imply that the Garnet Range is about 100 m thick, the McNamara about 30 m thick, and the Bonner about 90 m thick. Siliceous mud chips and red and green chert, characteristic of the McNamara, were not observed, however, and nowhere else are these units nearly so thin. Therefore, it would be rash to subdivide the 220 m of these strata to such an extent on the basis of the limited information from the drill hole. It is considered prudent to include all of these units in the Garnet Range and to consider the coarse arkose in the lower part to be merely a local basal facies that accumulated near the sediment source—this basal facies may interfinger with more typical Garnet Range basinward.

The absence of Belt rocks at several places in the region where Paleozoic strata are in contact with pre-Belt crystalline basement (Ruppel and others, 1993) suggests, but does not prove, limits to the Belt Basin. Belt rocks could have been deposited and then eroded before Cambrian deposition. At such places as the Blacktail Mountains, Ruby Range, and Tobacco Root Mountains (fig. 3), Flathead Quartzite is in depositional contact with the crystalline rocks. The contact of the Flathead and Archean crystalline rocks is also exposed about 25 km south of Argenta in the core of the Armstead anticline (fig. 3) (Lowell, 1965), which is slightly en echelon to the Humbolt Mountain anticline.

The nearest outcrops to Argenta of the upper part of the Missoula Group are near Jackson, Mont., 40 km west of Argenta (fig. 1). These rocks, however, were originally much more than 40 km from those at Argenta because they are on the Grasshopper thrust plate that has moved eastward an unknown, though probably large, distance. Garnet Range, McNamara, Bonner(?) and Mount Shields Formations of the Missoula Group on the Grasshopper plate were recognized by Ruppel and Lopez (1984) in the Warm Springs Creek drainage east of Jackson. Although they have not been studied in detail, the thickness of the Garnet Range, as preserved beneath Flathead Quartzite, is 0–800 m; the thickness of the McNamara is possibly as much as 2,300 m; and the McNamara overlies a very thick sequence of feldspathic quartzite that may include both Bonner and Mount Shields. This section of Missoula Group rocks may therefore be more than 7,000 m thick and, thus, much thicker than that at Argenta.

Missoula Group strata are also preserved 50 km north of Argenta in the Highland Mountains (fig. 1) (McMannis, 1963; O'Neill, in press), where they range from 16 m to 168 m thick (partially eroded beneath Flathead Quartzite) along an outcrop length of about 20 km. In the Highland Mountains, the Missoula Group consists largely of argillaceous quartzite, quartzite, and argillite. Except for being mostly gray rather than red, these strata are similar to those at Argenta, although the beds of arkose are less abundant. The difference in color may be metamorphic and related to thermal effects of the nearby Boulder batholith. Another difference between the Belt in the Highland Mountains and at Argenta is the presence in the Highland Mountains of a thick (1,000–3,000 m) sequence of middle and lower Belt rocks beneath the Missoula Group and their absence near Argenta.

Belt rocks are also exposed in small fault blocks in the Black Lion Mountain–Sheep Mountain area of the northeastern Pioneer Mountains (fig. 1). These rocks are interpreted to be lowermost Belt (R.C. Pearson and J.M. O'Neill, unpub. data). If Missoula Group rocks were ever deposited there, they were eroded before Cambrian strata were deposited on lower Belt, which is commensurate with the westward thinning of the Missoula Group in the Highland Mountains. The interpretation that these rocks are lower Belt differs from that of Zen (1988), who interpreted them to be partly of post-Belt age and partly Missoula Group rocks correlative with those a few kilometers to the west on the Grasshopper plate.

The locality nearest to Argenta where crystalline basement is known is in a petroleum test hole (American Quasar No. 27-22 Haganbarth) drilled about 16 km northeast of the Groundhog drill hole (fig. 3). Crystalline basement was encountered at a depth of 3,607 m (1,981 m below sea level) beneath sandstone and shale believed by Lopez and Schmidt (1985) to be Cambrian. If those Cambrian rocks were identified correctly, no Belt strata are present. W.J. Perry, Jr. (oral commun., 1993), however, interprets geophysical logs as possibly indicating a few tens of meters of Belt strata beneath Cambrian rocks. Cuttings from this well have not been examined to determine if rocks resembling the Belt Supergroup are actually present.

These examples of the presence and absence of Missoula Group and other Belt rocks in southwestern Montana, including the knowledge gained from the Groundhog drill core, suggest that the Argenta area is near the southern limit of extant autochthonous Belt rocks. That Belt strata older than Garnet Range Formation were deposited in the Argenta area and eroded prior to deposition of the Garnet Range cannot be proven, but such deposition of older Belt rocks seems unlikely. Lower and middle Belt strata are not known farther south than the Highland Mountains and the northeastern Pioneer Mountains. Those lower Belt rocks, particularly LaHood Formation, are interpreted as basin-margin deposits, and it is probable, therefore, that the lower and middle Belt was not deposited as far south as Argenta or the area of the present-day Tobacco Root Mountains and Ruby Range, despite the conclusions of Reynolds (1984) that the southern margin was that far south. The Missoula Group thins from several kilometers thick on the Grasshopper thrust plate to 220 m thick at the Groundhog drill hole and to near zero at the American Quasar Haganbarth drill hole 16 km northeast of the Groundhog drill hole. Thickness of the Missoula Group in the Highland Mountains is, at most, nearly as great as that at the Groundhog drill hole, but erosion prior to deposition of Flathead Quartzite caused thinning of the Missoula Group to as little as 16 m (O'Neill, in press) and may have affected the maximum thickness as well. Thus, Middle Proterozoic–Cambrian erosion could well be responsible for some of the variations in thickness of the Missoula Group observed in the region. Despite those uncertainties, however, the youngest Belt unit was deposited on pre-Belt basement, suggesting an onlap southern margin of the Belt Basin in southwestern Montana.

STRUCTURAL INTERPRETATION

Structural relations of the rocks exposed on the crest and east flank of the Humbolt Mountain anticline have been discussed by Shenon (1931), Myers (1952), Hobbs (1967), Brandon (1984), Ruppel and Lopez (1984), and Sears and others (1988), and depicted on a map by Ruppel and others (1993). The sequence of rocks at the Groundhog drill hole as described in this report, together with information derived from my recent field studies, helps to clarify structural relations and suggests modification of earlier conclusions. These new data show clearly that the Humbolt Mountain anticline is a basement-cored anticline similar to the Armstead anticline to the south (Lowell, 1965), the Biltmore anticline to the northeast (Schmidt and others, 1988), and numerous others in the foreland farther to the east. Many steep faults of various orientations break the rocks of the anticline, but all have small displacement and that displacement is mainly dip-slip. Previous interpretations of major through-going faults are not confirmed. It is much less clear if a blind thrust within the crystalline basement underlies the Humbolt Mountain anticline and the parallel folds in Frying Pan Basin to the east.

Mistakes in identification of stratigraphic units by previous workers have contributed to errors in interpretation of structure. The most notable example is a sequence of thin-bedded argillite and quartzite in the vicinity of the Midnight mine, which is about 670 m southwest of the Groundhog drill hole (fig. 2), that Shenon (1931) concluded was Proterozoic and was thrust against Paleozoic carbonate rocks. Myers (1952), Hobbs (1967), Brandon (1984), and Ruppel and Lopez (1984) concurred with Shenon's age assignment of these rocks. The rocks that Shenon identified as Proterozoic are green, gray, and red micaceous and sandy argillite and thin-bedded fine- to coarse-grained quartzite. This shaly interval is here reinterpreted as a Middle Cambrian unit, either Wolsey Shale or Silver Hill Formation; it will be referred to tentatively as Wolsey(?) Shale. Structurally, the Wolsey(?) near the Midnight mine is conformable between the Flathead(?) and overlying Cambrian dolostone, and hence, some of the faults mapped previously between these units are not required to explain juxtaposed units. Flathead(?) Quartzite in the area of the Midnight mine and the Groundhog drill hole has also been regarded as Proterozoic by Hobbs (1967), Brandon (1984), and Ruppel and others (1993). They included both the Flathead(?) and the Wolsey(?) with the Garnet Range Formation to form a combined Proterozoic unit, thereby making the eastern contact of the combined unit seem reasonably to be a through-going fault.

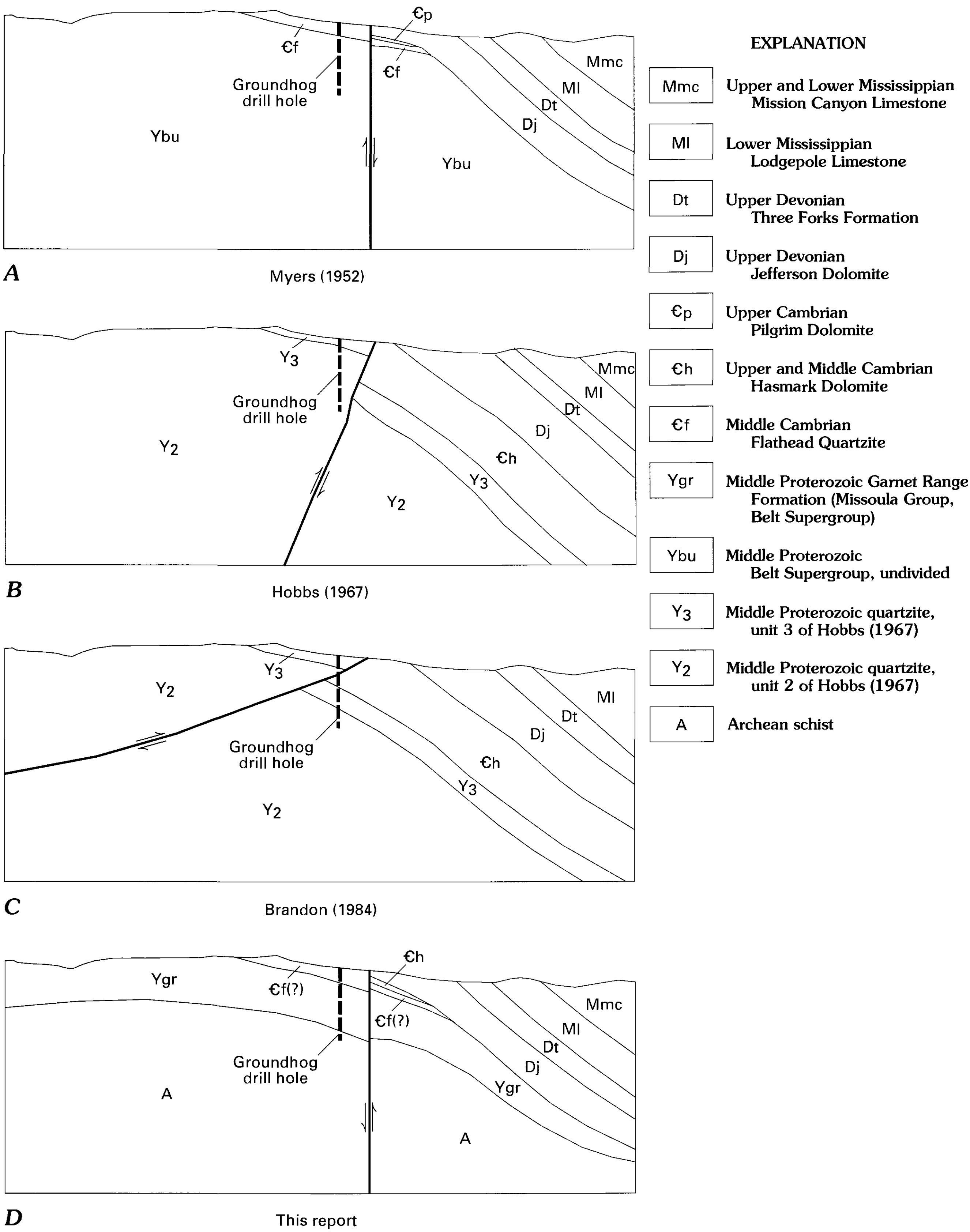


Figure 12. Diagrammatic cross sections illustrating several interpretations of the structure of the east flank of Humbolt Mountain anticline.

Myers (1952) also used the absence of the Flathead(?) and locally other Cambrian units in some fault blocks and their presence in others (as well as other arguments) as evidence for faulting, folding, and erosion in Cambrian time. Although not all of the evidence cited by Myers has been borne out by recent work, his principal conclusion is probably correct. North of the Groundhog drill hole, the Flathead(?) pinches out in a zone of faults, and, from there northward for about 3 km, Cambrian or Devonian dolostone is in depositional contact with Garnet Range Formation, or in some places, the contact may have been offset by steep faults of small displacement. Figure 12*A* is a diagrammatic representation of Myers' (1952) conclusions regarding the structure of the Humbolt Mountain anticline.

Hobbs (1967), who does not seem to have been aware of Myers' work and whose mapping is not as detailed as Myers', interpreted the east flank of the anticline to be broken by a through-going high-angle reverse fault whose trace is at the east edge of Proterozoic rocks, within which he included the Flathead(?) and Wolsey(?), as interpreted here, for the full length of the Humbolt Mountain anticline north of Argenta. Hobbs' interpretation is illustrated in Figure 12*B*.

Hobbs' inferred reverse fault is the same structure that Brandon (1984) later reinterpreted as a gently west-dipping thrust fault (fig. 12*C*) that he named the Argenta thrust. Brandon's interpretation was also expressed by Sears and others (1988). These reports (Hobbs, 1967; Brandon, 1984; Sears and others, 1988) assert that a fault exists at this contact but, except for a line on a map, present neither evidence nor arguments for its existence, nor do they attempt to counter Myers' conclusions regarding orogeny and resulting erosion, sedimentation, and unconformities during the Cambrian. Except for some details, Myers' interpretation is in accord with recent field observations and, with the exception of the misidentification of the Wolsey(?), fits best with the relations found in the Groundhog drill hole. The conclusions of Ruppel and others (1993) are similar to Hobbs' (1965) conclusions in the southern part, but they retained a thrust fault farther north along the east side of Humbolt Mountain at the position of Brandon's (1984) Argenta thrust.

The trace of the Argenta thrust—if such a structure exists—would be at the Groundhog mine 150 m east of the Groundhog drill hole, and, if gently west-dipping as implied by Brandon (1984), should be evident in the Groundhog drill core as an inverted age sequence in which Garnet Range Formation overlies Paleozoic strata. The lack of such evidence in the drill core or any other evidence for a thrust fault provides additional doubt for this fault's existence. The relations in the drill core and at the surface show that the Proterozoic rocks are very likely in their normal stratigraphic position between the Archean basement and Cambrian strata, as shown on fig. 12*D*, and are not riding on a thrust fault the same as, or similar to, the Kelley thrust a few kilometers to the west.

For similar reasons, the existence of the Ermont thrust, a structure proposed by Myers (1952) and discussed by Thomas (1981) to explain relations between Paleozoic and Cretaceous rocks near Ermont Gulch 3 km southwest of Argenta, is cast into doubt by the autochthonous relations in the Groundhog drill hole.

If thrust faults do exist in the sequence, the only alternatives for their location would seem to be bedding-parallel thrusts at some unknown positions in the rocks penetrated by the drill hole or a major decollement in the Archean basement at some depth below the bottom of the drill hole. Only the latter would seem to be likely in view of the strict parallelism of bedding and the complete absence of crumpling or minor folding in the core. Archean crystalline rocks core many anticlines in the foreland to the east, and they are also involved in thrust faulting in the region (DuBois, 1982; Schmidt and others, 1988). If such a decollement exists, its trace is unknown, and it may well be blind.

Except for the numerous high-angle faults of small displacement that break the rocks of the Humbolt Mountain anticline, the east flank of the anticline is homoclinal and passes eastward into the Cave Gulch syncline and, beyond that, into other folds in Frying Pan Basin (fig. 1) that trend north and parallel to the Humbolt Mountain anticline.

Between the American Quasar Haganbarth drill hole and the Groundhog drill hole, a distance of 16 km, structural relief on the basement surface is 3,817 m. The elevation of the surface rises from 1,980 m below sea level in the Haganbarth drill hole to 1,837 m above sea level in the Groundhog drill hole. Thus, between these two points the surface dips east at an average angle of 13.4°. Not being aware of the Groundhog drill hole, Lopez and Schmidt (1985) inferred a westward dip of the surface from east of the Haganbarth drill hole to the west and continuing at increasing depth beneath the thrust belt. This is clearly not the case unless the increase in elevation of the surface west of the Haganbarth drill hole is the result of thrusting within the basement and the surface continues to dip west in the lower plate of such a thrust.

REFERENCES CITED

Brandon, W.C., 1984, An origin for the McCartney's Mountain salient of the southwestern Montana fold and thrust belt: Missoula, University of Montana M.S. thesis, 128 p.

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

DuBois, D.P., 1982, Tectonic framework of basement thrust terrane, northern Tendoy Range, southwest Montana, *in* Powers, R.B., ed, Geologic Studies of the Cordilleran Thrust Belt, Volume 1: Denver, Colo., Rocky Mountain Association of Geologists, p. 145–158.

Geach, R.D., 1972, Mines and mineral deposits (except fuels), Beaverhead County, Montana: Montana Bureau of Mines and Geology Bulletin 85, 193 p.

Harrison, J.E., 1972, Precambrian Belt Basin of northwestern United States—Its geometry, sedimentation, and copper occurrences: Geological Society of America Bulletin, v. 83, p. 1215–1240.

Harrison, J.E., and Grimes, D.J., 1970, Mineralogy and geochemistry of some Belt rocks, Montana and Idaho: U.S. Geological Survey Bulletin 1312–O, 49 p.

Hobbs, B.B., 1967, Structure and stratigraphy of the Argenta area, Beaverhead County, Montana: Corvallis, Oregon State University M.S. thesis, 164 p.

James, H.L., 1990, Precambrian geology and bedded iron deposits of the southwestern Ruby Range, Montana: U.S. Geological Survey Professional Paper 1495, 39 p.

Lopez, D.A., and Schmidt, Christopher, 1985, Seismic profile across the leading edge of the fold and thrust belt of southwest Montana, *in* Gries, R.R., and Dyer, R.C., eds., Seismic Exploration of the Rocky Mountain Region: Rocky Mountain Association of Geologists and Denver Geophysical Society, p. 45–50.

Lowell, W.R., 1965, Geologic map of the Bannack-Grayling area, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–433, scale 1:31,680.

McMannis, W.J., 1963, La Hood Formation—A coarse facies of the Belt Series in southwestern Montana: Geological Society of America Bulletin, v. 74, p 407–436.

Myers, W.B., 1952, Geology and mineral deposits of the northwest quarter of the Willis quadrangle and adjacent Brown's Lake area, Beaverhead County, Montana: U.S. Geological Survey Open-File Report 147, 46 p., 2 pls.

Nelson, W.H, and Dobell, J.P., 1961, Geology of the Bonner quadrangle, Montana: U.S. Geological Survey Bulletin 1111–F, p. 189–235.

O'Neill, J.M., in press, Table Mountain Quartzite and Moose Formation (new names) and associated rocks of the Middle Proterozoic Belt Supergroup, Highland Mountains, southwestern Montana: U.S. Geological Survey Bulletin 2121–A.

Pettijohn, F.J., 1957, Sedimentary Rocks: New York, Harper, 718 p.

Reynolds, M.W., 1984, Tectonic setting and development of the Belt Basin, Northwestern United States, *in* Hobbs, S.W., ed. The Belt: Montana Bureau of Mines and Geology Special Publication 90, p. 44–46.

Ruppel, E.T., and Lopez, D.A., 1984, The thrust belt in southwest Montana and east-central Idaho: U.S. Geological Survey Professional Paper 1278, 41 p.

Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1°×2° quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1803–H, scale 1:250,000.

Schmidt, C.J., O'Neill, J.M., and Brandon, W.C., 1988, Influence of Rocky Mountain foreland uplifts on the development of frontal fold and thrust belt, southwestern Montana, *in* Schmidt, C.J., and Perry, W.J., eds., Interaction of the Rocky Mountain Foreland and the Cordilleran Thrust Belt: Geological Society of America Memoir 171, p. 171–201.

Sears, J.W., Johnson, L.M., Geiger, B.C., and Brandon, W.C., 1988, Southwest Montana thrust belt: Bannack to Melrose, *in* Link, P.K., and Hackett, W.R., eds., Guidebook to the Geology of Central and Southern Idaho: Idaho Geological Survey Bulletin 27, p. 305–319.

Shenon, P.J., 1931, Geology and ore deposits of Bannack and Argenta, Montana: Montana Bureau of Mines and Geology Bulletin 6, 77 p.

Thomas, G.M., 1981, Structural geology of the Badger Pass area, southwest Montana: Missoula, University of Montana M.S. thesis, 58 p.

Wallace, C.A., 1987, Generalized geologic map of the Butte 1°×2° quadrangle, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–1925, scale 1:250,000.

Wallace, C.A., Lidke, D.J., Elliott, J.E., Desmarais, N.R., Obradovich, J.D., Lopez, D.A., Zarske, S.E., Heise, B.A., Blaskowski, M.J., and Loen, J.S., 1992, Geologic map of the Anaconda-Pintlar Wilderness and contiguous roadless area, Granite, Deer Lodge, Beaverhead, and Ravalli Counties, western Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF–1633–C, scale 1:50,000.

Winston, Don, and Lonn, Jeff, 1988, Road Log No. 1: Structural geology and Belt stratigraphy of the Tarkio area, Montana, *in* Weidman, R.M., ed, Guidebook of the Greater Missoula Area: Missoula, Montana, Tobacco Root Geological Society 13th Annual Field Conference, p. 1–34.

Winston, Don, and Wallace, C.A., 1983, The Helena Formation and the Missoula Group at Flint Creek Hill, near Georgetown Lake, western Montana, *in* S.W. Hobbs, ed., Guide to field trips: Belt Symposium II, Missoula, Montana, p. 66–81.

Zen, E-an, 1988, Bedrock geology of the Vipond Park 15-minute, Stine Mountain $7^1/_2$-minute, and Maurice Mountain $7^1/_2$-minute quadrangles, Pioneer Mountains, Beaverhead County, Montana: U.S. Geological Survey Bulletin 1625, 49 p.

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Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales, they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. The series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; the principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

Catalogs

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