The Prichard Formation of the Lower Part of the Belt Supergroup (Middle Proterozoic), near Plains, Sanders County, Montana

U.S. GEOLOGICAL SURVEY BULLETIN 1553

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By EARLE R. CRESSMAN

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The Prichard Formation in western Montana is divided into eight informal members and its internal stratigraphy, depositional environments, and depositional history are discussed

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THE PRICHARD FORMATION OF THE LOWER PART OF THE BELT SUPERGROUP (MIDDLE PROTEROZOIC) NEAR PLAINS, SANDERS COUNTY, MONTANA

By EARLE R. CRESSMAN

ABSTRACT

The Prichard Formation, about 6,000 m thick near Plains, Montana, is the basal unit of the Belt Supergroup. The Prichard consists mostly of interlaminated and very thinly interbedded siltite and argillite that commonly occur as graded couplets. Quartzite is a minor constituent. The formation has been metamorphosed to the biotite zone of the greenschist facies. Several dioritic to gabbroic sills, one nearly 400 m thick, are intercalated in the section. The Prichard is no younger than 1,330 m.y. (million years) and no older than 1,700 m.y.

The Prichard Formation is divided into eight informal members designated A through H from base to top. Member A, 600 m thick, consists of interlaminated and very thinly interbedded argillic siltite and silty argillite. Member B, 1,000 m thick, is similar to member A but contains abundant slump folds. Attitudes of slump-fold axial planes and facing directions of beds in the folds indicate that slumping was mostly eastward. Member C, 75–110 m thick, is mostly argillic quartzite in beds 0.4–0.6 m thick. Most of the quartzite beds grade to argillite in their upper part. Member D is 290 m thick and is characterized by platy-weathering olive-gray silty argillite that becomes more silty up section. Member E, 825 m thick, consists of interlaminated siltite and argillite and some interbedded quartzite. Mud cracks, mud-chip breccia, scour-and-fill structures, and lenticular and irregular laminae typify the siltite-argillite. The quartzites are commonly crossbedded and discontinuous.

The contact between member E and F is sharp. The section from this contact to the top of the formation is more argillic than the section below the contact.

Member F, mostly 975–1,100 m thick, is interlaminated and very thinly interbedded silty argillite and argillite. Pyrite laminae are conspicuous in some intervals. Argillite-pebble conglomerate is present locally in the lower part of the member. Member G, 500 m thick, is characterized by quartzite that is interbedded with siltite and argillite. Member H, about 1,600 m thick, is similar to member F but becomes more argillic upward. Pyrite laminae are present only near the base.

The contact between the Prichard Formation and the overlying Burke Formation is placed for this report at the lowest occurrence of beds containing structures indicative of shallow-water deposition. This contact is about 500 m lower in the section than the traditional contact, which is the highest occurrence of argillites typical of the Prichard.

Argillite-clast breccia occurs (1) as tabular bodies as much as 600 m thick that cross the bedding at low angles and (2) along high-angle faults. The first type probably formed along the sole of a major shelf-edge slump. The origin of the second type is not known.

The Prichard Formation was probably deposited by a major river system on continental crust stretched and thinned in the early stages of continental separation. Depositional environments ranged from lower slope at depths of perhaps 1,000 m or more to the intertidal zone. Members A through E resulted from one basin-filling progradation and members F through H and the basal Burke Formation from a second.

INTRODUCTION

The Prichard Formation, the lowest unit of the Belt Supergroup of Middle Proterozoic age, was named by Ransome and Calkins (1908, p. 23, 24, 29–32) for Prichard Creek in the northern part of the Coeur d'Alene mining district, Shoshone County, Idaho (fig. 1). They gave the thickness as exceeding 8,000 ft (2,440 m) and described the formation as follows (Ransome and Calkins, 1908, p. 23).

It is a very thick accumulation of sediments, composed in greater part of argillite (indurated mud), regularly banded in lighter and darker shades of blue gray. The weathered surface is commonly stained with reddish-brown oxide of iron. The formation comprises also some gray indurated sandstone, which occurs at various horizons, but is especially abundant near the top.

Calkins (1909) subsequently identified the Prichard Formation in a number of areas in northern Idaho and northwestern Montana. One of these areas was in Sanders County, Mont., near the town of Plains and in the area considered in this report.

In British Columbia the equivalent of the Belt Supergroup is termed the Purcell Supergroup. In 1912, Schofield, working in the Purcell Mountains, named the lowest unit of the Purcell Supergroup as the Aldridge Formation and correlated it with the Prichard Formation of Montana and Idaho (Schofield, 1914). He described the Aldridge as consisting of rusty-weathering heavy- and thin-bedded argillaceous quartzite and slate that contain numerous sills of gabbro; the thickness was estimated as 1,830 m (Schofield, 1914, p. 221).

In 1892, the Sullivan deposit—subsequently one of the world's major producers of lead-zinc-silver ore—was discovered in rocks that Schofield later included in the Aldridge Formation (Ethier and others, 1976, p. 1570). The orebody, which is stratiform, was long considered to be an epigenetic hydrothermal deposit (Freeze, 1966, p. 264), but evidence indicating a syngenetic origin has been accumulating over the past decade. Geochemical and geologic data suggest that the metals were leached from the sedimentary pile by chloride-rich brines of meteoric derivation (Thompson and Panteleyev, 1976), and isotopic data indicate that the sulfur was derived from sea water (Campbell and others, 1978, p. 267). Thompson and Panteleyev (1976) and Campbell, Ethier, Krouse, and Both (1978, p. 267) suggested that the Sullivan orebody is analogous to the sulfide deposits now forming

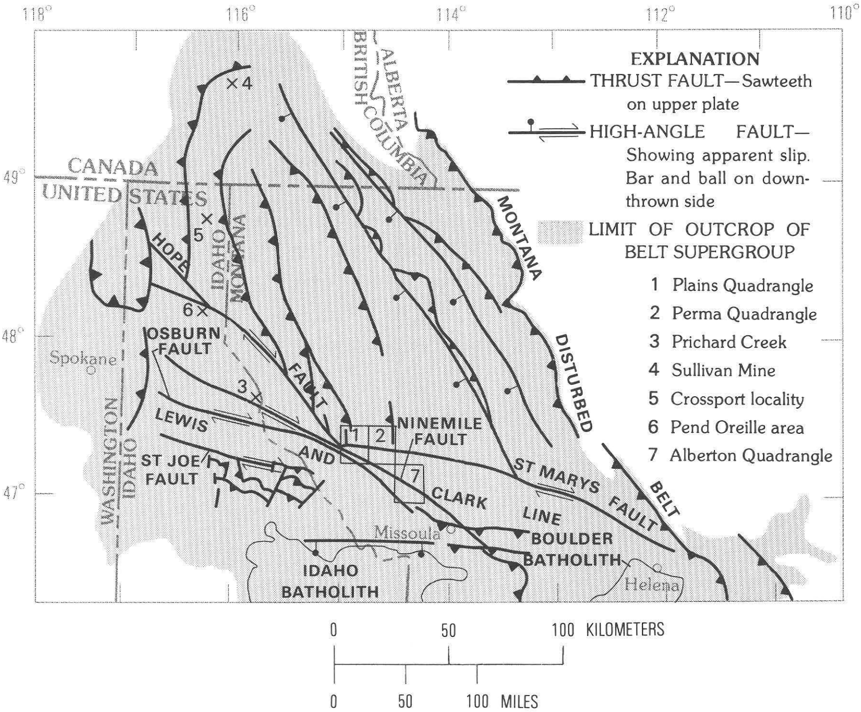


FIGURE 1.—Area of Belt terrane showing principal faults and localities mentioned in text. Modified from Harrison (1972, fig. 1) and from Harrison, Kleinkopf, and Wells (1980, fig. 2).

in the Red Sea. These new concepts have stimulated interest in other areas in which the Aldridge and Prichard Formations are exposed. Were the depositional environments elsewhere such as to have favored deposition of syngenetic sulfides?

The Prichard Formation near Plains, Mont., was reported by Wallace and Hosterman (1956, p. 579) to be at least 17,000 ft (5,700 m) thick, making it one of the thickest known exposures of the formation. Furthermore, the Plains and Perma quadrangles are within the Wallace 1°×2° topographic quadrangle which is being studied by the U.S. Geological Survey as part of the Conterminous United States Mineral Appraisal Program. Thus, the area seemed an appropriate one in which to initiate studies of the Prichard.

This report discusses the internal stratigraphy, the depositional environments, and the depositional history of the Prichard Formation in the Plains area. Data from these studies have been applied to the evaluation of the resource potential for Sullivan-type deposits in the folio for the Wallace 1°×2° quadrangle (Harrison and others, in press).

METHODS

The fieldwork on which this report is based was conducted in the summers of 1979 and 1980. The Prichard Formation in the Plains and Perma quadrangles (fig. 2) was subdivided into mappable units, and the sequence and distribution of these units were determined by mapping. The geologic map of that part of the area west of the Flathead Indian Reservation has been released (Cressman, 1981). The base maps were the 1:62,500 topographic maps of the 15-minute Plains and Perma quadrangles, both with a contour interval of 80 ft. Unit thicknesses were for the most part measured from the geologic map, and the generalized stratigraphic section (fig. 3) was constructed from mapping traverses. Stratigraphic sections of several critical intervals were measured by compass and tape or by compass and pace. Field studies were supplemented by the binocular examination of hand specimens, and about 60 thin sections were examined.

I was ably assisted in the summer of 1980 by Peter G. DeCelles who measured most of the slump-folds.

GEOGRAPHIC SETTING

The study area is in southern Sanders County, Mont., approximately 75 km west of Missoula, Mont., and 200 km east-southeast of Spokane, Wash. (fig. 1). It is centered about the junction of the Flathead River with the Clark Fork (fig. 2). The area is mountainous with a total relief of 1,425 m. The mountains within the bend of the Clark Fork and south of the Flathead River are the eastern part of the Coeur d'Alene Mountains, whereas those to the north are generally considered a southeastward extension of the Cabinet Mountains.

Much of the mountainous area is forested, and the Prichard Formation is best exposed in steep valley walls along the two rivers. These exposures can be examined only with considerable difficulty, but excellent exposures may be seen in cuts along Montana Highway 135 and along the Burlington Northern Railroad. Good access to the mountains is provided by gravel and dirt roads up most of the tributary valleys and by logging roads.

STRUCTURAL SETTING

The Plains and Perma quadrangles areas are on the north edge of the Lewis and Clark line of Billingsley and Locke (1939, p. 36; fig. 1), which they defined as a northwest-trending zone of tear faults that extends from just north of Yellowstone National Park to Spokane. Major tear faults within the line exhibit right-lateral strike-slip of 10–30 km (Harrison and others, 1974, p. 12, 13). The St. Mary's fault,

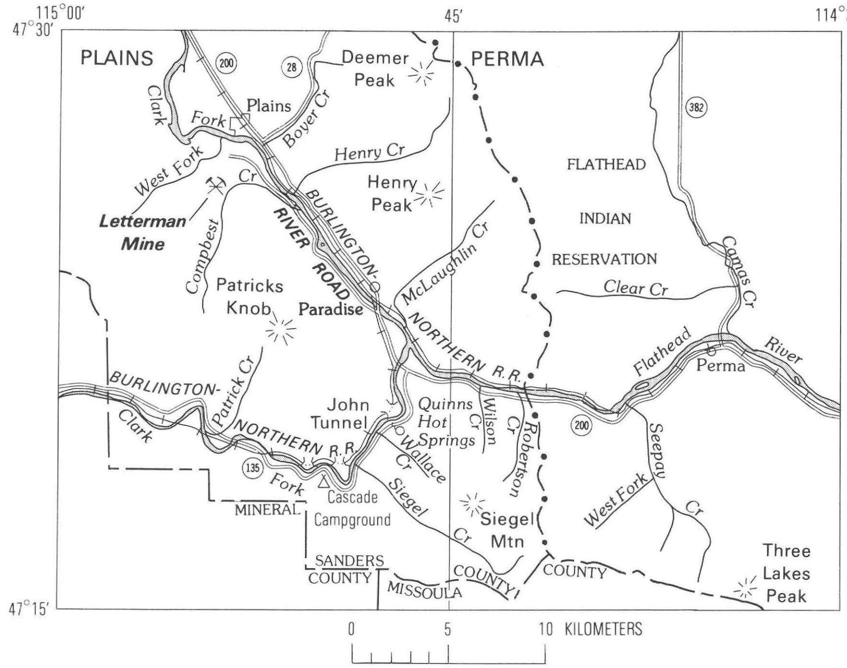


FIGURE 2.—Index map of the Plains and Perma quadrangles.

which crosses the Plains and Perma quadrangles from west to east, has been estimated to have an apparent right-lateral movement of 13 km (Harrison and others, 1974, p. 12). Within the study area, differences across the St. Mary's fault in the stratigraphic position of one of the sills in the Prichard Formation indicates at least 18 km of movement.

The rocks both north and south of the St. Mary's fault have been folded and faulted. Within the study area the folds are moderately tight, and dips commonly range from 35° to 50°. Most faults strike northwest and are of unknown but probably small displacement. Nearly all of the faults dip greater than 75°, and most are nearly vertical.

The Lewis and Clark line has had a long and complex structural history (Weidman, 1965; Harrison and others, 1974, Reynolds and Kleinkopf, 1977). Some faults apparently moved during Belt time (Chevillon, 1977), and some moved as recently as late as Tertiary (Harrison and others, 1974, p. 13).

STRATIGRAPHIC SETTING

The study area is near the center of the Belt basin, and the Belt Supergroup attains its greatest thickness in this vicinity (Harrison, 1972, fig. 3). The base of the Prichard Formation, which also is the base of the Belt, is not exposed, but nearly 7,000 m of Prichard (including the intruded sills) are present in the area. I have not studied the overlying rocks, but they have been described by Wells (1974) in the nearby Alberton quadrangle where the post-Prichard Belt rocks are 13,250 m thick. Thus, the total thickness of the Belt Supergroup in this area is about 20,000 m.

The Prichard Formation is directly overlain by the Ravalli Group, which in the Alberton quadrangle is 4,050 m thick. The Ravalli comprises from base to top, the Burke, Revett, St. Regis, and Empire Formations. The Revett is mostly quartzite; whereas, the other formations are mostly argillite and siltite. The Ravalli Group has been studied by Hrabar (1973), who concluded that it had accumulated as a subsea fan system that prograded from the south, and by Kopp (1973), who interpreted it as having been deposited as a tide-dominated delta.

The Ravalli Group is overlain by the Helena Formation to the east and the equivalent Wallace Formation to the west. In the Alberton quadrangle the Helena (or Wallace) is 3,050 m thick and consists of dolomite with some calcitic siltite and argillite. Stromatolites in the dolomite attest to deposition in shallow water.

The Helena and Wallace Formations are overlain by the Missoula Group, which is about 6,150 m thick in the Alberton quadrangle where the group is composed of the Miller Peak Formation, Bonner Quartzite, McNamara Formation, Garnet Range Formation, and Pilcher Quartzite, respectively, from bottom to top. The Missoula Group consists mostly of red and green argillite and red to pink and light-gray quartzite. The rocks contain mud cracks, mud-chip breccia, ripple marks, and cross lamination, all indicative of deposition near sea level. Winston (1973) concluded that the lower part of the Missoula Group was deposited as a braided stream and sea-margin complex. The Missoula Group is the uppermost component of the Belt Supergroup and is overlain unconformably by quartzite of Cambrian age (Harrison and Campbell, 1963, p. 1423).

PRICHARD FORMATION

GENERAL CHARACTER

The Prichard Formation in the study area is, with sills included, a maximum of about 7,000 m thick. The preponderant rock type is interlaminated to very thinly interbedded siltite and argillite that occur mostly as graded couplets. Quartzite is a minor part of the section but forms several fairly conspicuous mappable units. The upper half of the formation is noticeably more argillic than the lower half. Freshly broken rock is mostly laminated or banded dark and light gray, but nearly the entire section weathers moderate brown, the rusty color that is typical of the Prichard throughout the Belt basin. Dioritic to gabbroic sills, four of which are thick enough to map at the scale of 1:62,500, are intercalated in the section.

The average mineralogic composition, in percent, of the three principal rock types in the Prichard Formation as determined by Harrison and Jobin (1963, table 1) by X-ray diffraction of samples from the Pend Oreille area of northern Idaho are as follows:

	No. of samples	Quartz	Albite-oligoclase	Potassium feldspar	Sericite	Chlorite	Biotite
Argillite	11	30	19	Trace	23	8	10
Siltite	7	41	24	2	20	4	9
Quartzite	6	63	21	Trace	9	5	2

Considering the remarkable continuity of Belt rocks demonstrated by Harrison and Grimes (1970), these compositions are probably similar to those of the same rock types in the Prichard in the area of this present report.

METAMORPHISM

The Belt Supergroup has been subjected to weak regional metamorphism throughout most of the basin, and rocks of the Prichard Formation are in the biotite zone of the greenschist facies. In the Alberton quadrangle the biotite isograd is near the base of the Missoula Group (Wells, 1974); in the Pend Oreille area the isograd is at the top of the Burke Formation (Harrison and Jobin, 1963, p. K26).

Biotite occurs throughout the Prichard Formation as anhedral flakes that average about 40 μm (micrometers) in diameter. Biotite is generally more abundant in argillic siltite laminae and beds than in the argillite, and biotite is at least partly responsible for the generally dark color of the siltite layers. Well-sorted siltite layers contain little biotite and are lighter colored than the argillite.

The mineral commonly identified as sericite in the Prichard has been determined by Maxwell and Hower (1967) in the Pend Oreille area and by Wells (1974) in the Alberton quadrangle to be the *2M* polymorph of illite. The *2M* illite was converted from $1M_d$ illite, the common clay mineral in the upper part of the Belt (Maxwell and Hower, 1967). In the study area, both the grain size and the disorientation of the sericite increase down section. In the upper part of the

Prichard the flakes average less than 10 μm long and few exceed a length of 20 μm; whereas, in the oldest rocks the flakes average at least 20 μm in length and may exceed 40 μm. The sericite is distinctly though imperfectly oriented parallel to bedding in the upper part of the section, but no orientation is apparent in the basal part. Both the increasing grain size and increasing disorientation are sufficient to affect the megascopic appearance of the rock, and samples from the top and base of the Prichard can be distinguished on that basis alone.

Randomly oriented porphyroblasts of chlorite are common in the middle third of the Prichard and occur as poikiloblastic laths as much as several millimeters long. Garnet is not common but occurs in a few beds in the lower part of the section. The highest occurrence of garnet is about 4,270 m below the top of the formation. Quartz and feldspar grains in the quartzite are so sutured that it is difficult to estimate what the original grain sizes might have been.

AGE

The maximum possible age of the Prichard Formation is that of the pre-Belt crystalline basement of Montana and Alberta. The major metamorphic event that affected the pre-Belt basement of southwest Montana was at 2,730±85 m.y. (million years) (James and Hedge, 1980), but the isotopic clocks were reset by a thermal event at 1,600±100 m.y. (Giletti, 1966). In Alberta, K-Ar dates on biotite indicate that the basement was consolidated from 1,650 to 1,850 m.y. ago (Burwash and others, 1962).

A minimum age of the Prichard Formation is given by the 1,330±45 m.y. K-Ar date determined by Obradovcich and Peterman (1968, p. 745) for metamorphic biotite in the Prichard in the Alberton quadrangle. A similar age, 1,335 m.y., was determined by the Rb-Sr method for the Hellroaring Creek stock that intrudes the Aldridge Formation, which is the equivalent of the Prichard in southeastern British Columbia (Ryan and Blenkinsop, 1971). More recently, Zartman and others (1982) have determined a U-Pb age of 1,433±30 m.y. for zircon in a sill in the Prichard Formation in the Crossport area of northern Idaho. The sill is apparently near the base of rocks that in British Columbia would be referred to the middle member of the Aldridge Formation. The equivalent position in the section near Plains would probably be within member F of the Prichard. The sill may have been, and probably was, intruded during deposition of the upper part of the Prichard, so the date may not be taken as a minimum age of the formation, but it certainly indicates that most of the Prichard was deposited prior to 1,433 m.y. ago.

Taking 1,300 m.y. ago and 1,700 m.y. ago as the minimum and maximum permissible ages of the Prichard Formation gives a time span of 370 m.y., during which the formation could have been deposited. This is longer than the entire Paleozoic. If 1,433 m.y. is taken as the minimum, the time span is nearly 270 m.y., which is greater than the combined length of the Mesozoic and Cenozoic. The inability to be more precise about the time at which the Prichard Formation was deposited and the time span during which it was laid down severely inhibit interpretations.

SUBDIVISIONS

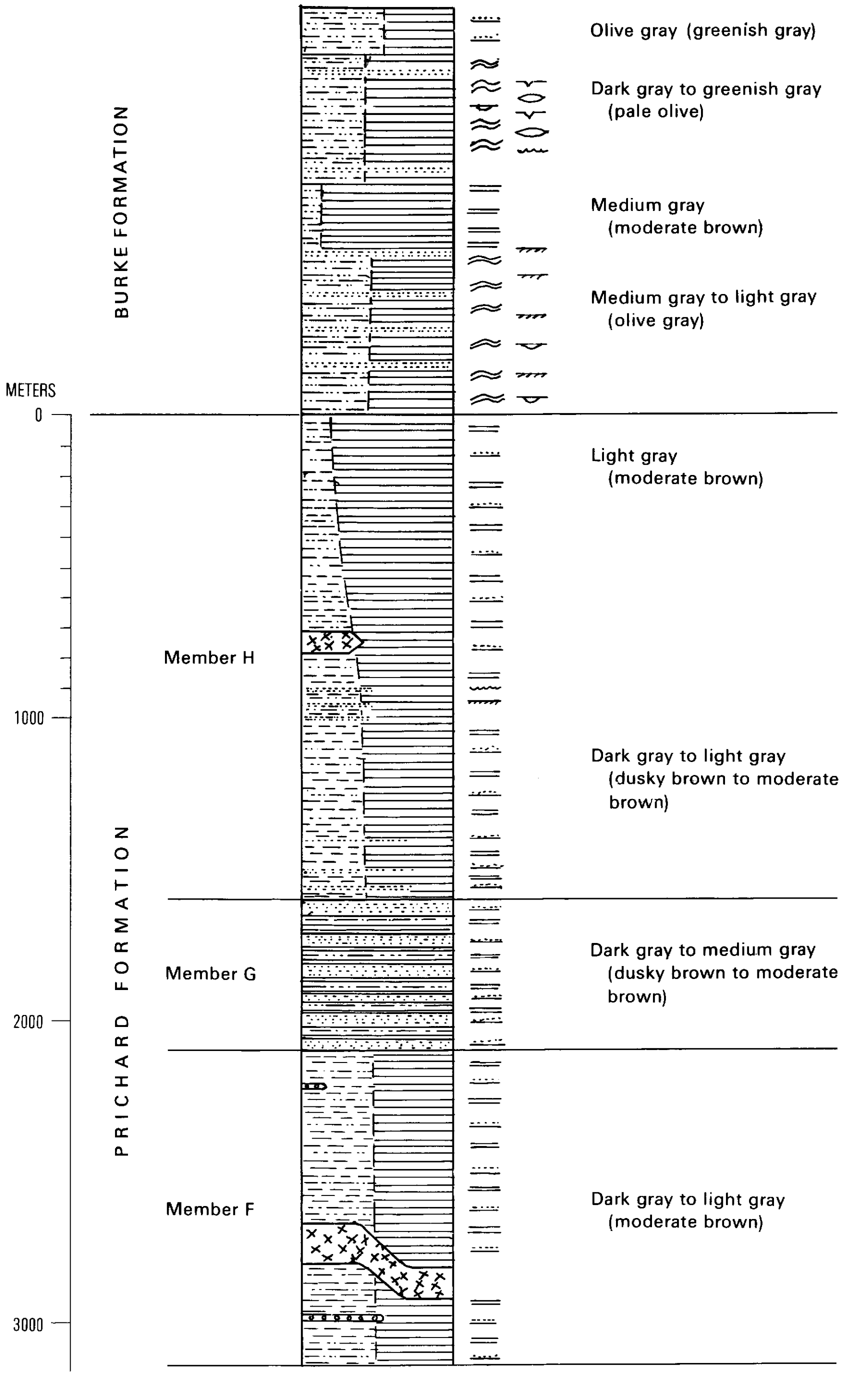
INTRODUCTION

In this report the Prichard Formation is divided into eight informal members that are recognizable throughout the two quadrangles. These members are illustrated in the generalized section of figure 3 and are described herein. Even though all the members are mappable at a scale of 1:62,500, they are considered informal and are designated members A through H from base to top. If future work shows these members to be recognizable and useful in other parts of the Belt basin, they can then be named and given formal status either as members or as formations within a group.

MEMBER A

The lowest member of the Prichard Formation is exposed in the valley wall just northeast of the confluence of the Flathead River with the Clark Fork and on both sides of Seepay Creek in the Flathead Indian Reservation. The member consists of interlaminated and very thinly interbedded argillic siltite and silty argillite. The siltite layers, mostly dark gray and from several millimeters to several centimeters thick, commonly grade upward into light-gray silty argillite layers that also range from several millimeters to several centimeters in thickness. The thicker siltite layers themselves may consist of graded siltite-argillite couplets 0.5–3 mm thick. Some siltite laminae and beds are well sorted, light colored, and cross-laminated, and their basal contact may channel several millimeters into the underlying bed. These siltite layers tend to be concentrated in certain intervals. A cut along a logging road southeast of the mouth of McLaughlin Creek exposes an angular unconformity of a few degrees. The unconformity may have resulted from slumping of the underlying beds or, more probably, from a brief period of submarine erosion.

The base of member A is the base of exposures. The top is placed at the base of the lowest diabase sill. As so defined, the member is about 600 m thick. Member A differs from member B chiefly in that slump folds and slump sheets are common and conspicuous in



BURKE FORMATION
PRICHARD FORMATION
METERS
0
1000
2000
3000
Member H
Member G
Member F
Olive gray (greenish gray)
Dark gray to greenish gray (pale olive)
Medium gray (moderate brown)
Medium gray to light gray (olive gray)
Light gray (moderate brown)
Dark gray to light gray (dusky brown to moderate brown)
Dark gray to medium gray (dusky brown to moderate brown)
Dark gray to light gray (moderate brown)

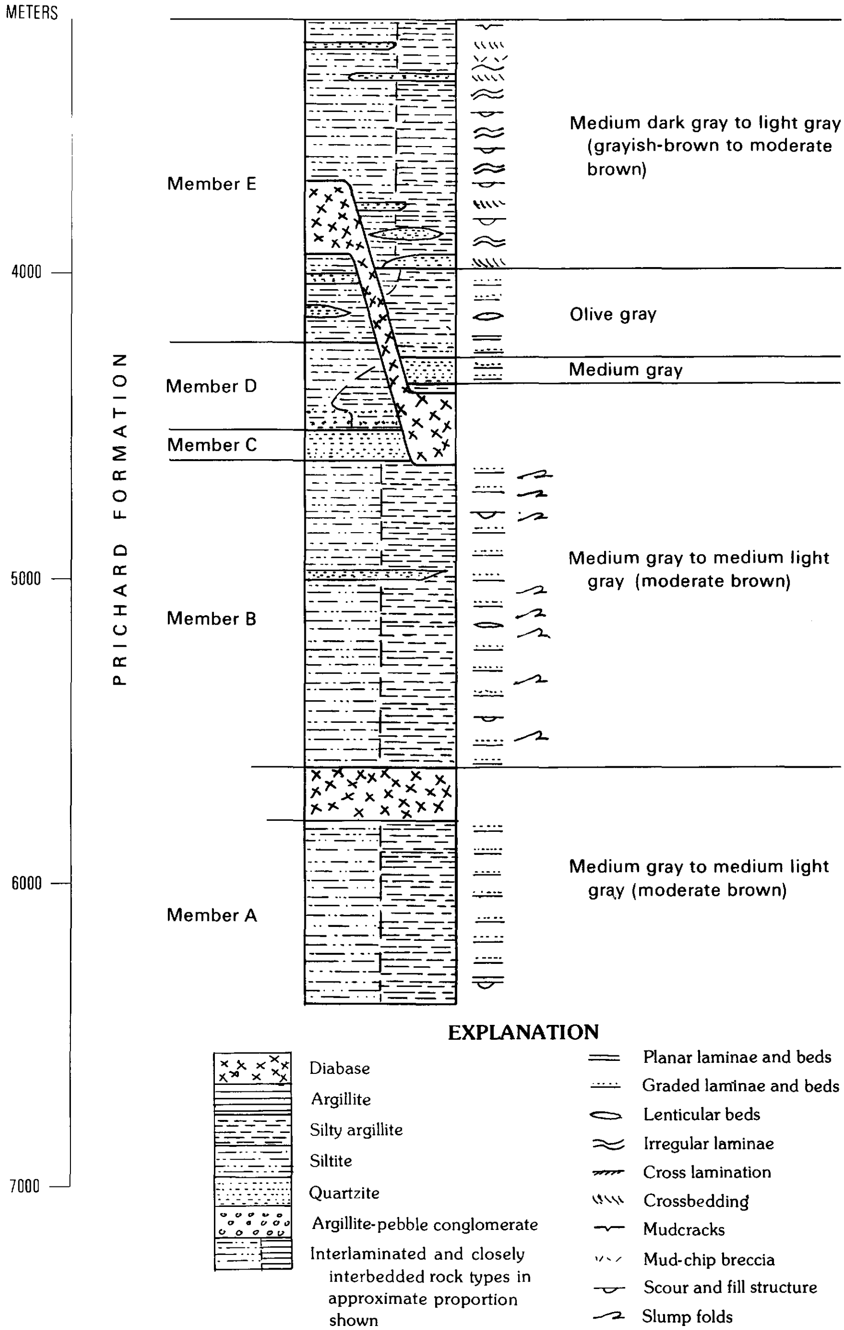


FIGURE 3.—Generalized stratigraphic section of the Prichard Formation in the Plains and Perma quadrangles. Weathering color in parentheses. Datum top of Prichard Formation.

member B but not in member A. I do not know whether or not the two units could be mapped separately by this criterion in the absence of the sill.

Member A is best exposed along the railroad southeast of McLaughlin Creek, along a logging road that ascends the mountain front east of the mouth of McLaughlin Creek, and along logging roads on both sides of Seepay Creek.

MEMBER B

Member B is similar to member A in that it consists nearly entirely of interlaminated and very thinly interbedded siltite and argillite that commonly occur as graded couplets (fig. 4). Member B also contains some zones in which light-colored, well-sorted, cross-laminated siltite layers are common. However, member B differs from member A in that it contains abundant sedimentary slumps and some quartzite.

The base of member B is the top of the lowest diabase sill and the top is at the base of a quartzite unit 75–110 m thick that constitutes member C. The thickness of the member as so defined is uncertain because of faulting. The best estimate, 1,000 m, is based on exposures on the west side of McLaughlin Creek and on both sides of Seepay Creek. It is possible that the lowest sill may change position over the area with a resulting change in thickness of the member, but there is no horizon with which the position of the sill can be readily compared.

SLUMP FOLDS

Slump folds were defined by Helwig (1970, p. 174) as "* * * prelithifaction folds attributed to gravity-induced horizontal mass movement and deformation of one or more beds in a coherent slump mass." The slump folds in the Prichard Formation are not very photogenic, but two are illustrated in figures 5 and 6. Several characteristics of these features in member B that demonstrate their syndepositional rather than tectonic origin are (1) the slump folds occur in packets underlain and overlain by undeformed beds; (2) there is no axial-plane cleavage; (3) the orientation of the slump-fold axes has considerable spread and has no obvious relation to the trends of tectonic folds and faults.

The amplitude of individual slump folds is mostly 0.3–0.5 m though some may be as large as 10 m. The folds are mostly isoclinal, nearly recumbent, and have a slip surface separating the lower limb from beds below. Though some folds occur singly, most are in composite slump sheets in which individual folds are piled one on another. The

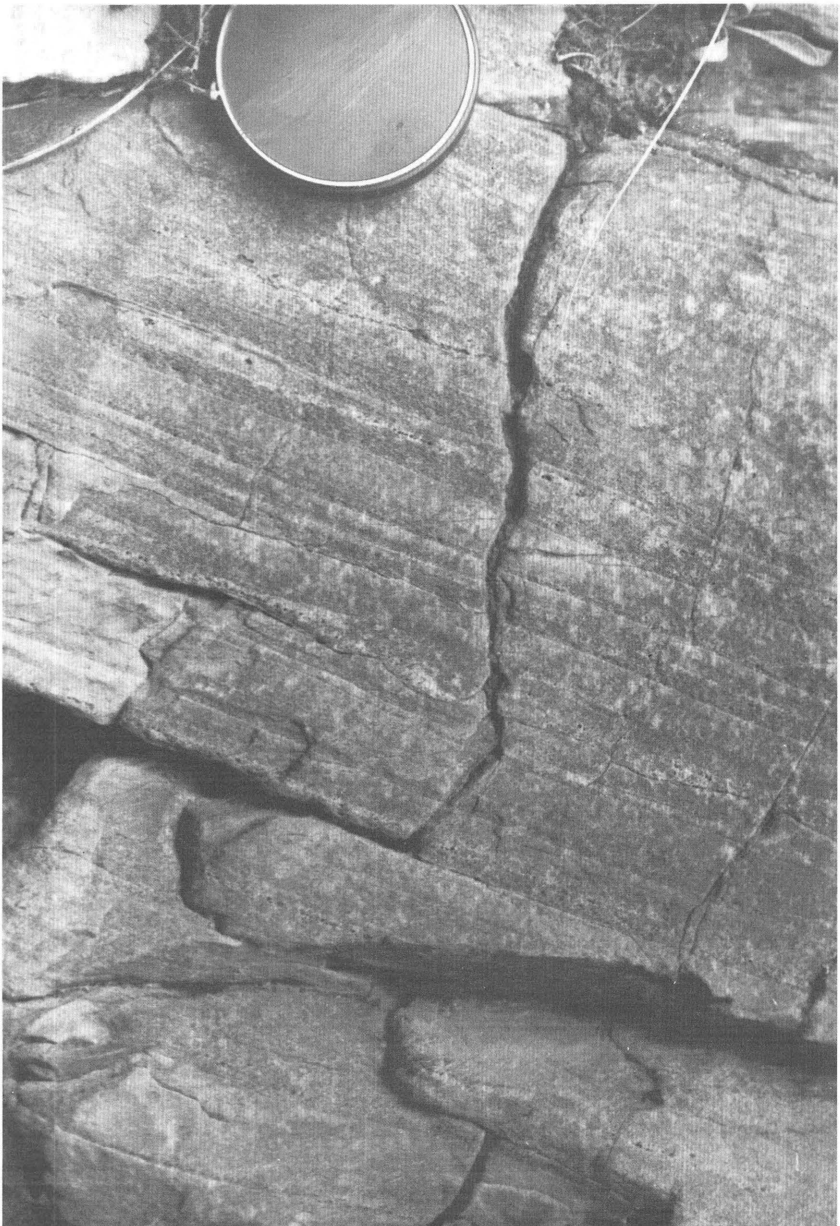


FIGURE 4.—Graded siltite-argillite couplets in member B. Dark layers are siltite, light layers argillite. Lens cap is 5 cm in diameter.

FIGURE 5.—Slump fold in member B. Exposed in roadcut on Montana Highway 135 1.6 km south of junction with Montana Highway 200.

fold illustrated in figure 6 is part of the composite slump sheet sketched in figure 7. The sheets may be as thick as 30 m, but more commonly they are about 8 m thick. The inclinations of the slump-fold axial planes commonly increase from base to top of the slump sheet. This is the case with the slump sheet of figure 7. Beds at the base of some slumps have been disrupted, and the segments have been rolled into balls.

Though slump folds are common and conspicuous in member B, their actual abundance is difficult to assess. Slumped beds make up about 15 percent of one well-exposed section that is 285 m thick and near the middle of the member. The slumps are not evenly distributed throughout the member but seem to be most common in the 100 m just below a quartzite unit near the middle of the member and in the uppermost few hundred meters. I have not noticed any irregularities in the geographical distribution of the slumps.

Slump folds are well exposed along Montana Highway 135 1.6 km south of its intersection with Montana Highway 200, along the River Road 3.2 km west-northwest of Paradise, and in the relatively new roadcuts along Montana Highway 200 west of Seepay Creek. The most spectacular exposure, illustrated in part by figure 7, is in roadcuts along Montana Highway 200 immediately east of Robertson Creek.

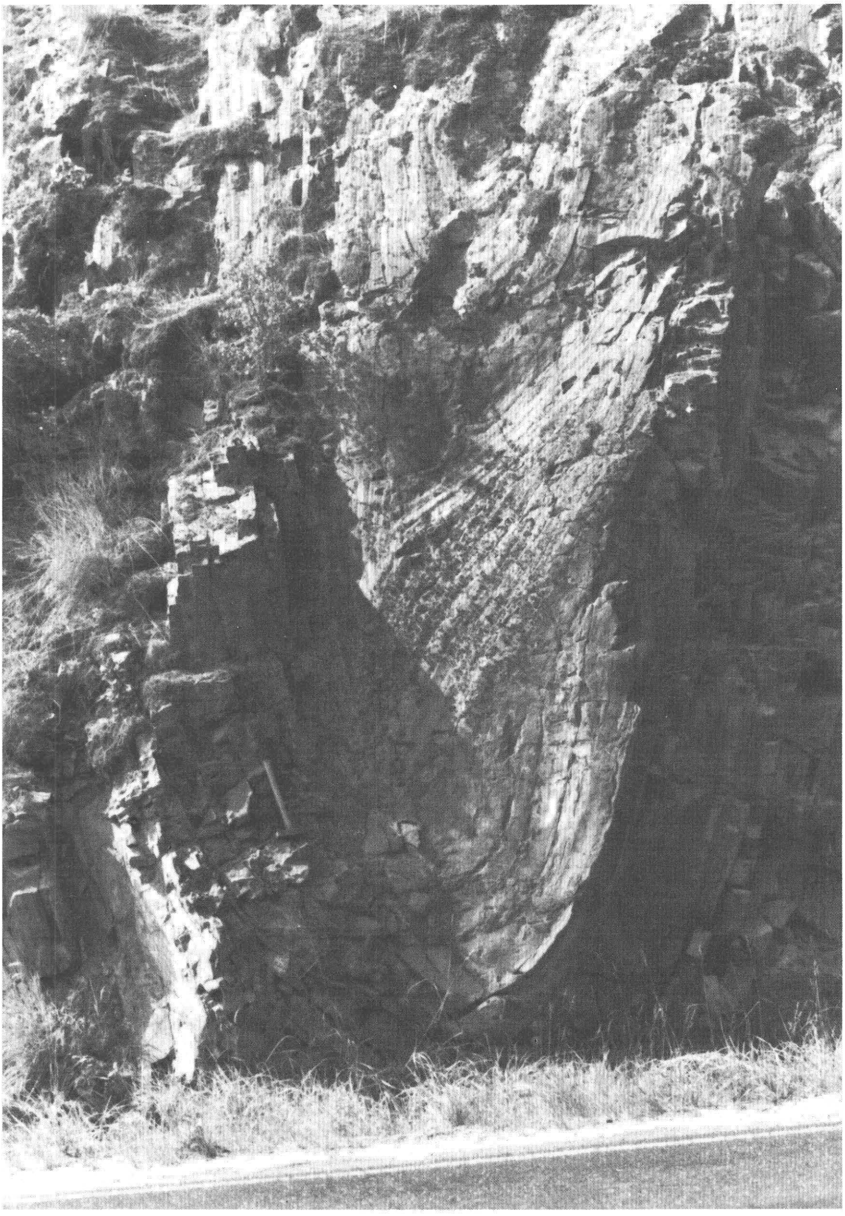


FIGURE 6.—Slump fold in member B. Beds face toward synclinal axis. Exposed in roadcut on Montana Highway 200 in Perma quadrangle immediately east of mouth of Robertson Creek.

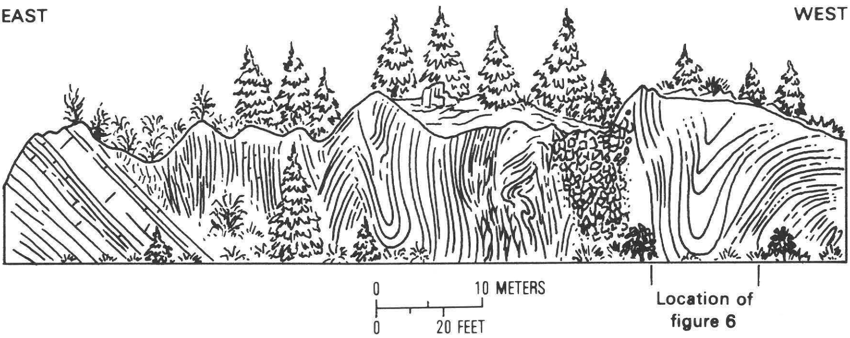


FIGURE 7.—Sketch of composite slump sheet exposed in roadcut on Montana Highway 200 west of Robertson Creek. Fold to right is one illustrated in figure 6. Beds face toward axes of syncline. Drawing by P. G. DeCelles.

The attitudes of the axial planes of 47 slump folds were measured to determine the direction of slumping and thereby the regional slope. Where possible, the facing direction of beds in the fold was recorded. The effects of tectonic dip were removed by calculations according to the method of Mertie (1922), and the results were checked by use of a stereographic net. The rationale for determining slump and slope directions from these measurements was formulated by Woodcock (1976, p. 171, 172) and is based on the assumption that prior to tectonic tilting the slump-fold axial plane will dip up the depositional slope and that the beds in the fold will face in the downslope direction. The results are presented in figures 8 and 9. In figure 8, the poles of all measured slump-fold axial planes are plotted on the southern hemisphere of a stereographic net. In figure 9, the data are plotted on a map, and the inferred slump directions are shown. The data show considerable scatter, as might be expected. An arcuate outline has been observed for many slumps and slides in recent sediments (Coleman and Garrison, 1977, fig. 5), and the prograding depositional slope in Prichard time is likely to have been irregular because of reentrants, salients, and valleys. I cannot document changes of orientation within a single-slump fold, but the variation within one composite slump sheet is illustrated in figure 8. Nevertheless, figures 8 and 9 both indicate that the dominant slump direction was to the east, and I assume that this was also the direction of regional slope.

Separate stereographic plots for slump folds north and south of the St. Mary's fault showed no obvious differences.

QUARTZITE MARKER

A unit of quartzite as much as 30 m thick occurs 250–500 m—the exact distance is unknown—below the top of member B. North of the St. Mary's fault the unit consists of medium-gray blocky-weather-

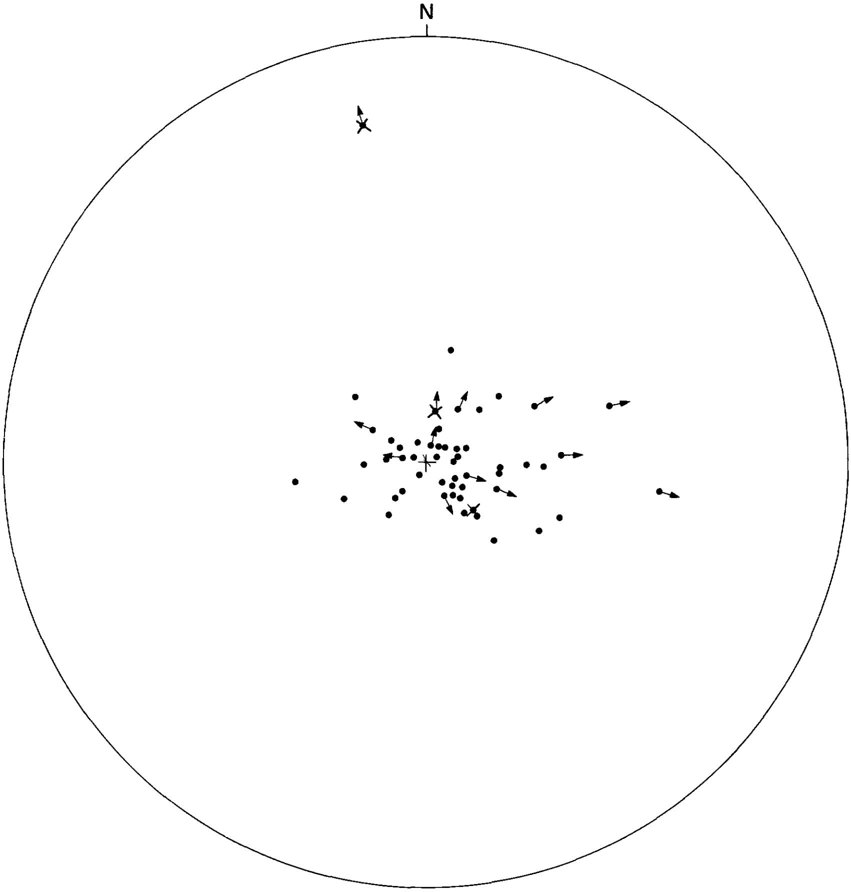


FIGURE 8.—Equal-area plot, lower hemisphere, of poles of axial planes of all slump folds measured in the Plains and Perma quadrangles. Arrows indicate facing direction. Poles shown by + are from within one composite slump sheet.

ing quartzite in beds mostly 0.3–1 m meter thick. The lower part commonly contains some interbedded argillite and siltite. Most quartzite beds grade upward through 2–5 cm to argillite. Though most quartzite beds are structureless, some are planar laminated. In roadcut exposures along Montana Highway 200 west of Robertson Creek and in cliff exposures on the north side of the Flathead River opposite Wilson Creek, some of the quartzites are in channels. Neither exposure can be examined closely, but I estimate the channels to be several meters deep and several tens of meters wide. The quartzite marker is thicker north of the St. Mary's fault than it is to the south, where locally it consists of a few thin quartzite beds. Although I have never found more than one quartzite unit in member B where I know the

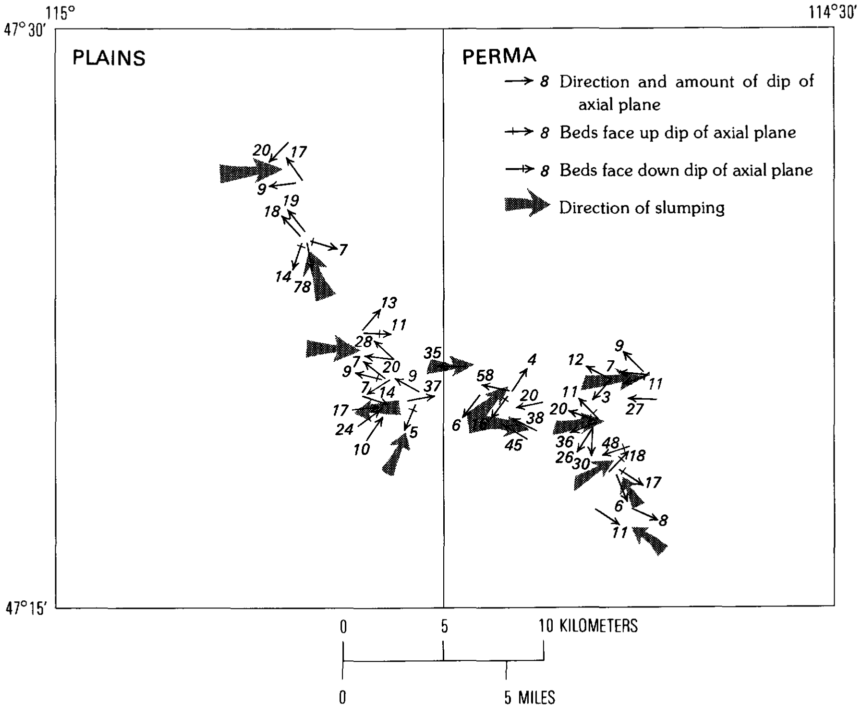


FIGURE 9.—Plains and Perma quadrangles showing direction and amount of dip of axial planes of slump folds, facing direction of beds in folds, and inferred direction of slumping.

section to be relatively unfaulted, it is at least possible that several discontinuous quartzites occur at somewhat different horizons within the member.

MEMBER C

Interlaminated siltite and argillite of member B is overlain by 75–110 m of quartzite and intercalated siltite-argillite that constitute member C. The quartzite is argillic, very fine to fine grained, medium gray to medium light gray, and blocky weathering. It occurs in sets from 1 to 10 m thick. The argillite, inconspicuous except in excellent exposure, is in sets mostly 2 or 3 m thick. Beds within quartzite sets are generally 0.4–0.6 m thick. Most of these beds grade to argillite in their top 1 or 2 cm. The quartzite is mostly massive or planar laminated, but cross-lamination is present in the top few centimeters of many beds, and ripple marks are present on some bedding surfaces. The sedimentary structures are inconspicuous, and as a result Bouma cycles (Bouma, 1962) are difficult to apply. If the massive-appearing quartzite is the Bouma A interval, then the most common cycles are ACDE, ADE, and AE. On the other hand, the massive quartzites may be the Bouma B interval in which original lamination has been obscured by regional metamorphism. In that case, the cycles are BCDE, BDE, and BE. Most beds are planar at the base, but a few beds channel as much as 0.5 m into the underlying bed. I have not seen sole marks; if present, they must be extremely uncommon.

The base of member C is the base of the dominantly quartzite section; a few quartzite beds are present at least locally in the upper part of member B, but in the few areas where I have mapped member C, the contact has been sharp. The top is placed at the top of the dominantly quartzite section, and though quartzite interbeds are present in the lower part of member D, the contact is sharp.

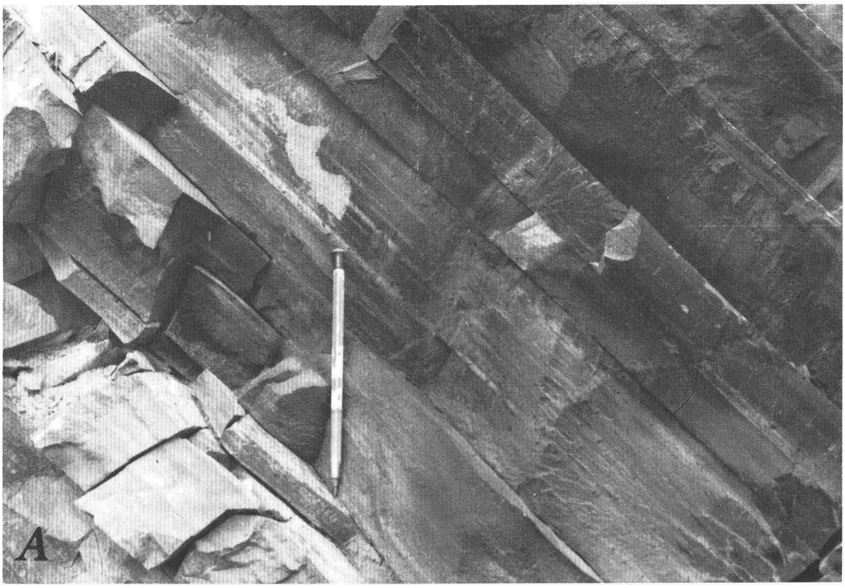
Member C is present throughout the area except between Wilson Creek and the ridge just east of Quinns Hot Springs where member D rests directly on member B, separated by a thin argillite-clast breccia. Member C is particularly well exposed along the Burlington Northern Railroad in the first cut south of John Tunnel.

MEMBER D

Member D consists of a variety of rock types, but platy-weathering olive-gray silty argillite containing sparse garnet and randomly oriented chlorite porphyroblasts is characteristic. Similar beds are present at least locally in the lower part of member E, but any occurrence of the olive-gray argillite in thicknesses of 50 m or more is diagnostic of member D. The best estimate for the thickness of the member is 290 m, but map measurements indicate some thicknesses as great as 410 m. The greater thickness probably results either from undetected faulting or from inconsistencies in mapping the upper contact.

The basal 70 or 80 m of member D consists of planar-laminated siltite and argillite interbedded with quartzite. The quartzite, which is dark to light gray and somewhat argillic, is in sets mostly 3–6 m thick. Both planar laminae and obscure lenticular bedding may be present. The siltite and argillite are in couplets and are similar to the siltite and argillite of members A and B. A few small slump folds are present locally.

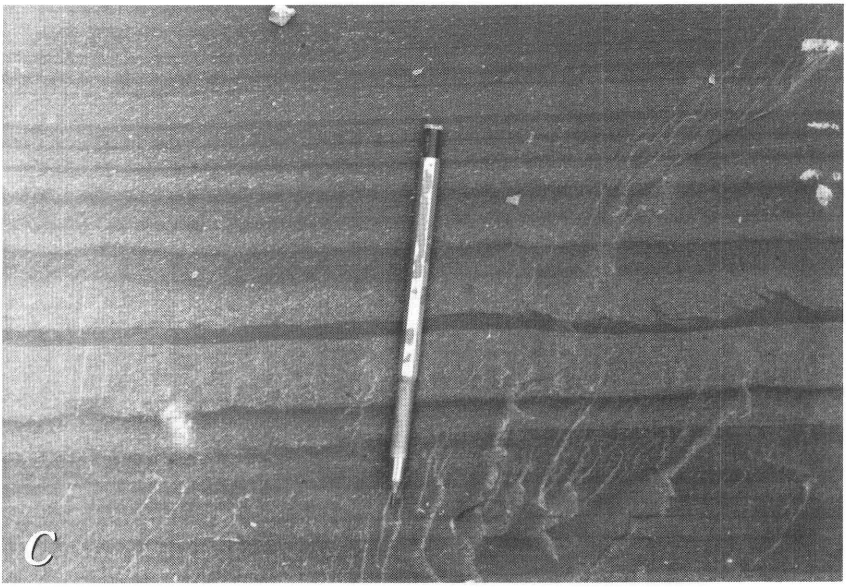
The overlying three-fourths of the member comprises a coarsening-upward sequence beginning at the base with the platy-weathering olive-gray silty argillite (fig. 10*A*). The silty argillite contains inconspicuous planar siltite laminae. Up section the siltite laminae thicken, and some form lenticular beds several centimeters thick (fig. 10*B*). The lenses are cross-laminated, and the lenticular layers probably



A, Platy-weathering silty argillite in lower part of member.

B, Wavy to lenticular beds of siltite several centimeters thick in silty argillite near middle of member.

FIGURE 10.—PHOTOGRAPHS OF MEMBER D



C, Very thinly interbedded siltite and argillite near top of member. Lighter colored layers are siltite, which makes up most of the rock here as opposed to the mainly argillite content of the lower part of member D shown in figure 10*A*.

FIGURE 10.—PHOTOGRAPHS OF MEMBER D—Continued

originated as a ripple-bedded sheet of silt. Farther up section the siltite layers become still thicker and more closely spaced until they make up most of the rock. The siltite layers, several centimeters thick, commonly have sharp bases and gradational tops (fig. 10*C*). Load casts are present at the base of some. These predominantly siltite beds, in turn, pass upward into siltite with scour-and-fill structure that is commonly interbedded with quartzite.

The upper contact of member D is placed where irregular to wavy laminae and scour-and-fill structure typical of member E become dominant over the the planar lamination and bedding typical of member D. At some localities the contact is fairly abrupt and can be located within a few meters. Elsewhere, intervals typical of member D alternate with intervals typical of member E. I do not know whether these two situations represent real differences in the section from place to place or whether they are a function of the type and amount of exposure.

Partial exposures of member D may be seen in road cuts along Montana Highway 135 between Quinns Hot Springs and Wallace Creek.

FIGURE 11.—Outcrop of member E on west side of the Clark Fork south of John Tunnel.

MEMBER E

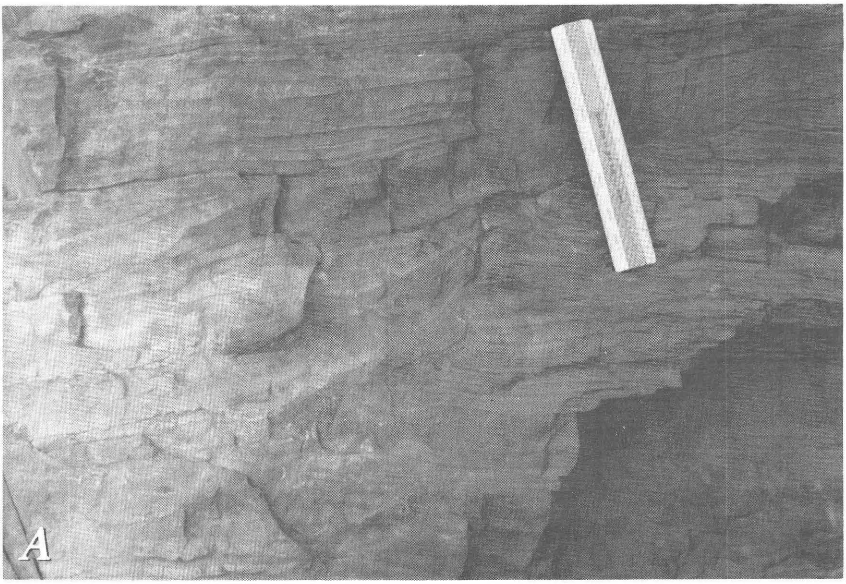
This member, approximately 825 m thick exclusive of the sill that is present in its lower part north of the St. Mary's fault, consists of laminated siltite and argillite with some interbedded quartzite. The rocks exhibit abundant current-produced structures, such as scour-and-fill and crossbedding, and some contain mud-chip breccias and mud cracks indicative of periodic exposure. The member is siltier and more resistant to weathering than the underlying and overlying members and commonly crops out as cliffs and bold ledges (fig. 11). The rusty-weathering color, though present, is not as pronounced in this member as in the rest of the Prichard Formation.

Most of member E consists of interlaminated light-gray siltite and dark-gray argillite that commonly occurs as graded couplets. The laminae are mostly less than 1 mm thick, but particularly in the lower part of the member bedding sets several centimeters thick of the very thinly laminated siltite-argillite may alternate with wavy to lenticular beds of siltite several centimeters thick. In general, though, the lamination is considerably thinner in member E than in the other members of the Prichard. The laminae are mostly wavy to crinkly, and planar laminae that are so typical of the rest of the Prichard Formation are uncommon.

The lower part of the member contains scour-and-fill structures 15–

20 cm deep that are filled by interlaminated siltite and argillite that drapes into the scour (fig. 12*A*). Many of the siltite layers in the lower part are irregular in thickness, and some are lenticular. The combination of scour and fill, irregular and lenticular beds, and the effects of differential compaction impart an irregular wavy appearance to this part of the section (fig. 12*B*). Higher in the member the thicker layers become less common, the laminae become irregular to crinkly, and mud cracks and mud-chip breccias become common (fig. 12*C*). The mud cracks are well formed and polygonal.

Quartzite forms a minor but locally conspicuous part of member E. The quartzite, considerably less sericitic than quartzite in member C, is in beds mostly about 0.5 m thick and in sets as thick as 9 m. Flaser bedding, ripple bedding, and crossbedding, some of the herringbone type, are common (figs. 13*A*, *B*). Planar and trough crossbedding have been observed in sets as thick as 0.7 m. Wedge-shaped sets of high-angle, small-scale planar crossbeds (fig. 13*C*) are present in one quartzite bed that is well exposed in the first gully north of the mouth of Siegel Creek. Most of the quartzite is fairly clean, but the dark laminae are sericitic. Quartzite beds are present throughout the member but are most numerous in the lower one-third. Individual



A, Scour-and-fill structure near base of member. Scale is 17.5 cm long.

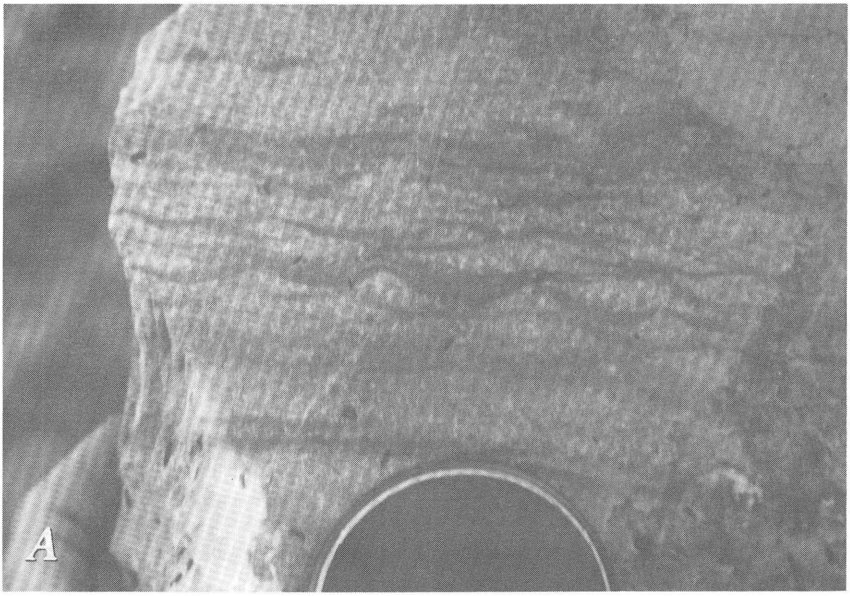
FIGURE 12.—SEDIMENTARY STRUCTURES IN INTERLAMINATED SILTITE AND ARGILLITE OF MEMBER E

B, Lenticular and wavy bedding.

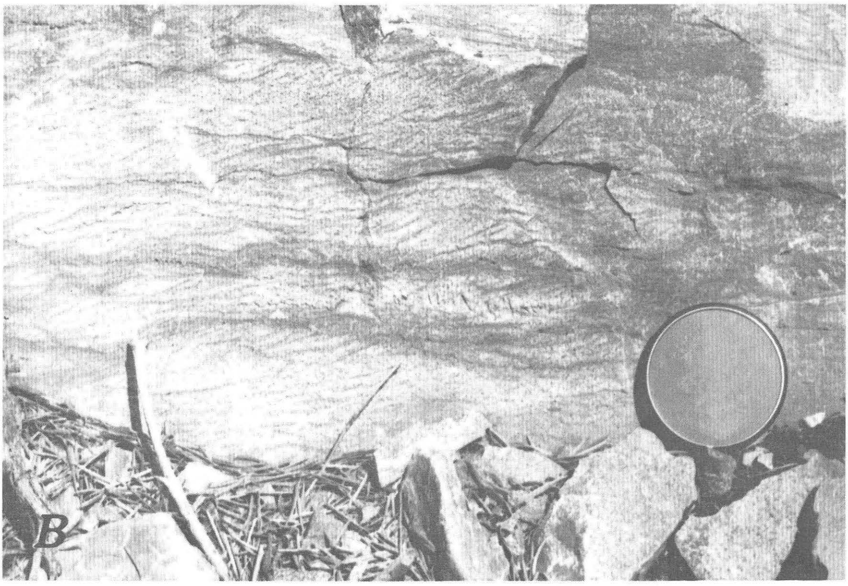
FIGURE 12.—SEDIMENTARY STRUCTURES IN INTERLAMINATED SILTITE AND ARGILLITE OF MEMBER E—Continued

C, Mud-chip breccia (b) in upper part of member.

FIGURE 12.—SEDIMENTARY STRUCTURES IN INTERLAMINATED SILTITE AND ARGILLITE OF MEMBER E—Continued



A, Lenticular and wavy bedding; some wavy flaser bedding (nomenclature of Reinech and Wunderlich, 1968).



B, Ripple crossbedding.

FIGURE 13.—SEDIMENTARY STRUCTURES IN QUARTZITES OF MEMBER E

C, Wedge-shaped sets of high-angle small-scale planar crossbeds.

FIGURE 13.—SEDIMENTARY STRUCTURES IN QUARTZITES OF MEMBER E —Continued

quartzite units do not seem to be continuous. Planar-laminated quartzites, such as those in member C, are not present.

Platy-weathering olive-gray silty argillite similar to that which characterizes member D is present at least locally in the lower part of member E where it constitutes an interval a few tens of meters thick. These occurrences suggest that members D and E intertongue. On the mountainside east of Quinns Hot Springs and on the west side of Seepay Creek, this interval contains a thin, speckled, nearly white bed that consists of quartz, chlorite, and garnet.

The upper contact of member E is sharp and marked by the abrupt upward passage from the thinly laminated siltite-argillite exhibiting various shallow-water structures to planar laminated and very thinly interbedded argillite and silty argillite of the overlying member F.

Typical exposures of member E may be seen along Montana Highway 135 between Wallace and Siegel Creeks.

MEMBER F

The cliff- and ledge-forming siltites of member E are overlain by silty argillite of member F that weathers to yield abundant platy float. Measurements from the geologic map suggest that member F is from 730 to 1,200 m thick, but this range probably results more from unmapped structure than from an actual range in thickness. The best estimates are that this member is 975 m thick south of the St. Mary's fault and is 1,100 m thick north of the fault. Even so, I am not certain that these differences are real.

Typical exposures of member F consist of interlaminated and very thinly interbedded silty argillite and argillite. The two may form graded couplets, or the contacts may be sharp. Most commonly the layers range from 1 to 6 cm thick, and the rock has a banded appearance. The silty argillite is generally dark gray and the argillite medium to light gray, but in parts of the section the silty layer is the lighter of the two. Most laminae and beds are planar, but a few silty beds pinch and swell and channel the underlying argillite. Many silty argillite layers are internally laminated; the laminae consist of silty argillite-argillite couplets, concentrations of carbonaceous matter within otherwise uniform argillite, or pyrite (fig. 14). Pyrite as discontinuous laminae generally less than 1 mm thick and as grains strung along

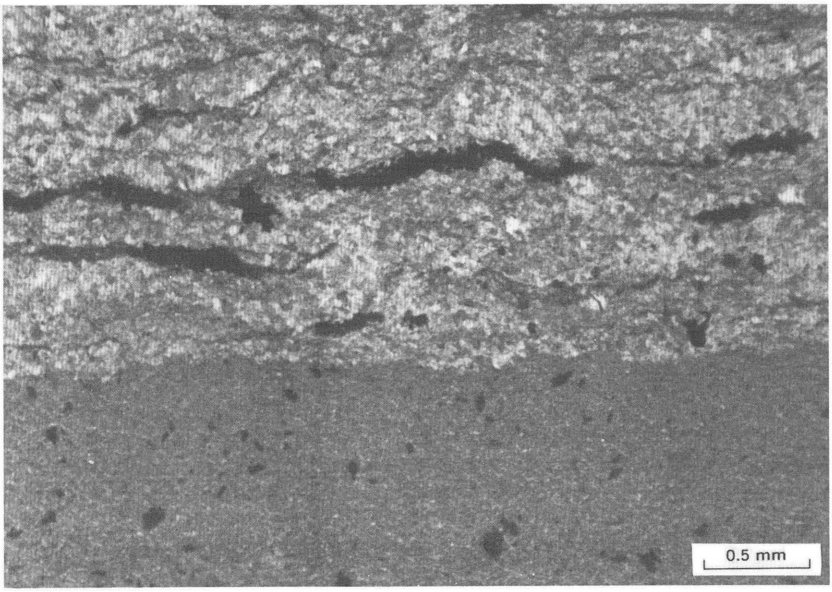


FIGURE 14.—Photomicrograph of interlaminated siltite and argillite from basal part of member F. Black discontinuous laminae are pyrite; black spots are mostly biotite.

bedding is characteristic of member F. Though the discontinuous pyrite laminae are not present in all beds, I have seen them in all parts of the member. Inasmuch as similar pyrite laminae are also present in the lower part of member H, the presence of the laminae, though very suggestive of member F, is not diagnostic. A few argillite beds are as thick as 0.5 m and contain few or no silty laminae. These weather to light-gray massive-appearing outcrops that are particularly characteristic of the lower part of the member. The banded argillite of member F splits very evenly and is locally quarried on a very small scale for flagstone (fig. 15).

A roadcut for Montana Highway 135 just south of Siegel Creek exposes several layers of argillite-pebble conglomerate (figs. 16, 17). These beds described by the following section:

		Meters
9	Argillite, silty, medium-dark-gray	0.3
8	Argillite, similar to unit 7, but consists of faulted and rotated blocks that were formed before deposition of overlying bed .	0.5
7	Argillite, laminated medium-dark-gray and medium-light-gray; laminae mostly 1–15 mm thick; some light-colored laminae pinch and swell, channeling underlying laminae	3.2
Conglomeratic zone		
6	Argillite, medium-light-gray; contains some siltite pebbles in top 0.5 m	1.5
5	Siltite, argillic, medium-gray, massive; contains disseminated pyrite grains as much as 0.7 m in diameter; grades to argillite in top 2 m	7.5
4	Argillite-pebble conglomerate, medium-light-gray; pebbles, about 50 percent of rock, are poorly sorted, subangular to subrounded, oriented subparallel to bedding and as much as 3 mm in diameter; 90 percent are argillite, 10 percent siltite; matrix is poorly sorted argillic siltite	1.5
3	Siltite, argillic, medium-dark-gray, massive; contains disseminated pyrite grains as much as 0.7 mm in diameter	9
2	Argillite-pebble conglomerate, medium-dark-gray, massive; pebbles are poorly sorted, subangular to subrounded, elongate, poorly oriented, mostly 1–2 mm but as much as 4 mm in diameter; mostly argillite but some siltite; matrix is poorly sorted argillic siltite	4
	Total thickness of conglomerate zone	23.5
1	Argillite, silty, medium-gray; lower two-thirds structureless; overlain by interlaminated argillic siltite and argillite; in uppermost part laminae are broken and stretched to irregular streaky patches of light-gray argillite in an argillic siltite matrix; base is 150 m above base of member F	3

A semiquantitative spectrographic analysis of a sample of unit 6 gave 2,000 ppm (parts per million) Zn and 50 ppm Pb.

FIGURE 15.—Flagstone quarry in member F. In NW¼NW¼ sec. 13, T. 19 N., R. 26 W., Plains quadrangle.

Units 3 and 5 are not laminated and are much more poorly sorted than bedded siltites elsewhere in the section. These characteristics suggest that units 3 and 5 resulted from nearly complete disaggregation and mixing of the laminated siltite-argillite by thixotropy and flow. The conglomerate probably resulted from less severe thixotropy in which the silty layers completely disaggregated whereas the clayey layers broke to fragments. I do not know whether the disruption of the sediment resulted from surface flow or whether it might have resulted from slip along a zone within the sediment.

An argillite- and pyrite-clast conglomerate very similar in appearance to those in the measured section is present in about the same stratigraphic position, though perhaps a little lower, on the southwest flank of Henry Peak, and an argillite-clast conglomerate similar to units 2, 4, and 6 and also at about the same stratigraphic position is exposed 2.8 km northwest of Three Lakes Peak. Neither of these conglomerates can be traced more than a few hundred meters along strike, and they are undoubtedly discontinuous. A bed that closely resembles units 3 and 5 and contains pyrite grains that may be clasts crops out near the top of the member 1.2 km east-southeast of Siegel Mountain.

Black chert and light-colored chert float occur about 315 m and 400 m, respectively, above the base of member F along the boundary

FIGURE 16.—Argillite-pebble conglomerate in lower part of member F.

of the Flathead Indian Reservation east of Siegel Mountain. The black chert does not extend any farther west, but the white chert is present on the east flank of Siegel Mountain. I have not seen either chert

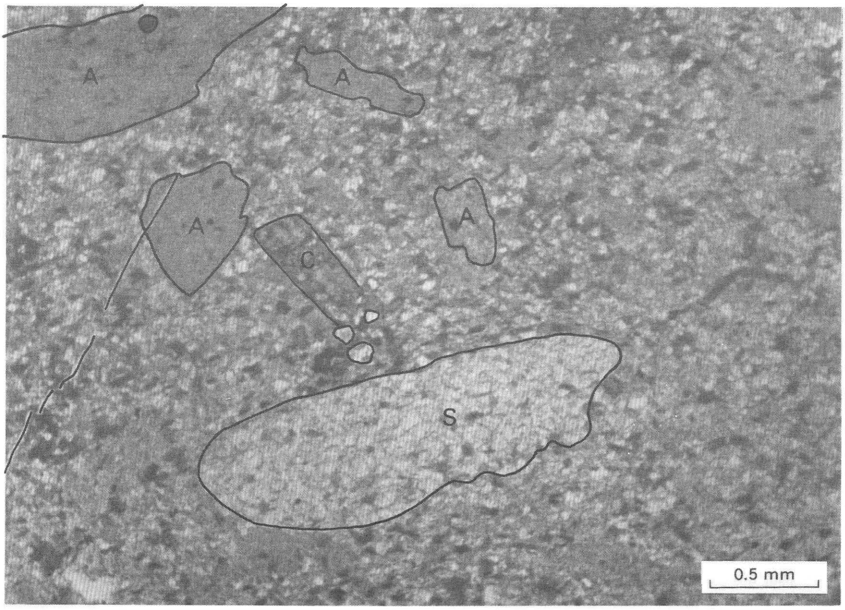


FIGURE 17.—Photomicrograph of argillite-pebble conglomerate from lower part of member F. A, argillite clasts; S, siltite clast; C, chlorite porphyroblast. Matrix is argillic siltite. Polarized light.

in place, but the amount of float suggests that neither bed can be more than a meter thick. The light-colored chert is banded light gray and very light gray in the same manner and scale as the silty argillite-argillite of member F. Microscopically, it consists of microcrystalline quartz that ranges in crystal size from less than 1 μm to 100 μm. At least some of the larger crystals were probably deposited as quartz silt. Biotite, chlorite, and sericite are concentrated in poorly defined laminae. The black chert is tourmalinized and contains as much as 10,000 ppm boron (R. E. Van Loenen, written commun., 1981).

The lower part of member F is well exposed along Montana Highway 135 in the first roadcut south of Siegel Creek. Exposures of the middle and upper parts may be seen along a Forest Service road that ascends Henry Peak from Henry Creek.

The contact of member F with the blocky-weathering quartzite and siltite of member G is fairly sharp in those few localities where it is well exposed, but it is generally concealed by quartzite rubble derived from member G.

The contact between members F and G is well exposed in the first roadcut just west of Cascade Campground.

FIGURE 18.—Interbedded quartzite, siltite, and argillite in basal part of member G. Roadcut on State Highway 135, 600 m north of Cascade Campground.

MEMBER G

Member G consists of interbedded quartzite, siltite, and argillite, of which quartzite is the most abundant (fig. 18). The member caps ridges, peaks, and knobs, and on weathering yields abundant blocky quartzite float that locally forms extensive talus. It is about 500 m thick.

Quartzite, the characteristic component of the member, occurs in planar beds mostly 0.2–0.5 m thick and in sets as much as 5 m thick. The beds commonly grade to argillite in their uppermost few centimeters, and some channel several centimeters into the underlying bed. The quartzite is mostly structureless, though planar lamination is present locally. The rock is mostly medium gray to medium dark gray and weathers dark gray.

The siltite is mostly medium light gray and typically weathers light olive gray. It is in planar beds mostly 0.1–0.2 m thick and in sets 1–2 m thick. Faint planar lamination is common.

The argillite is similar to that in member F and in the lower part of member H.

The upper contact of member G is sharp and is marked by the upward passage from thick beds and sets of hard, resistant quartzite to argillite. Locally, quartzite is interbedded with argillite in the basal part of member H, and the contact between the two members is difficult to select. The top of member G forms the lip of Cascade Falls above Cascade Campground, and the contact may be examined on the trail from the campground to the falls.

Near Cascade Campground in exposures on both sides of the Clark Fork a unit about 100 m thick of interlaminated and interbedded silty argillite and argillite indistinguishable from much of member F occurs about 20 m above the base of member G. This suggests that regionally members F and G intertongue. I have not identified this unit elsewhere.

The best exposures of the member are in roadcuts along Montana Highway 135 about 1.2 km west of Cascade Campground.

MEMBER H

Member H is the uppermost unit of the Prichard Formation. The argillites of the member are rather poorly exposed, and the unit is thick and contains few marker beds to facilitate mapping. I am, therefore, less certain of the thickness and, to some extent, less certain of the lithologic character of this member than I am of the others. Combining the lower part of the member northwest of Patricks Knob with the upper part east of Patrick Creek by means of a ripple-marked and cross-laminated unit in the middle of the section gives a thickness of 1,770 m. On the other hand, a measurement from the map of the thickness near Deemer Peak gives about 1,450 m. Unfortunately, these sections are too poorly exposed to know whether or not the differences between these two figures reflects an actual difference in thickness. Elsewhere within the study area faulting prevents an estimate of the thickness. J. E. Harrison (oral commun., 1978) has estimated the thickness from the base of member G to the top of the Prichard Formation in other parts of the Wallace 1°×2° quadrangle to be a little more than 2,100 m. Inasmuch as member G is 500 m thick, Harrison's figure gives a thickness of about 1,600 m for member H.

The predominant lithologies in member H are interlaminated and very thinly interbedded medium-light-gray argillic siltite (or silty argillite) and medium-dark-gray to light-gray and light-olive-gray argillite (fig. 19). They occur as couplets mostly 1 to 3 cm thick in which the silty layers make up one-fourth to one-third of the couplet. Some couplets are graded though many are not. In general, the argillite layers are thicker and the colors are lighter in the upper part of the section. The entire unit weathers to a rusty color.

Near Siegel and Patrick Creeks the basal 200 m of member H contains some quartzite in beds 5–25 cm thick and sets as much as 3

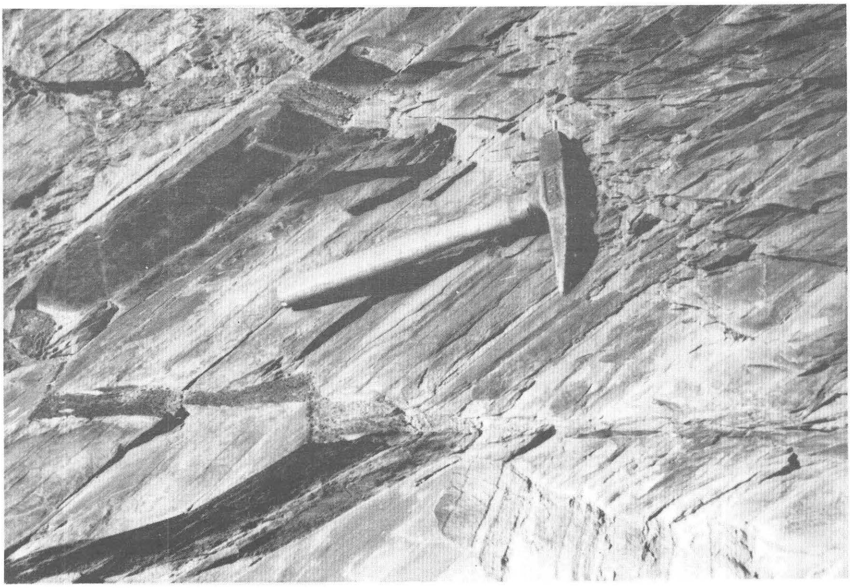


FIGURE 19.—Argillite in lower part of member H. Thin, darker layers are siltite laminae.

m thick (fig. 20). Most of the quartzites are planar laminated and grade upward to argillite; some channel 1–2 cm into the bed below. Pyritic and carbonaceous laminae are also present in some of the siltite-argillite in the lower part of the member, though not so abundantly as in parts of member F (fig. 21).

Northwest of Patricks Knob, beginning about 1,100 m above the base of member H and continuing nearly to the top, the member contains intervals as much as 6 m thick of massive-appearing silty argillite (fig. 22). In a cut on the road to Patricks Knob the lowest of these massive intervals contains some soft-sediment deformational features that are probably slump folds. The massive intervals make up only a small part of the section in which they occur.

A 90- to 120-m-thick unit of interbedded siltite, quartzite, and argillite occurs about 610 m above the base of member H near Patricks Knob and near Patrick Creek. Cross-lamination, small-scale scour-and-fill structures, and ripple marks are common in the siltite and quartzite. The quartzite beds are as much as 1.5 m thick. The unit is well exposed in several cuts on the road to Patricks Knob. I have not found this unit elsewhere in the report area.

North of Montana Highway 200, member H is partly exposed along several logging roads near Deemer Peak. In this area I have seen neither the quartzites near the base, the quartzite-siltite interval near the middle, nor the massive-appearing silty argillites. Nearly all of

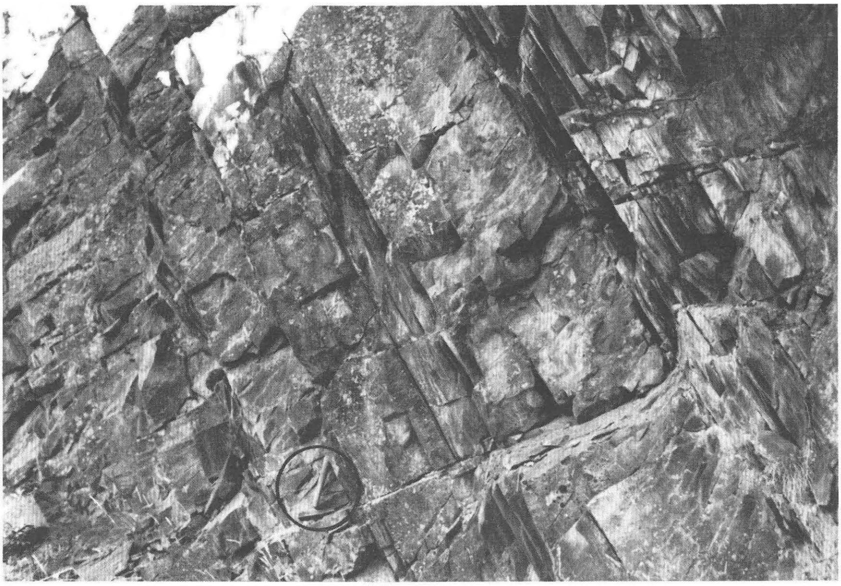


FIGURE 20.—Quartzite interbedded with argillite in lower part of member H. Exposed in cut on abandoned road, SW¼NE¼ sec. 35, T. 18 N., R. 25 W., Perma quadrangle. See hammer in circle for scale.

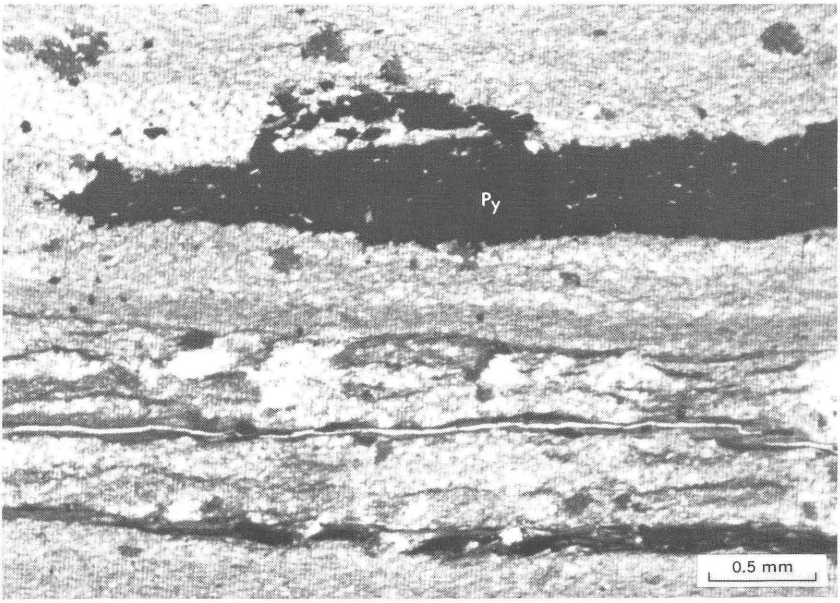


FIGURE 21.—Photomicrograph of interlaminated siltite and argillite from lower part of member H. Py is pyrite; thin, dark laminae in lower part contain carbonaceous matter and some pyrite.

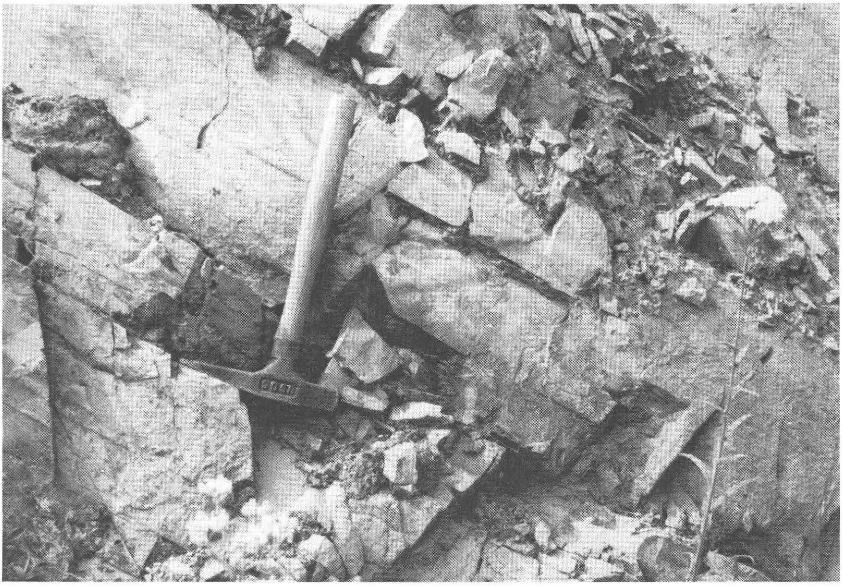


FIGURE 22.—Massive silty argillite in middle of member H. Exposed in W½ sec. 22, T. 19 N., R. 26 W., along road to Patricks Knob.

the exposures consist of the very thinly interbedded siltite and argillite. Light-colored siltite float is common, but I have seen it in place in only one locality near the base of the member. Some of the siltite beds exhibit climbing ripples at the base and parallel lamination at the top.

CONTACT WITH THE BURKE FORMATION

Ransome and Calkins (1908, p. 24) named the Burke Formation in the Coeur d'Alene district and described it as

> * * * composed of siliceous rocks, prevailingly fine grained, thin bedded, and of a light greenish-gray tint. Their lithologic character ranges, however, from that of fairly pure, nearly white quartzite to that of dark-gray siliceous shale. The quartzite is more abundant in the upper and the shale in the lower part of the formation, which therefore exhibits a transition into the quartzitic and argillaceous formations that lie above and below it, respectively. The Burke formation is characterized from top to bottom by shallow-water features.

They described the contact between the Prichard and Burke Formation as follows (Ransome and Calkins, 1908, p. 29, 30):

> Within a few hundred feet of the upper limit of the [Prichard] formation, a fairly rapid though not abrupt change in the character of the beds takes place. The indurated sandstones, sandy shales, and quartzites increase in abundance, and in the uppermost part appears a greenish-gray siliceous shale like that which constitutes the greatest

part of the Burke formation. Most significant as indicating the conditions under which these upper beds were laid down is the appearance of such features as ripple marks and sun cracks, indicating deposition in very shallow water and frequent exposure to the atmosphere. The shallow-water features occur throughout the overlying Burke formation, and this fact, as well as the occurrence of gray siliceous shale, like that which mainly composes the Burke, in the upper part of the Prichard, indicates the gradual nature of the transition from the one formation to the other.

This gradual transition naturally causes difficulty in fixing the Burke-Prichard boundaries and necessitates the choosing of some lithologic character which shall consistently be considered as differentiating the two formations. The diagnostic feature of the Prichard is the presence of a considerable amount of blue-gray argillite, for nothing like this typical rock is found in the Burke formation proper except locally and in small amount.

This transition zone between the lowest occurrence of rocks typical of the Burke and the highest occurrence of rocks typical of the Prichard was mapped separately by Hobbs, Griggs, Wallace, and Campbell (1965, p. 33–34) and found to increase in thickness across the Coeur d'Alene district from 180 m on the west to nearly 610 m on the east. They followed Ransome and Calkins in assigning the transition zone to the Prichard Formation.

In this report I have placed the top of the Prichard at the base rather than the top of the transitional sequence. Thus, the contact is defined as the lowest occurrence of rocks containing sedimentary structures indicative of deposition in shallow water. This contact was chosen because (1) it is the contact that has been mapped in adjacent parts of the Wallace 1°×2° quadrangle (J. E. Harrison, oral commun., 1980), (2) the contact marks a significant change in depositional environments, (3) the transition zone is not well exposed in the study area, and (4) the 7,000 m of rock below the transition zone was quite thick enough to absorb all my attention for the two field seasons.

The top of the Prichard Formation as used in this report and the nature of the overlying transition zone is illustrated by the following section measured 4 km north of the Plains quadrangle. The Prichard-Burke contact by the original definition would have been placed at the top of unit 29; whereas, the contact I have used is at the top of unit 6. Thus, the transition zone is about 550 m thick. This interval exhibits a number of interesting features and is worthy of study in itself.

BURKE FORMATION (LOWER PART) AND PRICHARD FORMATION (UPPER PART)

Section of lowermost Burke and uppermost Prichard Formations measured by pace and compass from outcrops along Mont. Highway 28 in T. 21 N, R. 24 W., and T. 21 N., R. 25 W. Sanders County, Mont. Base of section is in SW¼NE¼ sec. 31, T 21 N., R. 24 W, 565 m northeast of Welcome Spring; top of section is opposite entrance to campground at east end of Rainbow Lake. Measured by E. R. Cressman in August, 1980.

	Thickness (meters)	*Cumulative thickness (meters)*
Burke Formation (lower part only)		
37. Siltite and argillite, interlaminated and very thinly interbedded; medium gray to olive gray (weathers mostly greenish gray, moderate brown along some joints); siltite and argillite in even layers 0.5–5 cm thick; silt layers exhibit load-casts at base and grade into overlying argillite layers	Not measured	
36. Poorly exposed; the few small exposures are similar to unit 33	19	19
35. Quartzite, medium-gray to olive-gray (weathers mostly light olive gray, moderate brown along some joints) in even beds mostly 0.2–0.4 m thick; contains some faint wavy to planar laminae	9	28
34. Similar to unit 33; ripple marks common in lower half, mud cracks in upper half. Interval about 50 percent covered	320	348
33. Siltite and argillite, interlaminated; siltite is dark gray (weathers pale olive), argillite is greenish gray (weathers moderate brown along joints); laminae from less than 1 mm to 1 cm thick; siltite laminae commonly lenticular and channel into underlying argillite; mud cracks common. Outcrop appears massive; splits along planar bedding surfaces about 0.6 m apart	22	370
32. Quartzite, medium-gray (weathers light brown) in even beds 0.1–0.3 m thick; faint planar and trough lamination	10	380
31. Covered	35	415
30. Siltite, medium-gray (weathers greenish gray); in beds mostly 5–20 cm thick; contains some inconspicuous wavy laminae. Weathers to blocky fragments. Interval about 50 percent covered	16	431
29. Covered; hillside exposures suggest interval is mostly argillite similar to upper part of unit 28	44	475
28. Argillite and siltite; upper one-third is medium-gray well-cleaved argillite containing a few planar siltite laminae 1–2 mm thick and a few cross-laminated siltite lenses as much as 1 cm thick; middle one-third is interlaminated siltite and argillite containing some planar to broadly lensing siltite beds several cm thick; lower one-third is similar to upper one-third. Partly covered	36	511
27. Mostly covered; hillside float and a few exposures near road suggest that upper one-fourth is interlaminated siltite and argillite with irregular laminae and small scale scour-and-fill features and that lower three-fourths is well-cleaved argillite similar to that of unit 23	103	614

	Thickness (meters)	*Cumulative thickness (meters)*
Burke Formation (lower part only)—Continued		
26. Quartzite, light-gray (weathers light olive gray to grayish orange) in beds mostly 0.1–0.2 m thick; some beds channel as much as 5 cm into bed below; dark planar to wavy laminae, small scale scour-and-fill, and low-angle trough cross-lamination present in upper part of some beds. Upper one-third poorly exposed	24	638
25. Covered	23	661
24. Siltite interbedded with interlaminated siltite and argillite; similar to unit 19; thickness and abundance of siltite beds increase upward; uppermost 1 m is quartzite. Basal contact gradational through several meters	11	672
23. Argillite, dark-gray (weathers light brown); contains a few planar siltite laminae and one slump fold 0.4 m thick. Unit is well cleaved	13	685
22. Siltite and argillite interlaminated; similar to unit 14	15	700
21. Siltite interbedded with interlaminated siltite and argillite; similar to unit 19, but siltite beds decrease upward in thickness and abundance	13	713
20. Quartzite, light-gray (weathers light olive gray to light brown) in beds mostly 0.12–0.4 m thick; contains faint planar laminae	2	715
19. Siltite interbedded with interlaminated siltite and argillite. Siltite is medium gray (weathers olive gray, moderate brown on some joint and bedding surfaces) in beds 0.1–0.2 m thick and sets as much as 2 m thick; faintly laminated in part; laminae planar to markedly wavy; some siltite fills broad channels; load-casts common at base of beds. Interlaminated siltite and argillite similar to unit 14; in sets about 0.5 m thick	17	732
18. Covered	4	736
17. Siltite and argillite, interlaminated; similar to unit 14. Grades from bed below	12	748
16. Quartzite, medium-gray (weathers yellowish gray) in slightly irregular beds mostly 0.2–0.4 m thick; load-casts at base of some beds, and some contain dewatering channels; wavy siltite and argillite laminae present between some beds	7	755
15. Covered	18	773
14. Interlaminated siltite and argillite interbedded with siltite; similar to unit 13 but without quartzite interbeds; some siltite beds are as much as 0.5 m thick; some siltite as lenses and channel fill	25	798

	Thickness (meters)	Cumulative thickness (meters)
Burke Formation (lower part only)—Continued		
13. Interlaminated siltite and argillite interbedded with siltite and quartzite. Interlaminated and very thinly interbedded light-gray siltite and dark-gray argillite make up most of unit; laminae and beds, from 1 mm to several cm thick, are wavy, lenticular in part, cross-laminated in part; contains some small scale scour-and-fill structures. Siltite is light gray (weathers dark gray) in beds about 10 cm thick; load-casts common at base of beds. Quartzite, mostly near top and base of unit, is light gray (weathers light olive brown) and in beds mostly 10–20 cm thick . . .	12	810
12. Interlaminated siltite and argillite interbedded with siltite. Interlaminated siltite and argillite similar to that in unit 9 makes up most of unit. Siltite is medium light gray (weathers light olive gray to greenish gray, moderate gray on some surfaces), in beds 5–20 m thick; are alternating light and dark wavy laminae from 1 mm to several cm thick; contains abundant scour-and-fill structures several cm deep; many fills are cross-laminated; load-casts present at base of many beds; weathers to blocky float. Unit is poorly exposed; described from ledges on on hillslope north of Welcome Spring	94	904
11. Mostly covered; contains one small outcrop of argillite similar to that of unit 10	15	919
10. Argillite, greenish-gray; contains some siltite laminae several mm thick that exhibit low-angle cross-lamination	15	934
9. Siltite and argillite, interlaminated; siltite is light gray (weathers light olive gray), argillite is medium dark gray; weathers moderate brown to light brown on joint surfaces; laminae, mostly 1–2 mm thick, are somewhat wavy and graded in part; some laminae are lenticular, and some siltite layers fill channels as much as several cm deep and 10 cm wide. .	3	937
8. Covered	26	963
7. Siltite and argillite, interbedded; siltite is medium light gray (weathers greenish gray to brownish gray), speckled with iron oxide grains less than 1 mm in diameter; in part laminated greenish gray and brown (weathered colors); laminae irregular, cross-laminated in part, and exhibit some scour-and-fill; some cusp-shaped laminae may be water-escape features; load-casts present at base of some beds; in sets several meters thick. Argillite similar to that of unit 5. Interval about 50 percent covered	15	978

	Thickness (meters)	*Cumulative thickness (meters)*
Prichard Formation (upper part only)		
6. Mostly covered, about 10 percent of this interval consists of beds of well-cleaved medium-gray (weathers brownish gray) argillite	45	1023
5. Argillite, medium-light-gray (weathers greenish gray to moderate brown), massive	6	1029
4. Quartzite, very light gray to yellowish-gray (weathers moderate brown) in even beds 2–20 cm thick; upper 0.5–1 cm planar-laminated and argillaceous . . .	2	1031
3. Argillite, light-gray to light-greenish-gray (weathers moderate brown to light brown), speckled with randomly oriented biotite flakes 0.5–1 mm across; strongly cleaved, cleavage surfaces have distinct sheen produced by oriented sericite; contains a few planar siltite beds 5–10 cm thick that grade upward to argillite	32	1063
2. Covered	43	1106
1. Argillite, medium-light-gray (weathers moderate brown); contains some planar siltite laminae as much as 2 mm thick and spaced several mm to several cm apart; some thicker siltite laminae grade upward to argillite, some intervals consist of nearly one-half siltite laminae, whereas others contain very few; upper part contains some planar beds several cm thick of light-gray siltite that grade upward to argillite and contain irregular laminae in upper part	76	1182

SILLS

The Prichard Formation in the study area contains four dioritic to gabbroic sills sufficiently thick to map at the scale of 1:62,500. The most conspicuous of the four is locally as much as 400 m thick. In addition, several sills of local extent were too thin to map except as a line. I have not studied the sills, but Calkins (1909, p. 48, 49) described them as follows:

> These intrusive bodies consist for the most part of a very dark, somewhat greenish, hypidiomorphic-granular, medium-coarse to fine-grained rock. The most conspicuous mineral, megascopically, is greenish-black hornblende, usually somewhat fibrous, but feldspar and quartz are easily recognizable in all but the finest-grained specimens.
>
> Examined in thin section, this rock is found to be composed chiefly of hornblende, plagioclase, and quartz, with variable but generally small amounts of orthoclase and biotite. The common accessories are iron ore and apatite. The plagioclase crystals generally show far larger extinction angles at the center than on the periphery, but the more basic grades into the more acidic feldspar, so that distinct zones are not recognizable. The species represented range from labradorite to oligoclase. The orthoclase commonly is intergrown with quartz, which in some specimens is very abundant.

More recently, Bishop (1973) made a thorough investigation of the sills that intrude the Prichard at the Crossport locality east of Bonners Ferry, Idaho. He reported them to consist of continental tholeiite. According to Bishop, the sills are concordant with schistosity of the host rock where they intrude argillite, and the initial schistosity has been recrystallized in the contact zone. He concluded from this that the intrusion of the sills was synkinematic with the first recrystallization of the Prichard. One of these sills is the one dated by Zartman, Peterman, Obradovich, Gallego, and Bishop (1982) as 1,433 m.y. old.

In the area studied for this report the lowest sill is that between members A and B. It is mostly 160–200 m thick, though it is somewhat thinner in the drainage of Seepay Creek.

The next higher mapped sill ranges from a featheredge to nearly 400 m in thickness. South of the St. Mary's fault it is mostly within member D, but near Seepay Creek it is at or near the base of member C. North of the St. Mary's fault the sill is mostly in the lower part of member E; however, near Henry Creek it appears to cut approximately 600 m down section from the lower part of member E to within or below member C. Near the junction of Clear Creek with Camas Creek the sill dies out within member E, but two thin sills that appear in member D about 1 km to the north may be part of the same body.

The third mapped sill is in the lower part of member F. It ranges in thickness from 75 to 140 m and is present throughout the area. North of the St. Mary's fault the sill ranges from 450 to 520 m above the base of member F. South of the fault the sill is about 220 m above the base where exposed in a roadcut south of the mouth of Siegel Creek and 230 m above the base on Siegel Mountain.

The highest mapped sill is in member H in the Compbest Creek drainage. It is 85 m thick and about 900 m above the base of the member. This part of the section is faulted out south of the St. Mary's fault, and the sill is not present north of Montana Highway 200.

The ages of the sills within the report area have not been determined, but elsewhere in the Belt basin K-Ar ages indicate two periods of intrusion—the first at about 1,300 m.y. and the second at 750–850 m.y. (Harrison and others, 1974, p. 3, 5). Bishop (1973, p. 61) calculated a Rb-Sr isochron of 1,320 m.y. for one of the Crossport sills indicating that they belong to the first group. The U-Pb age of 1,433 m.y. for a sill from the same area (Zartman and others, 1982) is probably a more accurate date for the older group of sills. Sills from the younger group have been reported in the Prichard Formation about 18 km northeast of the Plains-Perma area where K-Ar ages of 803 ± 8 m.y. and 845 ± 20 m.y. were obtained on hornblende (J. D. Obradovich, unpub. data, cited by J. E. Harrison, written commun., 1981).

Mudge (1968) concluded that most concordant igneous masses in the Western United States that had intruded flat-lying sedimentary rocks had intruded under a cover of at least 3,000 ft (900 m) but less than 7,500 ft (2,300 m). If Mudge's conclusions can be applied to the Belt, all of the sills except that in member H must have been intruded before the end of Prichard sedimentation, and even the sill in member H must have been intruded before the end of Burke time. I therefore suspect that the sills in the report area are of the older group.

BRECCIA

An unusual feature of the Prichard Formation in the study area is breccia that occurs (1) as tabular bodies disposed at a low angle to bedding and (2) along high-angle faults. These two types will be described in order.

The most spectacular breccia of the first type is the westernmost one shown in figure 23. The breccia body consists of at least two rock subtypes. The most abundant is a high-matrix argillite-clast breccia in which the fragments constitute about 30 percent of the rock. The fragments are mostly angular and lath shaped, have an average length of about 2 mm, and have a maximum length of 15 mm. A few clasts are oval and rounded; most are of argillite, but a few are of siltite or quartzite. The matrix is very poorly sorted argillic siltite. In thin section the borders of most fragments are indistinct and are crossed by biotite and chlorite porphyroblasts. Much of the rock is well cleaved. Figure 24 is a photomicrograph of a fairly typical specimen.

The second subtype is dark- to medium-gray very poorly sorted, hard, massive argillic siltite that contains disseminated pyrite grains and a few indistinct argillite and siltite clasts. The pyrite grains are equant to tabular in shape and average 1–2 mm in diameter, though some are at least 10 mm across. Megascopically the pyrite grains appear to be clasts, but in the few thin sections I have examined, it is not clear whether the pyrite actually occurs as clasts and parts of clasts or whether it has replaced clasts or matrix.

I have not been able to determine whether or not there is any regularity to the occurrence of these two subtypes in the breccia bodies. The two are very similar to the two types interbedded in the conglomerate zone in member F (p. 20).

The easternmost breccia of the area of figure 25, which is the largest outcrop of breccia in the report area, is exposed mostly on the steep valley wall on the south side of the Clark Fork. Much of its outcrop is inaccessible, but contacts have been located in enough places so that the general map relations are clear, though details are not. As shown by figure 23, the breccia rises stratigraphically southward from just below the base of member C to near the top of member E, a thickness of 1,200 m in a distance of 8 km. The southern end terminates against the St. Mary's fault. Assuming that the breccia body dips in the same directions as the enclosing rocks, it is as much as 600 m thick, though it may have been thickened by undetected faults. The breccia truncates several folds and faults in the overlying beds and is itself cut by a diorite sill that has contact-metamorphosed the adjacent breccia.

The northern part of the breccia is bordered on the west by a syncline consisting mostly of rocks of member E. Another breccia body of the well-cleaved argillite-clast type crops out on the west flank of the syncline. The attitude of this breccia is not obvious, but the map pattern suggests that it extends beneath the syncline to merge with the larger breccia mass. The smaller breccia body seems to thin southward and pass into a fault that terminates against the thicker breccia.

The structure is illustrated by the section of figure 25*A*. The section is interpretive and is based largely on northwestward projection of the surface structures.

What can be said about the origin of these breccias? They certainly formed before regional metamorphism and before intrusion of the sills, but though they formed early, at least some of the clays were sufficiently indurated to break into angular fragments. As interpreted in figure 25*A* the larger mass cuts across bedding at an angle of only a few degrees where it is low in the section but the breccia mass cuts bedding by as much as 30° or 40° where it is high in the section, so it is probably listric. At its south end the main breccia is in the upper part of member E, which exhibits many features indicative of deposition in shallow water; whereas, near the northern end the breccia is in argillite of member D and the parallel-laminated quartzite of member C, both of which represent deposition in deeper water. Inasmuch as the breccia cuts across section, it could not have been deposited as a surface slump or mudflow, nor could it have formed by any other sedimentary process. Stratigraphic displacement across the breccia masses is small and this, together with the low angle at which the main breccia body crosses bedding, is strong evidence that tectonic faulting was not the cause.

The most reasonable explanation for the origin of the breccias is that they formed at the base of and within a major shelf-edge slump. Watkins and Kraft (1978, p. 271–273) noted from seismic reflection profiles that on the Louisiana and Texas Continental shelf and slope that both growth faults and the base of shelf-edge slumps are concave upward, and both pass downward into acoustically amorphous horizons that might be analogous to the breccias of the Prichard Formation.

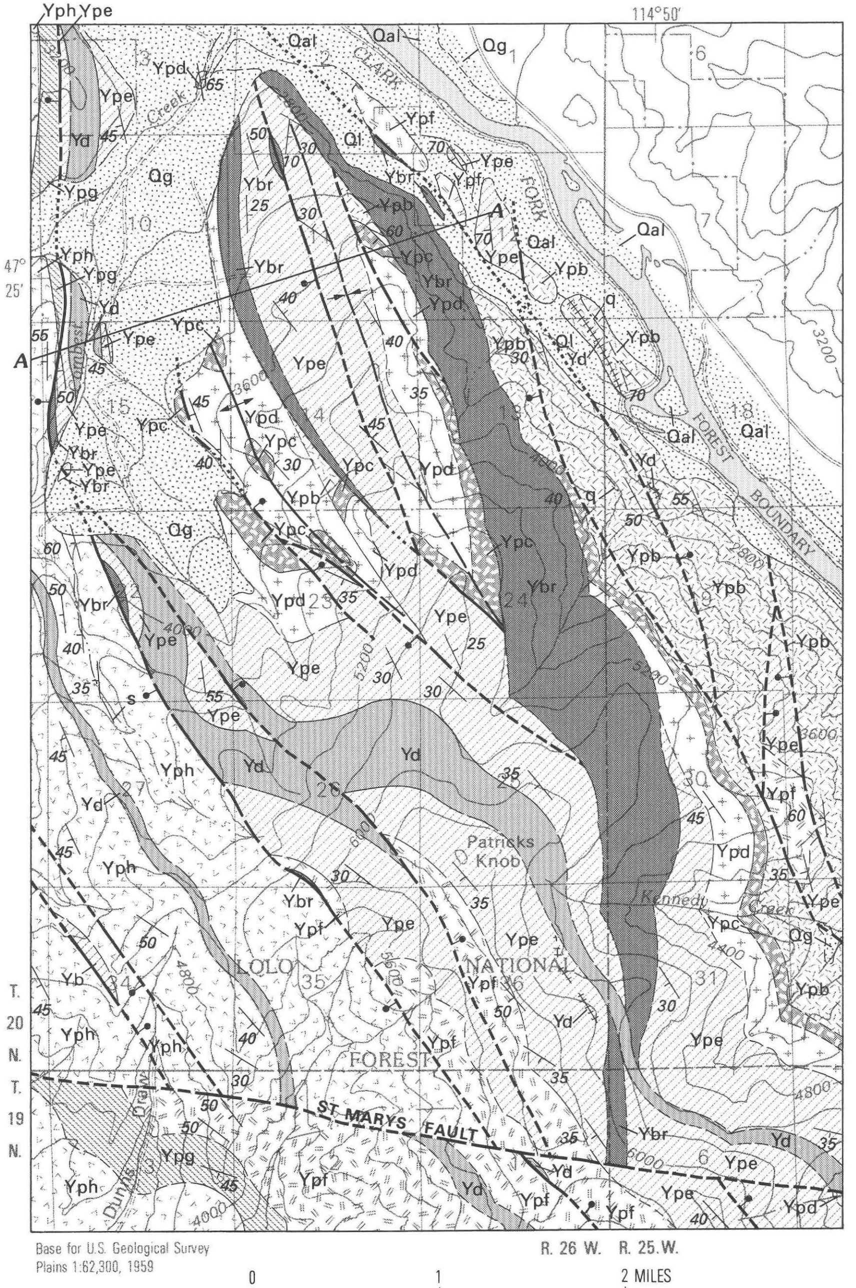
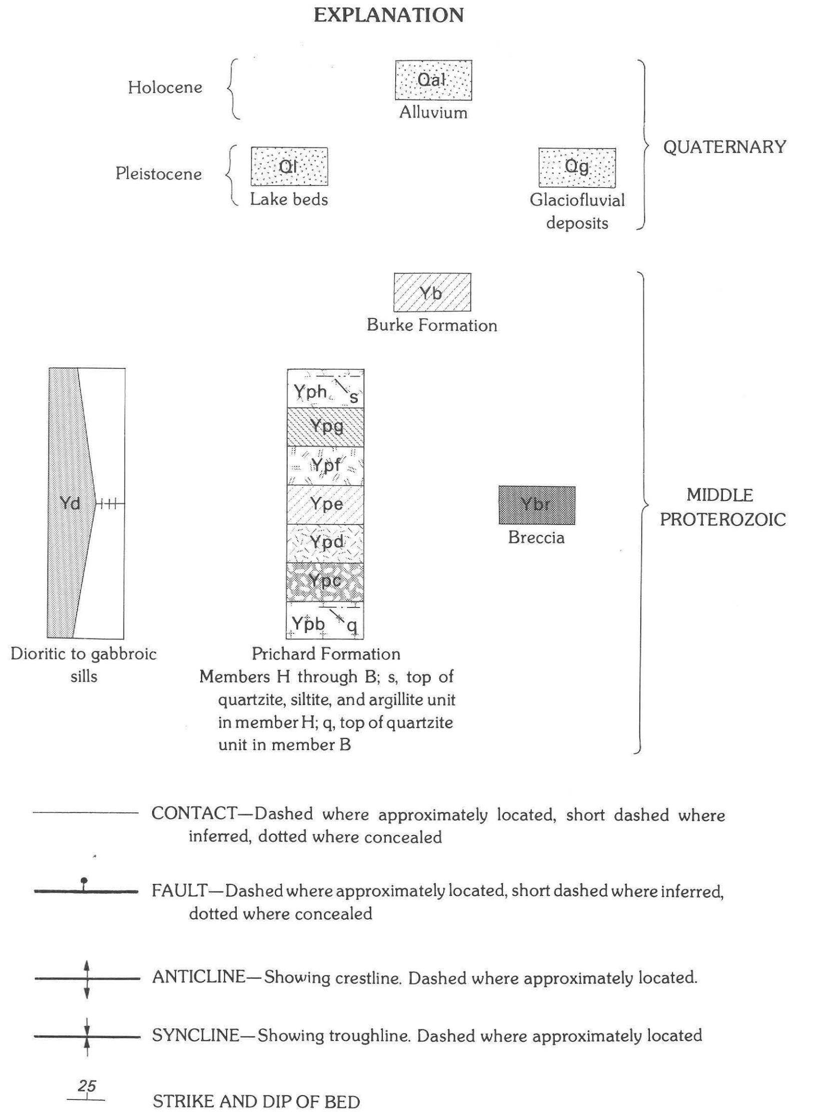


FIGURE 23.—Geologic map of part of the Plains quadrangle. Contour interval 400 ft.



However, the slump in the Prichard Formation involves at least 1,200 m of section as compared to 300–600 m for shelf-edge slumps off the Gulf Coast (Watkins and Kraft, 1978, p. 273) and a maximum of about 720 m for shelf-edge slumps off the coast of southern Africa (Dingle, 1980, p. 338, 340), so perhaps some very unusual event was required to initiate sliding. The map pattern, though not entirely unambiguous, suggests that slumping was toward the east-northeast. This is consistent with the generally eastward slope indicated by the slump folds

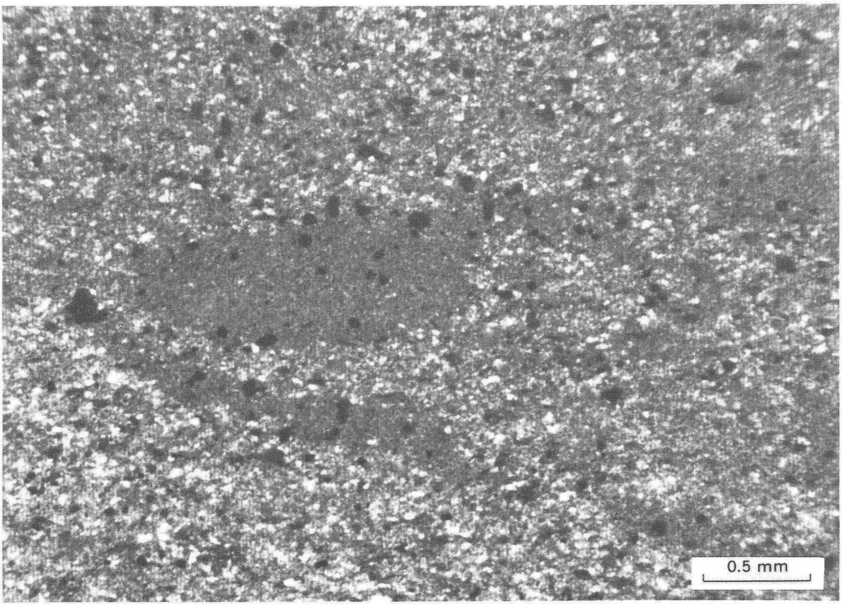


FIGURE 24.—Photomicrograph of breccia showing argillite fragments in poorly sorted argillic siltite matrix. Dark grains are biotite. Polarized light.

in member B. A possible section of the slump, reconstructed in part from the structure section of figure 25*A*, is shown in figure 25*B*.

A very similar breccia is exposed on Three Lakes Peak, on the left side of the West Fork of Seepay Creek, and between Wilson and Robertson Creeks. I have not mapped most of this area, but I suspect that the three exposures are all part of the same breccia sheet. All are in the lower part of member E but are probably at somewhat different horizons.

Another breccia was observed at two localities between Quinns Hot Springs and Wilson Creek. At both places it separates member B from member D, member C being absent. Its fragments are more rounded than in other type 1 breccias and the rock is not cleaved.

I am aware of only two reports in the literature of breccias that resemble those described for this report; one in the Tertiary of Peru and the other in the Precambrian of the Northern Territory of Australia. The occurrences in Peru were described by Baldry (1938) as low-angle normal faults inclined 7°–10° to the bedding. The faults (referred to by Baldry as slip planes) are accompanied by breccia zones from several inches to several hundred feet thick. According to Baldry (1938, p. 357), "The slips were probably due to gravity and took place

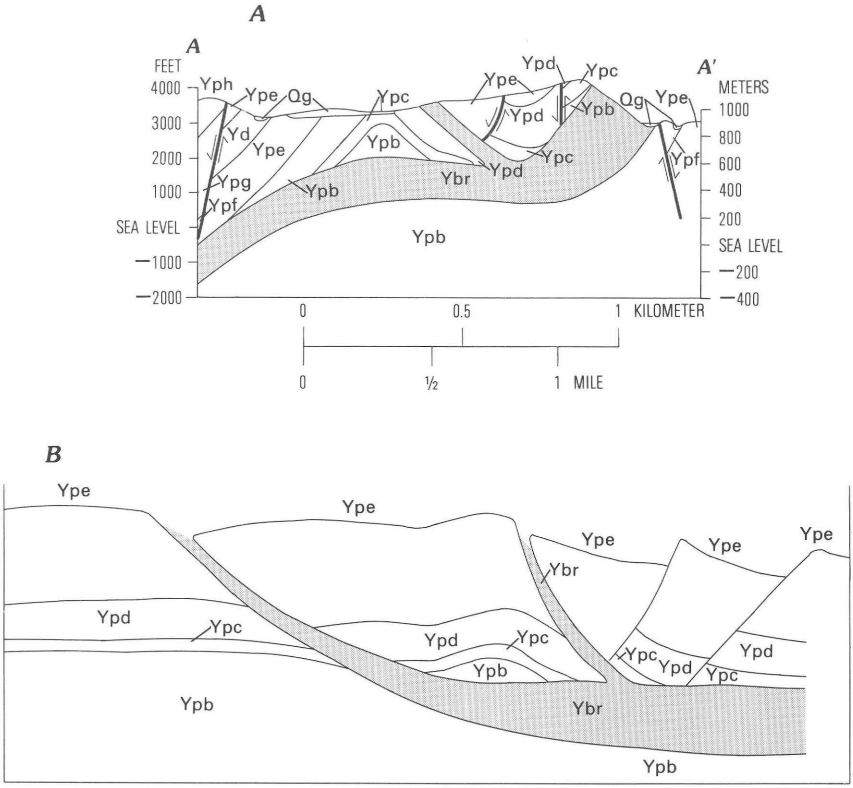


FIGURE 25.—Structure sections showing present and original configurations of breccia illustrated in figure 23. See figure 23 for location of section and for explanation of symbols. *A*, present configuration; arrows along faults show relative movement. *B*, inferred configuration after formation of breccia but before tectonic faulting and folding; scale same as in *A*.

after several thousand feet of strata had accumulated but before they had been distorted and displaced by normal faults." These occurrences sound similar to those described in this report, but the breccias themselves consist of masses of rock, boulders, and highly polished pebbles from many formations (Baldry 1938, p. 350) and are very different from the breccias in the Prichard. Knights (1956) stated that Baldry's hypothesis has not generally been accepted by other geologists working in the area.

Breccia zones in a Precambrian turbidite sequence in the Northern Territory of Australia were described by McNeil (1963, 1966) as occurring within a slip complex, which he defined as consisting of large masses of distorted sediment that were rafted on an infra-formational collapse zone. McNeil (1963, p. M3) described one of these "slip complexes" as follows:

[It] consists of a series of sub parallel breccia and quickstone lenses which represent major movement on slip surfaces, separated by disturbed slates and greywackes. * * * The disturbed rocks are overlain by normal greywackes and shales, but the underlying rocks are not well exposed, and the lower boundary of the complex is inferred. * * * Three main breccia horizons are present, all sub parallel to the regional dip. The central breccia zone is 3,000 feet long and reaches a maximum width of 150 feet. * * * The boundary between the breccia and surrounding disturbed sediments is usually sharp, but in a few places it tends to be gradational.* * * The breccia varies in grain size from fine even grained, (fragments less than ½ an inch in diameter), to coarse-grained with blocks of sediment 12 to 15 feet long separated by a matrix of fine-grained breccia. In appearance the breccia varies from a typical fault gouge to a soft sediment breccia with streaky banding and bent and wispy fragments. Several thixotropically mobilized or liquidized rock masses, quickstone and quickstone breccia lenses occur in the northeast part of the slip complex. * * * The quickstones are essentially fine-grained rocks which contain varying amounts of shale and numbers of quartz collocrysts. The amount of incorporated shale varies considerably and depends on the degree to which the sediment was mobilized. Granular quickstone is quickstone that has been completely liquidized and contains very little shale. Slaty quickstone is quickstone that has been partly liquidized and consists almost entirely of shale, each shale fragment being separated by a thin film of mobilized sediment. Both types can occur together. The granular matrix consists of silt size particles of sericite, quartz and chlorite.

From this description one can see similarities between the Australian breccias and those described in this report. However, neither the map nor other illustrations presented by McNeil are sufficiently detailed to know whether or not his "slip complexes" and the breccias of the Prichard Formation are similar phenomena.

The second type of breccia occurs along high-angle faults. One occurrence is on the divide north of lower Siegel Creek where the uppermost beds of member E are faulted against the lower part of member F. The breccia there is hard, massive, and dark gray. The inconspicuous clasts average several millimeters in diameter and are mostly argillite. Microscopically, the clast boundaries are indistinct, and biotite and chlorite porphyroblasts cross clast boundaries. The matrix is poorly sorted argillic siltite. It is possible that the breccia is bedded in member F and that its position adjacent to the fault is fortuitous.

Breccia also occurs at several localities along a high-angle fault near Compbest Creek that has displaced the lower part of member H and the upper part of member G against members E and F (fig. 16). At the southernmost locality, 1.6 km west of Patricks Knob, the breccia is uncleaved and massive. The fault here is between argillite of member F and argillite of member H. The argillite fragments constitute about 20 percent of the rock and range from lath shaped and angular to oval and rounded. The fragments are similar in size to those of the other breccias. Farther north, in section 22, where member H is faulted against member E, the breccia is highly cleaved and is very similar to the thicker breccia masses to the east. The breccia band is at least 20 m wide and is without question directly along the fault. A quartz vein is present along the fault at its northernmost exposure and is apparently the vein on which the Letterman mine was located. Zartman and Stacey (1971) reported a Mesozoic or Cenozoic age for lead from the mine. Two interpretations of the relations along this fault are possible. The first is that the fault may have formed before regional metamorphism and may have had recurrent movement. The second is that the southern breccia may be bedded in unit F and the fault is actually to the west of the breccia; the breccia in section 22 may be part of a breccia sheet within member E that has been emplaced against member H by later faulting.

INTERPRETATION

SEDIMENTARY STRUCTURES AND DEPOSITIONAL ENVIRONMENTS

In rocks of Phanerozoic age, fossils and fossil traces are by far the most useful indicators of depositional environments. The stratigrapher dealing with rocks of Proterozoic age, such as those of the Prichard Formation that were deposited before evolution of the metazoans, is more severely handicapped than his colleagues studying younger rocks, and he must rely nearly exclusively on sedimentary structures to decipher the conditions of deposition. Unfortunately, most sedimentary structures are indicative of process rather than specific environment, and only a small number of environments, all either continental or in very shallow water, can be determined unequivocally by sedimentary structures alone.

Some of the problems in interpretation are illustrated by the graded siltite-argillite couplets—the most common sedimentary structure in the Prichard Formation. These couplets closely resemble similar features that in the Gulf Coast region alone have been described and pictured as from environments as disparate as interdistributary bars (Roberts and others, 1976) and the abyssal plain (Bouma, 1972, fig. 2–16). In terms of process the Gulf Coast couplets have been ascribed to low-density turbidity currents (Bouma, 1972) and to seasonal variations in the sedimentary load of the Mississippi River (Huang and Goodell, 1970, p. 2093).

In the Prichard Formation, only member E contains sedimentary structures sufficiently diagnostic to permit a reasonably certain interpretation of the depositional environment. In the upper part of the member the mud-chip breccias are reminiscent of the mud flakes described by Evans (1965, p. 221) as occurring on the intertidal mudflats of the Wash of eastern England where the mud flakes are produced by tidal waters stripping the surface laminae. The lamination in this part of the section is itself very similar in character to that of the intertidal zone of the delta of the Colorado River (Thompson, 1968, pl. 9). Mud cracks and shallow scours are also common on the mudflats of the Wash, and both are also present in the upper part of member E. Features similar to mud cracks can result from subaqueous syneresis of clayey sediments (White, 1951; Burst, 1965; Donovan and Foster, 1972), but neither the experimental syneresis cracks nor the well-documented examples of syneresis from the older rocks figured in these references form as regular and complete polygons as those seen in member E. Furthermore, in the Prichard Formation, the mud-crack polygons occur only in the upper part of member E where they are associated with other features indicative of extremely shallow water. The quartzite, consisting of wedge-shaped sets of small scale crossbeds (fig. 13*C*), resembles in structure some modern beach sands (Reineck and Singh, 1973, p. 316), and both the flaser-bedded quartzite and those with herringbone crossbedding were most likely deposited by tidal currents. The discontinuous quartzites in the lower part of member E were probably offshore bars and sand waves; they are certainly not channel fills, and the crossbedding indicates deposition from traction currents. Scour-and- fill structures and discontinuous bedding in the siltites and argillites in the lower part of the member suggest deposition under the influence of fluctuating currents. Inasmuch as no mud cracks or mud-chip breccias are present in this part of the section, the most likely environment would have been a shallow shelf under the influence of tides and storms. Recent analogs do not exist because of pervasive bioturbation in present-day shallow water environments. The entire assemblage of structures in member E suggests deposition on a prograding shelf with at least some of the uppermost beds having been deposited in the intertidal zone. The dominance of argillite and siltite, the pervasive lamination, and the apparently lenticular shape of the quartzites all suggest that the shelf was tide dominated rather than wave dominated.

The slump folds so conspicuous in member B obviously resulted from failure of the sediments on a slope. Sediment failure will occur when stresses on the sediment exceed the strength, so that failure can result from either increasing the stress, decreasing the strength, or both. According to Coleman, Prior, and Garrison (1978), the stresses on the sediment are mostly of two types—gravitational and cyclic loading by waves; gravitational stresses may be increased by increasing the slope by sedimentation or by tectonic tilting. Sediment strength may be reduced by increasing pore-water pressure through rapid loading by sediments or by big waves, by methane production, and by disruption of the fabric by seismic shaking.

Contemporary soft-sediment deformation has been investigated intensively in the past decade because of the importance of sediment instability to the construction of offshore drilling and production platforms and submarine pipelines. Summaries of results have been presented by Coleman and Garrison (1977) and Watkins and Kraft (1978). These studies have documented a wide variety of sediment failures ranging from mudflows, in which all coherence has been lost, to rotational slumps and sedimentary plates translated downslope with little internal deformation (Twitchell and others, 1979). Sediment instability occurs in environments ranging from upper delta fronts at water depths of less than 5 m (Coleman and others, 1978, p. 1067) to the continental rise at water depths of more than 3,000 m (Twitchell and others, 1979). Slopes may be as low as 0.2° (Coleman and Garrison, 1977, p. 22) and as much as 10° (Twitchell and others, 1979). Inasmuch as sediment failures can occur over such a wide range of environments, the following attempt to interpret the slump folds of the Prichard Formation in terms of a specific environment is obviously speculative.

In member B, slump folds were overwhelmingly the dominant type of mass movement. I have seen no beds in this part of the section that could represent mudflows, collapse depressions, bottleneck slides, or mud diapirs, all common off the Mississippi delta (Coleman and Garrison, 1979). This suggests that the sediment was more stable than that of the Mississippi area, perhaps because of slower deposition or because of the paucity of organic matter that could have been converted to methane. Instability, then, would have occurred only where the applied stresses were severe. The most likely locale would have been on the upper continental slope where progradation could have resulted in oversteepening. This is the case in the present Gulf of Lions where Got and others (1979) noted that slumps are most common at the break between shelf and slope.

Terzaghi (1962, p. 1430), in a discussion of a report by Mathews and Shephard (1962), wrote the following with respect to slumps on the Delta of the Fraser River in British Columbia.

> The top layer of the sediments is in a semi-liquid condition and starts to slump as soon as the inclination of the surface exceeds about 2°. That is the "critical slope angle." A slide reduces the slope angle to a much smaller value. Therefore, during the decades or centuries following the slide, the hummocky area becomes buried beneath fresh sediments which afface the slide topography and the slope angle slowly increases until the critical slope angle is again reached. In the meantime slumping occurs in other areas. According to this concept the slumping is a rather rare event and takes place in different areas at different times. The close spacing between the hummocks observed by the authors [Mathews and Shepard] indicates that the surfaces of sliding are located at a very shallow depth. Within this depth the stratification is obliterated, and the disturbed layers will assume the character of relatively thin lenses of distrubed clay scattered throughout a mass of stratified sediment.

I suspect that the slump folds and sheets of member B formed in a similar manner except that the strata maintained their coherence during movement.

If member B was deposited in the upper slope, then member A, similar to member B but without the soft-sediment deformation, was deposited on the lower slope.

The quartzites in the middle of member B and in members C and G all exhibit sharp bases, some of which channel the underlying bed; and the quartzites have tops that grade to argillite. By far the most common sedimentary structure is planar lamination. The absence of large-scale crossbedding and the paucity of even cross-lamination suggests that the quartz sand could not have been transported by traction currents, and though they exhibit few sole marks and though Bouma sequences are not obvious, they were probably deposited from turbidity currents. I have not observed features in the quartzites that indicate environment rather than process, but both member C and the quartzite unit in member B are just above zones of prominent slump folds. Perhaps these two quartzites were deposited in lows on the upper slope that had been formed by slumping.

SEDIMENTATION AND STRUCTURE

The Plains and Perma quadrangle areas are on the north edge of the Lewis and Clark line, which has had a long and complex structural history, probably beginning as early as Belt time (p. 5). If the faults that make up the Lewis and Clark line were active during deposition of the Prichard Formation, they could have provided conduits for mineralizing fluids, so the timing of the faulting is of considerable practical importance.

The St. Marys fault that crosses the Plains and Perma quadrangle areas (fig. 1) is the northernmost major fault of the Lewis and Clark line. The Prichard Formation does differ in some details across the St. Marys. Several sills are at different horizons across the fault (p. 43); the quartzite marker of member B is thicker on the north side of the fault than on the south, and member F may be thicker north of the fault. Also, the large breccia mass illustrated in figure 23 terminates against the fault. However, Harrison, Griggs, and Wells (1974, p. 12) have estimated an apparent right lateral movement of 13 km along the St. Marys, and the slight differences in the Prichard here are most simply explained by juxtaposition of slightly different sections by postdepositional faulting. The slump folds in member B, which might be expected to show some relations to contemporaneous faults, are as common north of the St. Marys fault as south of it, and the original orientation of the slumps is the same to the north and south (p. 14).

In summary, I have found no evidence within the report area that the St. Marys fault was active during deposition of the Prichard Formation. Possibly, a larger area of exposure would be necessary to detect any effects of faulting on the sediments. This discussion has no bearing on whether or not other faults within the Lewis and Clark line were active in Prichard time.

SOURCE

The Prichard Formation is an enormous accumulation of fine-grained quartz and clay. At the present time, 18×10^9 metric tons of suspended solids are carried annually to the world oceans, more than one-third of the total being contributed by about a dozen major rivers (Holeman, 1968). According to Drake (1976, p. 135–136), less than 10 percent of this material reaches the deep sea; about 50 percent accumulates in estuaries and coastal wetlands, and the remaining 40 percent is deposited off about two dozen major river mouths. The Prichard Formation of the Plains area is certainly not an estuarine deposit, and only the upper part of member E could have been deposited in coastal wetlands, so we can reasonably conclude that the Prichard was deposited as part of a delta complex off the mouth of a major river system. The slump-fold measurements of member B indicate that the local deltaic lobe prograded eastward and that the river system supplying the detritus was to the west. Considering the complex shape of deltas, it is not difficult to imagine situations in which the supply could have been from the southwest or south, but any other direction for supply to the Plains area seems unlikely. No sediment transport directions were obtained from members F, G, or H, so these conclusions as to the direction of the source apply only to the lower part of the section.

TECTONIC ENVIRONMENT

The Prichard Formation, as exposed in the Plains and Perma quadrangle areas, is about 6,000 m thick exclusive of the sills. Though remarkably uniform in composition and texture from base to top, the formation seems to comprise two sequences of basin fill. The first is from the base of the section to the top of the shallow water member E and is about 2,700 m thick, again exclusive of the sills; the upper sequence includes those beds from the top of member E to the base of the shallow-water Burke Formation; this interval is about 3,300 m thick. What conditions could have permitted the accumulation of such a thick pile of sediments?

Sweeny (1977, p. 44) wrote, "A necessary condition for the evolution of a sedimentation basin is the presence of a related depression at the earth's surface. Sedimentary basins are developed by the filling of depressions with sediment and by response of the earth to the resulting sediment load." The depth of the original water-filled depression required to accumulate a given thickness of sediment depends on what assumptions are made as to the nature of the crust. Assuming an Airy-type crust, a sediment density of 2.4–2.5 g/cm^3, and a mantle density of 3.3–3.4 g/cm^3, an original water-filled depression 900–1,200 m deep would have been required to accumulate the 2,700 m of sediment that make up the lower sequence of the Prichard. If, instead, the elastic beam theory is applied, using an amplification factor of 3.4–4.1 (Sweeney, 1977, p. 45), an original depth of 660–820 m would have been required. Inasmuch as the base of the Prichard Formation is not exposed, both the thickness of the depositional sequence and the calculated water depths are minimums. How could a basin of the requisite depth have formed?

Several mechanisms have been proposed to account for the formation of basins in the interior of continental plates. As reviewed by McKenzie (1978), these include (1) phase change in the Moho as a result of sedimentary loading, (2) thermal contraction following the rise of a mantle diapir, and (3) McKenzie's own proposal that involves crustal stretching and thinning, upwelling of asthenospheric material, and subsequent cooling and subsidence. McKenzie pointed out difficulties inherent in the first two hypotheses. According to his own hypothesis, the requisite depth of water for the lower sequence of the Prichard to accumulate could be attained by stretching the crust by a factor of between 1.25 and 1.5 (McKenzie, 1978, fig. 4). Stretching of this amount seems feasible. However, the crust would have to stretch by a factor of 3 to account for the entire Prichard.

Bott (1976) has taken a slightly different approach. He cited evidence that the continental crust is divided into a brittle upper layer 10–20 km thick and a ductile lower layer. If crustal stretching takes place, the ductile layer responds by thinning and lateral flow while the upper crust responds by normal faulting and wedge subsidence. Bott calculated that under these conditions a graben with a width of 30–60 km would form. Computation of the energy budget led him to conclude that more than 5 km of sediment could accumulate provided that water pressure would reduce friction on the bounding faults. This predicted maximum thickness is inadequate to account for all of the Prichard Formation, and it fails to account for the total Belt Supergroup by a factor of 4.

None of these mechanisms seem adequate to account for the Prichard Formation, so it seems very unlikely that the Prichard could have accumulated on a plate interior. A more likely hypothesis is that the Belt Supergroup was deposited on thinned continental crust on a passive continental margin, as proposed by Harrison and Reynolds (1976). Price (1964, p. 422) and Gabrielse (1972, p. 525) have both proposed that the Purcell Supergroup accumulated as a continental-terrace wedge, basing their conclusions largely on thickness and facies trends, and Sears and Price (1978) have suggested that the Belt basin was formed by rifting of a combined Siberian-American plate about 1,500 m.y. ago. Williams (1980) suggested from paleomagnetic data that the plate just west of North America in mid-Proterozoic time was Africa; the Siberian platform lay farther north.

The general model for rifting and subsequent subsidence of the continental margin is doming caused by rising hot mantle material, thinning of the crust by erosion on the crest of the dome, rifting, subsidence of the new continental margin due to thermal contraction, and amplification of subsidence by sedimentary loading. Gravitational creep of the lower ductile crust and erosion of the lower crust by the mantle may also enhance subsidence by thinning the crust. Bott (1979) gave four main stages in the subsidence history of passive continental margins. These are (1) rift-valley stage, (2) a youthful stage, lasting about 50 m.y. after the onset of spreading, characterized by rapid regional subsidence of the outer shelf and slope, (3) a mature stage marked by more subdued regional subsidence (this is the present stage of the Atlantic and Indian Ocean margins), and (4) a fracture stage when subduction starts and thereby terminates the history of the passive margin. The Prichard Formation does not fit easily into these stages. The sills of continental tholeiitic suggest the first stage, but the great thickness of sediments suggests stage two. The rifting model was developed mostly from the post-Permian rifting of Gondwanaland. Plate tectonic regimes were probably in effect by Early Proterozoic time (Choubert and Faure-Muret, 1980, table 1), but the bulk Earth heat production was considerably greater in the Early and Middle Proterozoic than during the breakup of Gondwanaland (Goodwin, 1981, p. 57), and the crust might have responded somewhat differently.

As previously discussed, the vast amount of terrigenous fines that constitute the Prichard Formation imply derivation from a major river drainage, and slump directions demonstrate that the sediments prograded eastward. Yet strontium isotope ratios indicate that the edge of the older Precambrian basement is only about 150 km west of the study area (Armstrong and others, 1977, p. 406–408). Furthermore, Muehlberger's reconstruction of North America at an age of 1,700 m.y. ago indicates no continental area of the requisite size to either the west or south (Muehlberger, 1980, fig. 15.2). Where, then, is the westerly to southerly source for the Prichard? If rifting began about 1,500 m.y. ago as suggested by Sears and Price (1978), the Siberian (or African) platform might have been close enough to supply sediment.

DEPOSITIONAL HISTORY

Subsidence as a result of rifting and crustal stretching formed a basin at least 600 m and probably more than 1,200 m deep. The shape of the basin is not known; and, as pointed out by Harrison and others (1980), the discovery of thrust faults of considerable tectonic transport north of the Lewis and Clarke line renders previous isopach, lithofacies, and paleogeographic maps obsolete.

In the Plains and Perma area, the basin began to be filled by sediments of a major delta complex that at least in this area prograded eastward. The oldest rocks, those of member A, were probably deposited on the lower delta slope. The siltite-argillite couplets may have settled from suspension and may have resulted from seasonal or longer term variations in the sediment supply, or they may have been deposited by low-density turbidity currents. Light-colored cross-laminated silt layers were deposited or reworked by traction currents; at the water depth inferred for member A, contour currents seem the most plausible mechanism.

Member B was deposited on the upper slope where more rapid sedimentation oversteepened the slope and led to instability and slumping.

Member C is somewhat enigmatic. I have previously suggested that the quartzites were deposited by turbidity currents in slump-formed valleys on the upper continental slope, but how was the sand delivered to the shelf edge? Perhaps at this time the distributaries discharged directly at the shelf break so that bedload sand would have been immediately available. If so, subsidence must have directly followed deposition of member C, for member D seems to have been deposited on a submerged shelf.

The coarsening-upward sequence of member D suggests progradation of a delta lobe across the shelf. The sequence begins with bottomset beds and proceeds upward through beds deposited on prodelta slopes and terminates with shallow-water quartzites and siltites of the overlying member E.

Member E, deposited in intertidal and shallow subtidal environments, represents the outer part of the subaerial delta and the adjacent submarine delta platform. With the lack of obvious distributary sands and the passage from mudflat to shallow marine muds, the unit is reminiscent of the outer delta plain of the Orinoro, described by vanAndel (1967, p. 302) as follows:

> Seaward the delta merges imperceptibly into extensive tidal mud flats, generally without beach development. * * * [The] only evidence for fluviatile sedimentation is found in the wide estuaries themselves; elsewhere, the growth of the delta appears to take place predominantly by mud-flat accretion with or without intervals of chenier development. It is obvious * * * that the main body of the (subaerial) delta is predominantly composed of fine-grained sediment, and that a very large part of it is strongly influenced by marine depositional processes.

The initial progradation of the delta complex was terminated upon deposition of member E; subsidence followed. The succeeding 3,500 m of rocks that constitute the upper part of Prichard Formation contain little evidence of current activity and no unequivocal evidence of shallow water. The contact at the top of member E is sharp, which suggests that subsidence was rapid. The breccias interpreted as resulting from shelf-edge slumping may have formed at this time. I have seen no features in the rock by which the depth of subsidence would be determined, but inasmuch as the laminated siltite and argillite continue 3,500 m up section interrupted only by the turbidite quartzites of member G, I suspect that the sea floor must have been hundreds of meters deep during the early stages of deposition.

Deposition of member F began the second episode of basin filling. Members F and H, deposited during this second episode, are both considerably more argillic and less silty than are the underlying rocks deposited during the first episode of basin fill. The pyrite laminae formed because organic matter was deposited in sufficient quantity to permit sulfate-reducing bacteria to thrive. The organic matter itself was presumably of planktonic origin. The argillite-pebble beds in the lower part of member F may have been mudflows or they may be the soles of slides.

Mud deposition was interrupted by the emplacement of turbidite sands and silts that are now the characterizing quartzite and siltite of member G. Subsequently, deposition of terrigenous fines continued to fill the basin.

Similarities in lithologic character, sequence, and thickness suggest that members F and G are approximately equivalent to the middle member of the Aldridge Formation. The middle Aldridge consists of quartz-rich graywacke interbedded with dark carbonaceous argillite (Thompson and Panteleyev, 1976); the Sullivan deposit (fig. 1) occurs near the base of the member. The graywackes of the middle member of the Aldridge are turbidites derived from a southern source (Bishop and others, 1970). The middle member contains 14 interbedded marker beds that consist of finely laminated argillite and are of regional extent (Thompson and Panteleyev, 1976). The regional extent of the marker beds and their character are evidence that the sea floor in that area was deep and flat. I have not identified any of these laminite markers in the Plains and Perma areas (though other workers may have found at least one). The absence of all or most of the markers in the Plains area and the northward transportation directions in the middle member of the Aldridge of British Columbia combine to suggest that the Plains area was upslope from the basin floor on which the middle member of the Aldridge was deposited.

Finally, shallow-water sands and silts of the basal part of the Burke Formation prograded across the area, completing the second episode of basin filling and marking the end of the deposition of the Prichard Formation.

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