Stratigraphy and Lithocorrelation of the Snowslip Formation (Middle Proterozoic Belt Supergroup), Glacier National Park, Montana

By JAMES W. WHIPPLE and SUE N. JOHNSON

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CONVERSION FACTORS

For readers who wish to convert measurements from the metric system of units to the inch-pound system of units, the conversion factors are listed below.

Metric unit	Multiply by	To obtain inch-pound unit
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile

Stratigraphy and Lithocorrelation of the Snowslip Formation (Middle Proterozoic Belt Supergroup), Glacier National Park, Montana

By James W. Whipple *and* Sue N. Johnson

Abstract

The Snowslip Formation is in the upper part of the Middle Proterozoic Belt Supergroup; it is exposed in the central and western parts of Glacier National Park and composed mostly of fine-grained, terrigenous clastic rocks that were deposited about 1,200 Ma in a paralic, mixed siliciclastic-carbonate environment. In the northern part of the Park, the Snowslip Formation contains the Purcell Lava, which is a series of thin mafic flow units that are absent from the type section in the southern part of the Park. Because of the importance of the Purcell Lava as a time line in the Belt, a reference section is established at Hole-in-the-Wall in the northern part of the Park and subdivided into six informal members. The uppermost member (member 6) encloses the Purcell Lava.

Lithocorrelation of members exposed in the reference section, the type section, and two other sections of the Snowslip in Glacier National Park indicates a northward thinning of stratigraphic units. Compositional analysis of framework grains in arenite units suggests that Snowslip sediments were multicyclic and had a cratonic source. Based on changes in mineralogy and facies and limited paleocurrent measurements, sediment transport direction was northwest with minor directional components west and southwest.

Deposition of the Snowslip Formation was preceded by a period of erosion, interrupted by extrusion of the Purcell Lava, and punctuated by two episodes of fluvial sedimentation. These interruptions are interpreted to be related to periods of active tectonism during sedimentation. A polarity reversal is coincident with a disconformity at the base of the Snowslip.

INTRODUCTION

The Snowslip Formation is the lowermost stratigraphic unit in the Missoula Group of the Middle Proterozoic Belt Supergroup (fig. 1). In Glacier National Park, the Snowslip is exposed along the Akamina syncline, in the Apgar Mountains, and in the downthrown block of the Blacktail fault (fig. 2). It mostly consists of terrigenous clastic rocks that were deposited in a mixed siliciclastic-carbonate environment. In the northern part of the Park, the upper part of the Snowslip encloses the Purcell Lava, a series of thin mafic flow units that were emplaced in part subaqueously and in part subaerially (McGimsey, 1985). The type section of the Snowslip, which was named and described by Childers (1963), is on the flank and ridges of Snowslip Mountain in the southernmost part of Glacier National Park (fig. 2); here, it rests with apparent conformity rather sharply on the Helena Formation, does not contain the Purcell Lava, and is overlain conformably by the Shepard Formation.

The age of the Snowslip is uncertain. Hunt (1962) dated a hornfels below the Purcell Lava in Canada at 1,075 Ma; however, glauconite from the overlying Shepard Formation has been recently dated (Rb/Sr) at 1,170 ± 20 Ma (Obradovich, Peterman, and Zartman, reported by Harrison, 1984). A U/Pb date on zircon from a metabentonite bed about 65 m below the base of the Snowslip (in the Helena Formation) at Logan Pass in Glacier National Park yielded an age of about 1,350 Ma, although the zircon was observed to contain a possible detrital core (Harrison, 1984). Age correlation based on paleomagnetic pole positions of Belt strata on Proterozoic polar wandering paths (Elston and Bressler, 1980) suggests that the age of the Missoula Group is no younger than 1,200 Ma and that the Snowslip is about 1,375 Ma (Elston, 1984). A major polarity reversal, known to occur at or near the base of the Snowslip in most parts of the Belt basin (Evans and others, 1975; Elston and Bressler, 1980), has not been correlated with polarity zonation of other Proterozoic sequences in the North American Cordilleran, and so, regional age correlation using polarity zonation is not possible at this time. Considering these various dates, we feel the Snowslip was probably deposited somewhere between 1,350 and 1,170 Ma (fig. 1).

Geologic Setting

The geology of Glacier National Park consists mainly of allochthonous Belt Supergroup strata that have been subjected to lowermost greenschist-facies metamorphism (Maxwell, 1973) and have a maximum thickness

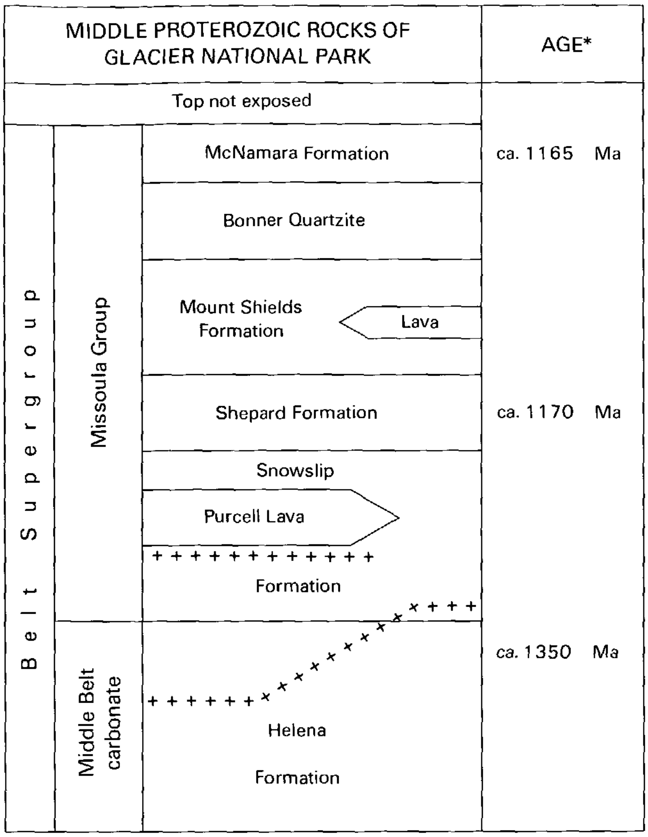


Figure 1. Stratigraphy and approximate age (based on lithostratigraphic correlation) of younger Middle Proterozoic rocks of Glacier National Park. Crosses, mafic sills. *As presented at Belt Symposium II, October 1983 (Obradovich and others, 1984).

of about 5,200 m (Whipple and others, 1984). For the most part, Proterozoic sedimentary rocks of the Park were deposited on or near a continental shelf and consist of terrigenous clastic rocks in succession with platformal carbonate units. Belt strata in Glacier National Park form the upper plate of the Lewis thrust fault, a major low-angle, west-dipping fault of early Tertiary age that has at least 40 km of northeast-directed transport (Dahlstrom, 1970). Consequently, all sections of the Snowslip that were studied in the Park have been transported northeastward by the Lewis thrust fault from their original sites of deposition, and some are separated by upper-plate structures that have uncertain geometries and amounts of displacement (figs. 2 and 3). Nevertheless, we feel that lithocorrelation of the Snowslip Formation in and adjacent to Glacier National Park is possible amidst these structural complexities.

Purpose

The objectives of this study are: (1) to establish a reference section of the Snowslip Formation that contains the Purcell Lava; (2) to subdivide the formation into informal members or lithostratigraphic units; and (3) to correlate lithofacies between measured sections in Glacier National Park. In addition, discussion here will touch on depositional setting, tectonics and sedimentation, and regional correlation. By elucidating the stratigraphy and lithocorrelation of the Snowslip Formation in Glacier National Park, we hope to gain a better understanding of the tectonic and time-stratigraphic significance of the Purcell Lava and polarity reversal at the base of the Snowslip, and consequently, of the correlation and interpretation of equivalent lithofacies across the northern part of the Belt basin. Also, the correlation of Missoula Group rocks of the Belt basin with rocks of similar age in the northern Canadian Cordilleran is linked to an understanding of the tectonosedimentary setting of the Snowslip Formation.

Data for this report were gathered as part of a comprehensive geologic study of Glacier National Park from 1979 to 1985. We wish to acknowledge the enthusiastic assistance of James C. Sample who helped us with the tedious chore of measuring sections.

STRATIGRAPHY

Four sections of the Snowslip Formation (fig. 2) were selected to examine changes that occur throughout the Park across facies or structural boundaries; one of these is the type section revisited. In the Park, the Snowslip is characterized by alternating reddish and grayish-green clastic rocks that are locally calcareous. Its thickness ranges from a maximum of 636.3 m at the Huckleberry Ridge section to a minimum of 357.5 m at Hole-in-the Wall; these two sections contain the Purcell Lava.

Because the type section of the Snowslip Formation does not contain the Purcell Lava, we feel that a reference section containing the lava should be established. The Hole-in-the-Wall section was selected for this purpose because it is accessible and well exposed and contains good exposures of the Purcell Lava and its contacts with enclosing sedimentary rocks.

Hole-in-the-Wall Reference Section

The reference section is in the northern part of Glacier National Park, just east of Boulder Pass, in the east-facing wall of the Hole-in-the-Wall cirque (fig. 4). Access is gained by well-maintained trails either from lower Kintla Lake (24 km), Bowman Lake (21.5 km), or the upper end of Waterton Lake (16 km). The Snowslip is well exposed in the cirque basin and can be traced laterally around the headwall, although some parts of the formation are inaccessible because of cliffs.

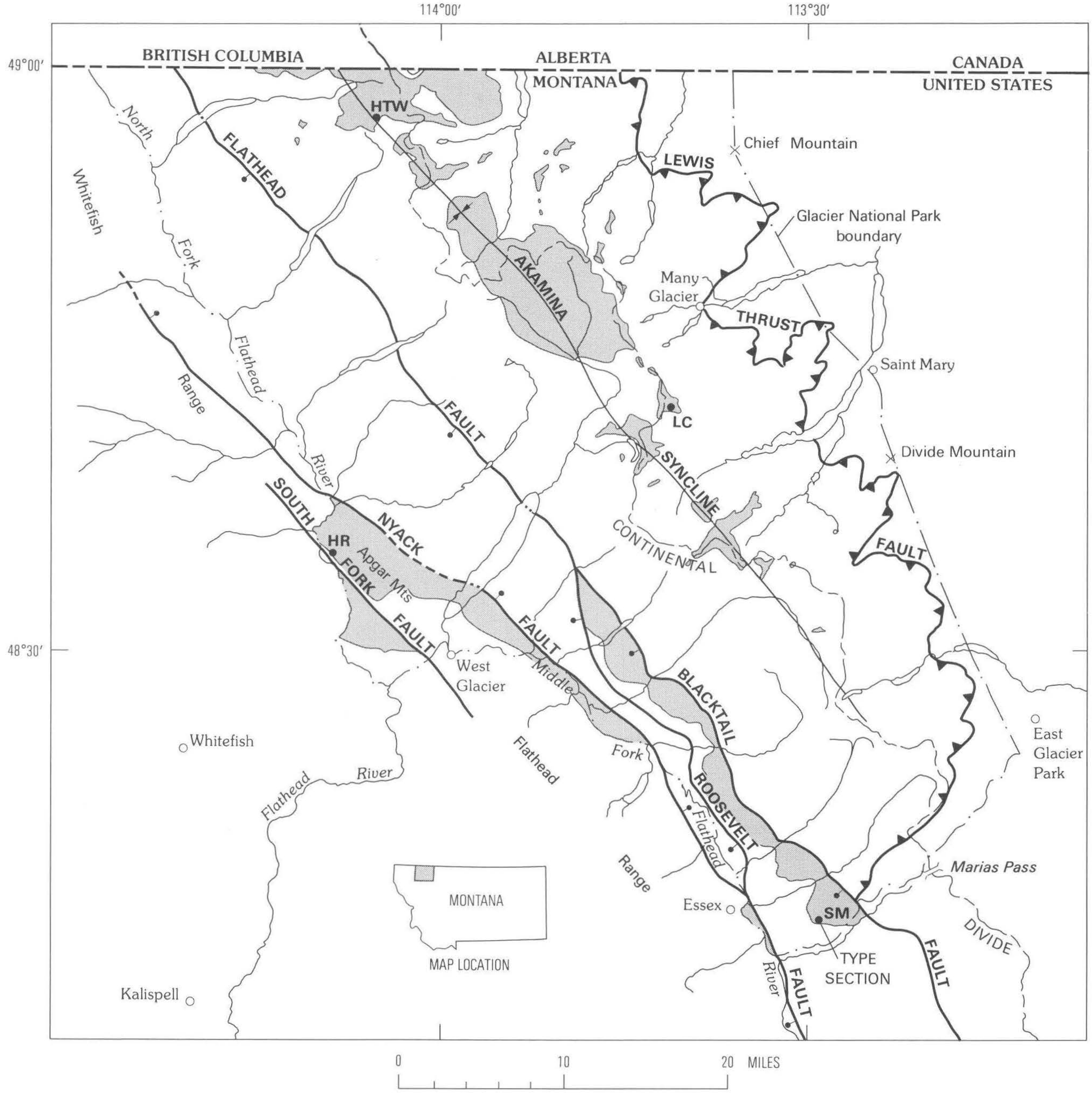
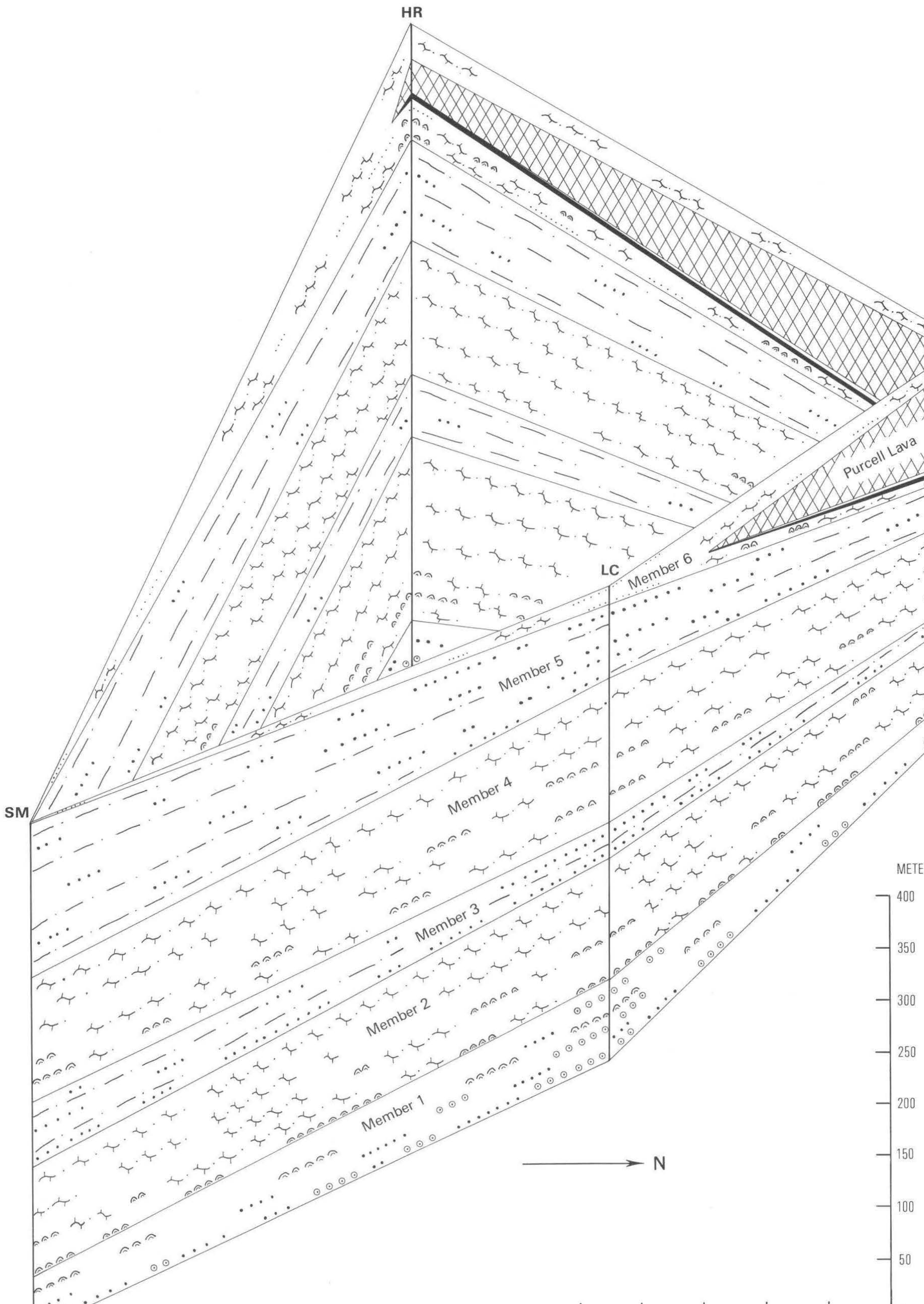


Figure 2. Generalized map showing distribution of the Snowslip Formation and younger strata (shaded), location of measured sections, and major structures in Glacier National Park. HR, Huckleberry Ridge; HTW, Hole-in-the-Wall; LC, Lunch Creek; SM, Snowslip Mountain.

At this locality, the Snowslip is subdivided into six informal members that are designated, from oldest to youngest, 1 through 6 (fig. 5); the uppermost member, 6, encloses the Purcell Lava. Upper and lower contacts of the formation are exposed, and the Snowslip appears to be conformable with adjacent stratigraphic units. The total thickness of the Snowslip, the Purcell Lava, and an enclosed diabase sill is 357.5 m.

Terms used in the following description of lithostratigraphic units come from a variety of sources. Lithologic terms are used in accordance with definitions from the second edition of the AGI Glossary of Geology (Bates and Jackson, 1980) or Pettijohn and others (1973). Rock color, where determined in the field, is expressed in alphanumeric units from the Geologic Society of America rock-color chart (Goddard and others, 1948); other color terms are subjective. Lamination and bedding style and thickness are from Campbell (1967), and


HR
HTW
SM
LC
Purcell Lava
Member 6
Member 5
Member 4
Member 3
Member 2
Member 1
N
METERS
400
350
300
250
200
150
100
50
0
25
20
15
10
5
0
KILOMETERS

EXPLANATION

- Interbedded oolitic arenite, lithic arenite, and siltite and argillite couplets
- Stromatolitic limestone and interbedded calcareous siltite
- Lenticular beds of arenite
- Calcareous, fining-upward couplets of siltite and argillite; minor thin lenticular beds of calcareous arenite
- Fining-upward sequences of ripple cross-laminated arenite, siltite, and mud-cracked argillite
- Diabase sill
- Basalt; Purcell Lava
- HTW Hole-in-the-wall
- HR Huckleberry Ridge
- LC Lunch Creek
- SM Snowslip Mountain
- U Upthrown side of fault
- D Downthrown side of fault

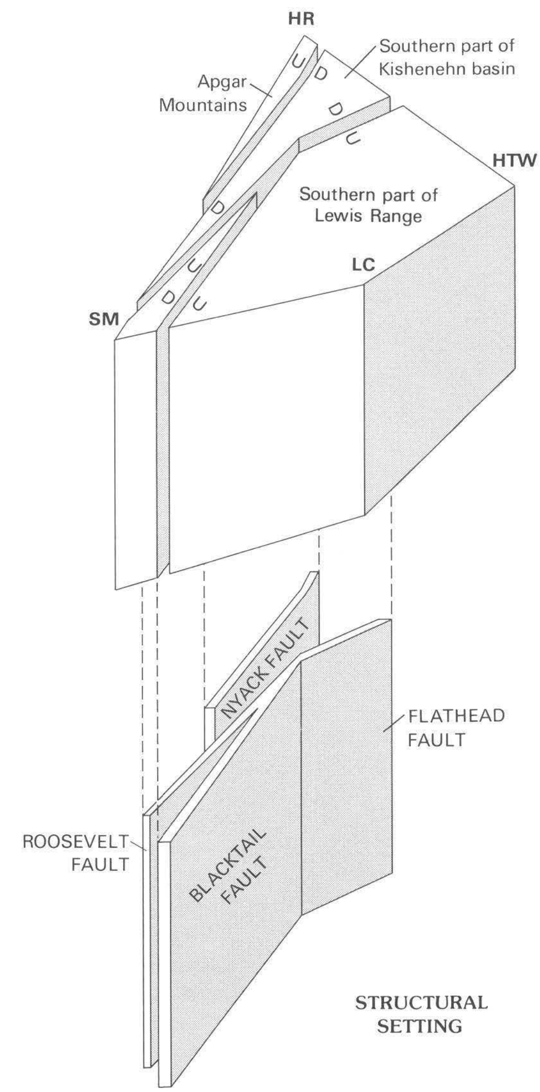


Figure 3(above and facing page). Schematic fence diagram showing lithofacies correlation among sections of the Snowslip Formation, Glacier National Park. Inset diagram shows structural setting of measured sections and relative fault movements.

descriptive terms of grain size are those of the Wentworth size classification.

Member 1

Interbedded calcareous siltite and argillite are the principal lithologies of member 1. They are typically arranged as wavy nonparallel, fining-upward couplets less than 10 mm thick, and they vary in color from reddish hues (5 R 5/4, 5 RP 6/2) to grayish green (10 G 6/2, 5 G 6/1). Although siltite and argillite are the most abundant lithologies, the member is characterized by thin (less than 3 cm thick) lenticular beds of poorly sorted, fine- to coarse-grained calcareous arenite. Clasts are dominantly rock fragments, quartz, and oolites, many of which are partially replaced and coated by hematite (fig. 6). Arenite beds are commonly light gray and weather tan. Mottling is common among the red and green strata such that rock color changes along strike. Sedimentary structures include syneresis and desiccation cracks, numerous thin laminae of mud-chip breccia, fluid-escape structures, some flaser lamination, and some small-scale cross-lamination in oolitic arenite beds. The lower contact is placed between the uppermost bed of pink to gray oolitic limestone of the Helena Formation and lowermost bed of poorly sorted calcareous arenite of member 1. Member 1 is 25.91 m thick.

Member 2

Member 2 is mostly composed of greenish-gray siltite (5 G 6/1) and olive (10 Y 5/2) argillite couplets. The siltite fraction is commonly two-thirds the couplet thickness. Couplets are as much as 4 cm thick but generally are only 10–20 mm thick. Outcrops, which generally weather recessively, are poorly exposed and are yellowish gray or brown because of local calcite and dolomite cements. Interbedded in member 2 are beds of pink, red, and cream-colored stromatolitic limestone as much as 15 cm thick (fig. 7). The distinct reddish color is the result of several laminae that contain fine-grained hematite (Horodyski, 1975). Commonly associated with stromatolites are beds as thick as 10 cm of pyritic flat-pebble conglomerate and poorly sorted lithic arenite. Clasts are mostly rock fragments (including limestone), quartz, and minor feldspar that are cemented by calcite and dolomite. Syneresis cracks are common in argillite laminae. Ripple cross-lamination occurs in most beds of arenite. The lower contact is placed at the base of a stromatolitic limestone which is underlain by reddish strata of member 1. Member 2 is 69.85 m thick.

Member 3

Member 3 consists of interbedded arenite, siltite,

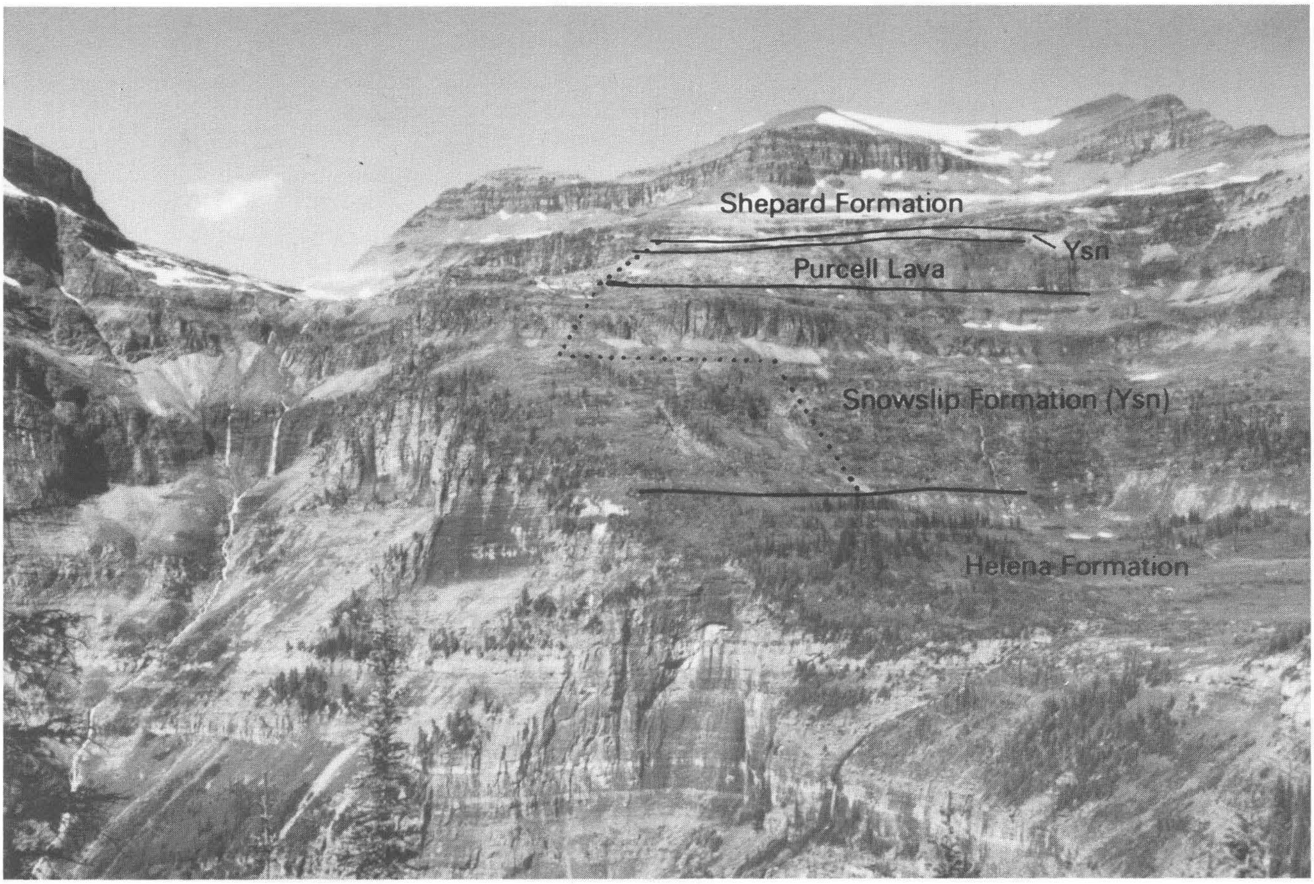


Figure 4. Hole-in-the-Wall basin, looking west at location of reference section. Dotted line is measured section.

and argillite that are arranged locally as fining-upward sequences less than 2 m thick. Arenite beds are white to greenish gray, less than 10 cm thick, and lenticular, and have erosional bases. Arenite grains are fine to medium sized, moderately sorted, and mostly composed of quartz, feldspar, and some rock fragments. Siltite and argillite in fining-upward sequences are grayish red and reddish purple (5 RP 5/2). Apart from fining-upward sequences, beds of siltite and argillite are greenish gray and locally dolomitic, similar to beds in member 2. Mud-chip breccias and mud chips aligned on foresets of cross-laminated arenite beds are present locally, particularly at the base of fining-upward sequences (fig. 8). Mud-draped ripples, shrinkage cracks, and fluid-escape structures are common. The lower contact is placed between calcareous, greenish-gray rocks of member 2 and beds of quartz and subfeldspathic arenite of member 3. Member 3 is 16.6 m thick.

Member 4

Member 4 is similar to member 2 in all respects, and differentiating the two in isolated exposures is difficult. The dominant lithologies of member 4, as in member 2, are greenish-gray siltite and argillite that are arranged as thin, wavy fining-upward couplets or rhythmic sequences as much as 25 cm thick. Argillite composes 80 percent of the interbedded and interlaminated lithologies in the lower part of the member but decreases to about 25 percent near the top. Stromatolitic limestone, pyrite, carbonate cement, and limonitic stain occur locally. In the upper part of the member, thin lenticular beds of very fine grained, calcareous arenite and gray dolomite are present. Syneresis cracks, fluid-escape structures, and mud-chip breccias are abundant. Arenite beds are typically ripple cross-laminated. The lower contact is placed on top of the uppermost reddish argillite of member 3. Member 4 is 79.6 m thick.

Member 5

In the Hole-in-the-Wall reference section, as elsewhere in the Park, member 5 is the most distinct and easiest to recognize subdivision of the Snowslip. It is resistant to weathering and forms bold outcrops. Beds of white, pink, and greenish-gray arenite are overlain

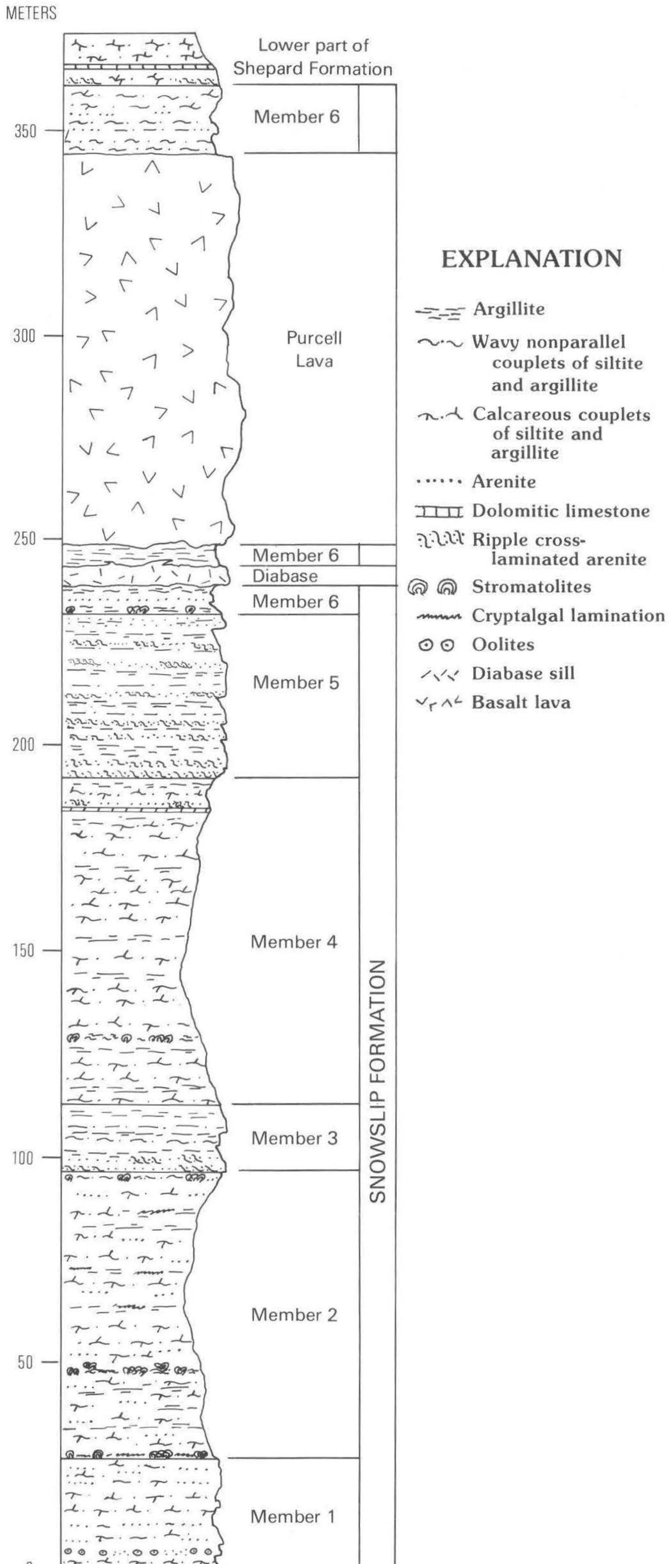


Figure 5. Diagrammatic stratigraphic column of the Snowslip Formation at Hole-in-the-Wall reference section; section includes Purcell Lava and diabase sill.

successively by reddish beds of interlaminated arenite and siltite, siltite and argillite, and finally argillite; this arrangement of lithologies forms distinct fining-upward successions that range in thickness from a few centimeters to as much as 3.5 m (fig. 9). Arenite beds are locally calcareous and commonly lenticular, and, in order of abundance, are composed of quartz, rock fragments, and feldspar (fig. 10). Siltite beds are grayish red (5 R 5/2); argillite beds are reddish purple (5 RP 5/2) and have very thin, wavy discontinuous laminae. Sedimentary structures abound in this member, and most are indicative of shallow water and subaerial exposure. These structures include a wide variety of ripple marks, raindrop impressions, wrinkle marks, desiccation cracks, mud-draped ripples, mud-chip breccias, and some fluid-escape structures. The lower contact of the member is placed at the base of the lowest bed of arenite where that bed and overlying reddish strata form a fining-upward sequence. Member 5 is 39.82 m thick.

Member 6

The uppermost member, 6, encloses facies of the Purcell Lava and is compositionally similar to members 2 and 4. It mainly consists of greenish-gray siltite and argillite couplets that are less than 1 cm thick. Thin lenticular beds of arenite (less than 10 cm thick), stromatolitic limestone, and thinly laminated dark-green argillite are present below the lava. Similar beds occur above the lava, but many are grayish red to reddish purple. One laterally continuous bed of red siliceous arenite just below a sill commonly contains pyrite and chalcopyrite. Sedimentary structures in the member include ripple cross-lamination in arenite beds, syneresis cracks, fluid-escape structures, and mud-chip breccias.

Although the lower contact of the Purcell Lava with member 6 is very irregular (probably due to loading by the basalt), no evidence of an unconformity was observed. No erosional surface was discovered at the upper contact; McGimsey (1985, p. 67) described the upper surface of the Purcell Lava at Hole-in-the-Wall as, "*** scoriaceous and/or smooth and ropy with a 1 to 5 cm pinkish-red oxidized horizon." Strata of member 6 appear to have been deposited conformably onto surface irregularities of the lava, and so at this locality, member 6 is interpreted to enclose the lava conformably. The stratigraphy of the Purcell Lava, which is shown in figure 11, was superbly described by McGimsey (1985). Of particular note, is about 12 m of pillow lava at the base of the Purcell, which suggests flowage into or under water (fig. 12).

Below the extrusive facies of the Purcell Lava and separated from them by 5 m of member 6, is a diabasic sill that is as thick as 20 m in many places. The sill, which locally intrudes the base of the pillow lava, is interpreted to be cogenetic with the Purcell Lava (McGimsey, 1985).

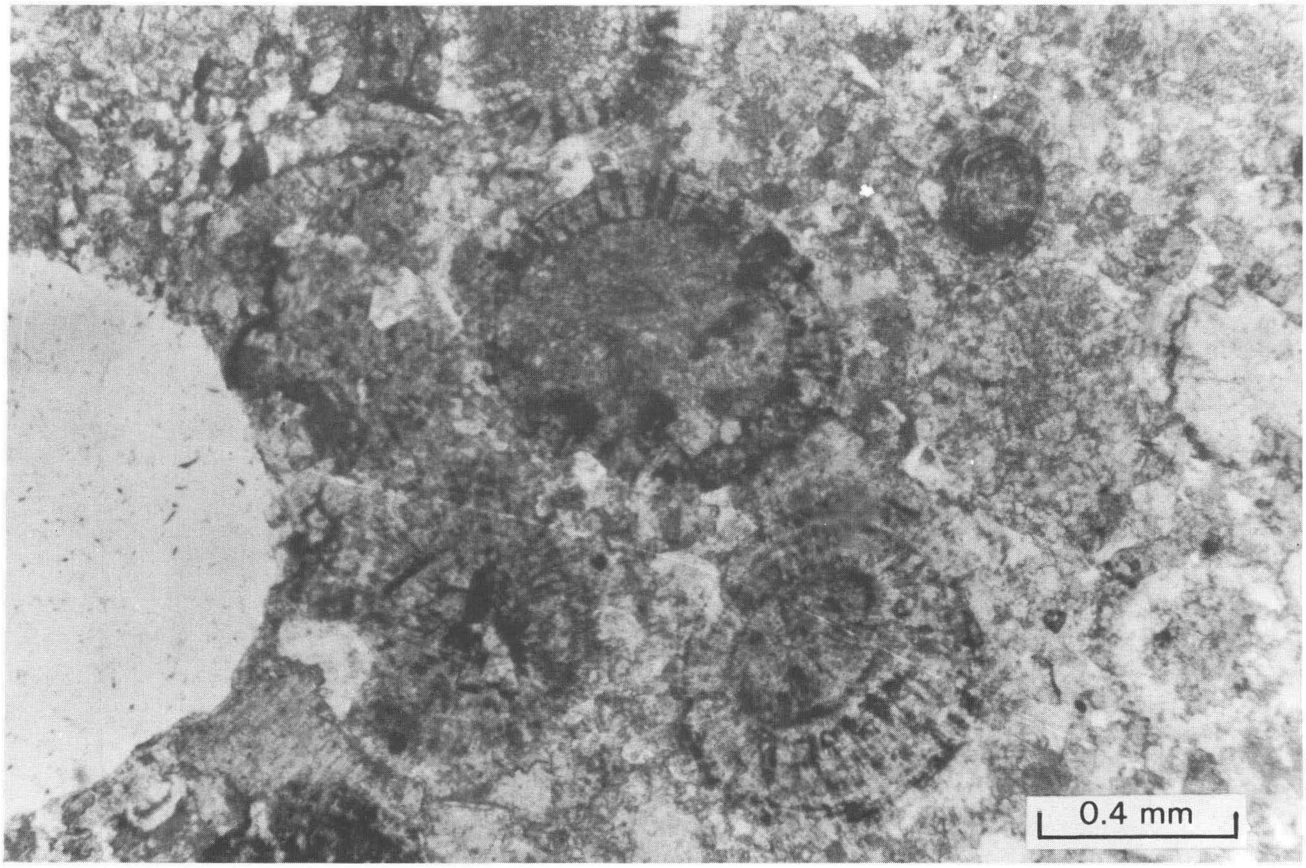


Figure 6. Photomicrograph (plain light) of member 1 ooliths showing hematite replacement and rims.

Upper and lower contacts of member 6 are conformable. The lower contact is placed between reddish argillite and siltite of the uppermost part of member 5 and thinly laminated greenish-gray argillite and interbedded arenite of member 6. The contact of member 6 with the Shepard Formation is placed at the top of the uppermost bed of argillite, where overlying beds of the Shepard, in order of abundance, consist of yellowish-gray weathering couplets of calcareous siltite and argillite, ripple cross-laminated dolarenite, and limestone. At the reference section, the total thickness of member 6, the Purcell Lava (99.6 m), and the diabase sill is 125.72 m (fig. 5 and Appendix).

LITHOCORRELATION

In addition to the reference section at Hole-in-the-Wall and the type section, two other sections were measured so that four sections in all could be used for lithocorrelation in Glacier National Park. The type section at Snowslip Mountain (fig. 13) was revisited, and stratigraphic units that had been measured and described by Childers (1963) (total thickness reported, 489.6 m) were recast in terms compatible with this report. The Lunch Creek section is 458.4 m thick and is in the central part of the Park on the west-facing flank of Piegan Mountain (fig. 14). The farthest west section of the Snowslip was measured on the west-facing side of Huckleberry Ridge in the Apgar Mountains (fig. 15), where this formation is 636.3 m thick. Although not well exposed, the Huckleberry Ridge section provides data west of and normal to the regional strike of sedimentary units, whereas the other three sections are positioned essentially along depositional strike.

The Snowslip Mountain, Lunch Creek, and Huckleberry Ridge sections can be subdivided into six informal members using the same lithostratigraphic criteria that were established at the reference section. The Purcell Lava is absent in sections at Lunch Creek and Snowslip Mountain, and all members thin to the north. Figure 3 is a schematic fence diagram that shows correlation and changes in lithofacies among the four measured sections.

Differences other than thickness exist among the four sections and are most noticeable in the mineralogy of the arenite beds and in the sedimentary structures. Because of numerous arenite beds, members 1, 3, and 5 best illustrate differences in lithofacies and are the focus

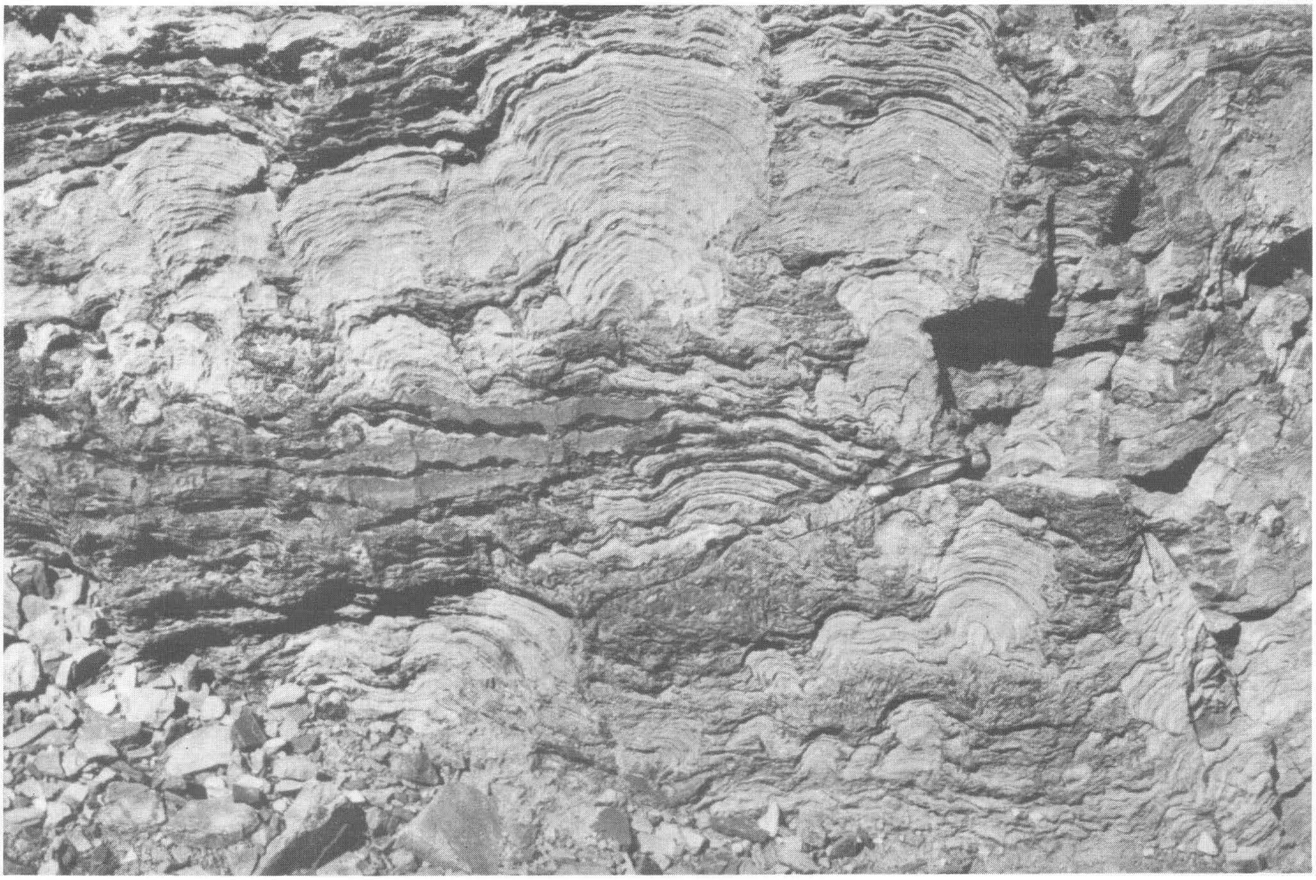


Figure 7. Pinkish stomatolitic limestone in member 2; knife is 8 cm long. Photo by O.B. Raup.

of the following discussion. Differences in lithofacies among sections in members 2 and 4 are not apparent, and in member 6 the major difference among sections is the presence or absence of the Purcell Lava (fig. 3).

Member 1

Most arenite beds in member 1 at all sections contain abundant dolomite clasts and ooliths and varying amounts of quartz and feldspar. All beds are poorly sorted and cemented by calcite and dolomite. Many ooliths are broken and deformed, some ooliths form aggregate spherules, and in the lowermost arenite beds, most ooliths are hematitic (figs. 6, 16). Small armored spherules are commonly intermixed with the ooliths (fig. 17).

Arenite beds are most abundant in the Lunch Creek section, where they are thicker and more feldspathic and contain more ooliths than at other sections. Arenite beds in the Huckleberry Ridge section contain the least feldspar and fewest oolite beds. Mineralogy, fabric, and texture of arenite beds in member 1 suggest that the source for most clasts was the dolomite and oolitic limestone beds of the uppermost part of the underlying Helena Formation.

Member 3

Red beds that contain several sedimentary structures indicative of subaerial exposure distinguish member 3 from the enclosing green beds of members 2 and 4. Member 3 is composed of rhythmic, fining-upward sequences that began with sand deposition and ended with silt and clay deposition. These sequences indicate cyclic sedimentation by waning-current flows and are thickest and most complete (in other words, resemble an ideal sequence; see fig. 9*B*) in the Lunch Creek section where they are 1–3 m thick. In the Snowslip Mountain section and to some extent in the Hole-in-the-Wall succession, incomplete, fining-upward sequences commonly consist of rhythmic arenite and argillite paired beds. The Huckleberry Ridge section contains only a few beds of arenite, and distinct fining-upward sequences are rare. Interbedded greenish-gray siltite and argillite, similar to

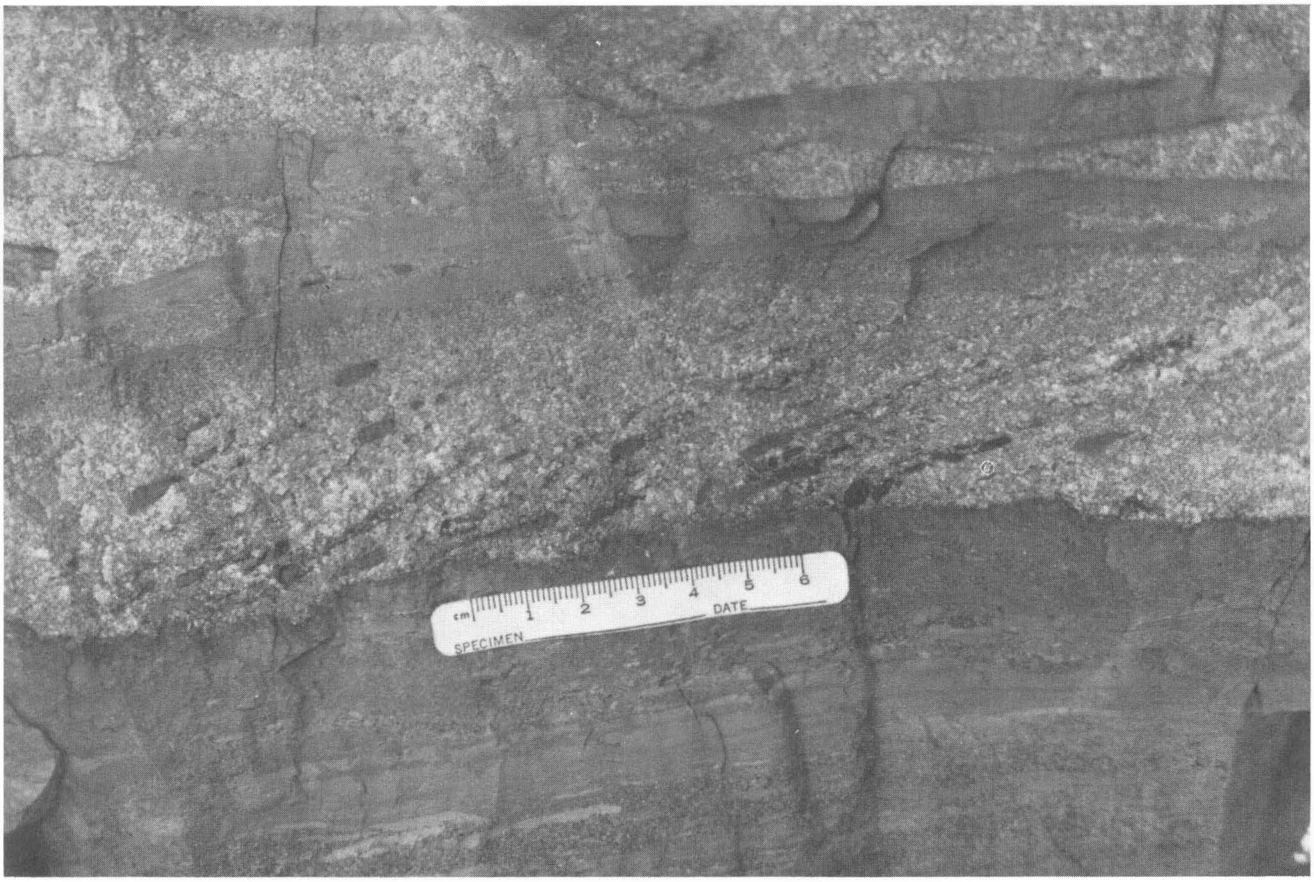


Figure 8. Mud chips (rip-up clasts) aligned on foresets of cross-laminated bed of arenite, member 3.

strata of member 2, are common in member 3 of the Huckleberry Ridge section.

Beds of arenite in all sections of member 3 are similar mineralogically; they mostly consist of quartz grains in both clast- and matrix-supported fabrics. All arenite units contain some carbonate and hematite as well as silica cement; at Huckleberry Ridge, dolomite clasts are common. Degree of clast rounding is the same in all sections and appears to be a function only of grain size and not of distance of transport. Quartz grains commonly have overgrowths, and at Huckleberry Ridge some of these overgrowths are abraded (fig. 18). At Hole-in-the-Wall some coarse-grained arenite clasts are intermixed with very fine grained clasts in such a manner as to suggest that the fabric and bimodal clast size are the result of eolian processes (fig. 19).

Member 5

Member 5 is the most distinct member of the Snowslip Formation and is present throughout Glacier National Park. Red beds that compose the member have lithofacies similar to those of member 3 except that fining-upward sequences are generally thicker and complete sequences are more abundant. The sequences are rhythmic and vary in thickness among sections. The thickest and greatest number of fining-upward sequences occur at Lunch Creek, where they are typically 7–8 m thick. Sequences at Snowslip Mountain and Huckleberry Ridge are commonly incomplete and distinctly thinner (35–85 cm thick) than those at Lunch Creek and Hole-in-the-Wall.

Beds of arenite in the lower parts of fining-upward sequences in member 5 vary in thickness, sedimentary structures, and mineralogy between sections. Where sequences are best developed, the lowermost arenite beds are as much as 30 cm thick, cross-bedded, and lenticular. Unidirectional trough cross-bedding and herringbone cross-bedding are commonly intermixed. Large assymetrical ripples are common and display wave lengths and amplitudes of as much as 14 cm and 1.4 cm, respectively. These lowermost beds contain numerous mud chips derived from the top of the underlying sequence and several varieties of rock fragments, particularly in the Snowslip Mountain, Lunch Creek, and Hole-in-the-Wall sections. Beds of coarse siltite and very fine to fine grained arenite, which overlie the coarser grained basal beds, are typically even-parallel laminated or ripple cross-laminated. Arenite beds of member 5 in all sections contain a wide assortment of lithic clasts, but most clasts are composed of monocrystalline quartz. At Snowslip Mountain, Lunch Creek, and Hole-in-the-Wall, assorted clasts consist of dolomite, ooliths (Hole-in-the-Wall), porphyritic diorite, chert, quartzite, and polymineralic grains of K-feldspar and quartz that range in size from very fine to coarse. At Huckleberry Ridge, clasts are dominantly medium-grained or finer quartz. Quartz grains and some K-feldspar have syntaxial overgrowths in all sections (fig. 20). Quartz and hematite cements are common in all arenite units, and calcite/dolomite cements are common in the Snowslip Mountain, Lunch Creek, and Hole-in-the-Wall sections.

Arenite Composition

A ternary QFL plot (fig. 21) of quartz, feldspar, and lithic fragment abundance for 43 arenite samples collected from the four measured sections of the Snowslip Formation and member 1 along Going to-the-Sun-Road shows range of framework-grain composition and some sediment distribution patterns. The mean composition of framework grains for the suite is $Q_{64}F_{13}L_{23}$ and is classified as a sublithic arenite (Pettijohn and others, 1973). The distribution of arenite samples from Huckleberry Ridge indicates that they are distinctly low in feldspar relative to other sections, whereas several of the Lunch Creek and Going-to-the-Sun Road samples are distinctly feldspathic. Hole-in-the-Wall samples show about equal amounts of feldspar and lithic fragments, regardless of quartz content. Such sketchy patterns and trends for arenite samples in the Snowslip need to be substantiated by additional and more complete sampling before they can independently support any interpretation of distance from source, transport direction, or compositional differences between sections. Nevertheless, when used in conjunction with other sedimentologic data, they corroborate the interpretations that are expressed in the following section of this paper.

DISCUSSION

Depositional Setting

Lithofacies of the Snowslip Formation in Glacier National Park were deposited primarily in a mixed

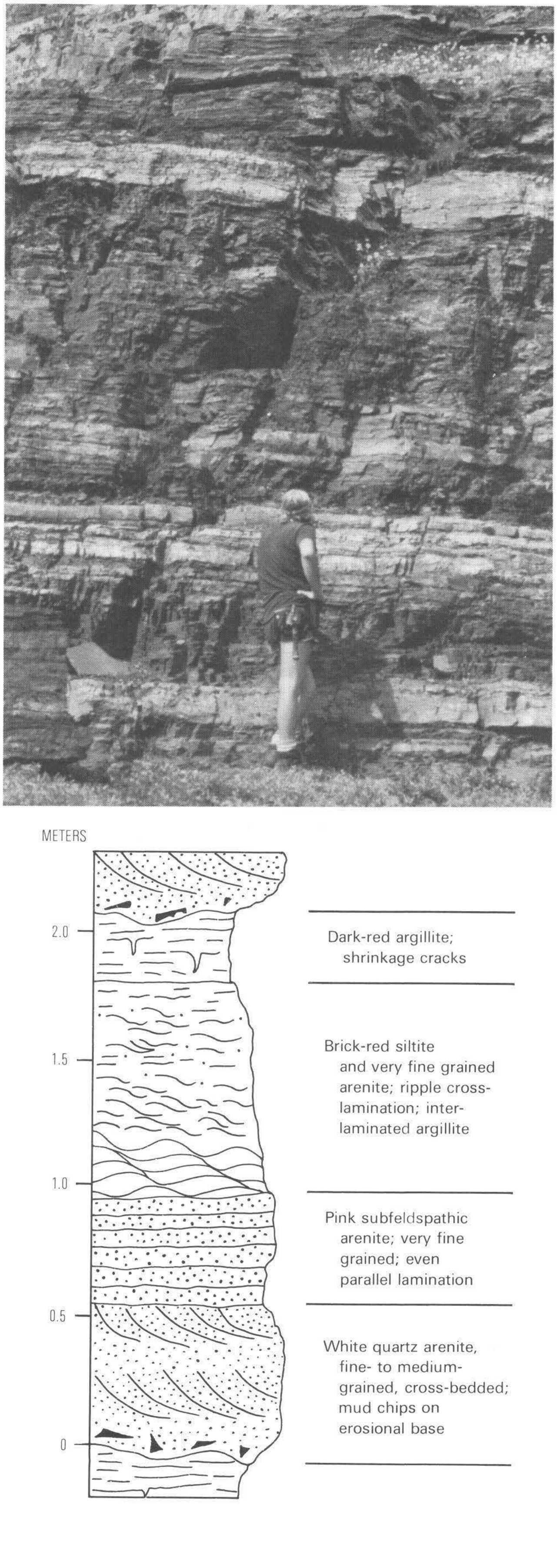


Figure 9. *A*, Cyclic fining-upward sequences in member 5 of the Snowslip Formation at Hole-in-the-Wall. *B*, Diagrammatic sketch of an ideal, complete fining-upward sequence in member 5.

Figure 10. Photomicrograph (crossed nicols) of arenite fabric and composition, member 5 of the Snowslip Formation at Hole-in-the-Wall reference section.

siliciclastic-carbonate environment. We believe that this environment was marine and that the majority of sediments were deposited in a peritidal setting. At the close of Helena time, numerous beds of oolites and stromatolites formed on a prominent carbonate shelf that had extensive shoals. Oolite beds in the upper part of the Helena commonly display herringbone cross-lamination which suggests that the environment was influenced by tides. The environment of deposition for the lower part of the Snowslip was still in an area of carbonate production as evidenced by interbedded calcareous siltite and oolite and stromatolite beds, particularly in members 2 and 4.

Members 3 and 5 represent a widespread influx of terrigenous clastic material that was probably caused by uplift in the source area, or increased basin subsidence, or both. Fining-upward sequences in these members are interpreted to be sheet-flood deposits that were formed by unrestricted, waning currents which flowed across an alluvial apron, adjacent to the peritidal environment. At times, these sediments were probably deposited in standing water, because several sedimentary structures indicate alternating periods of submergence and emergence. Fining-upward cycles that are thin, incomplete, or intercalated with green beds are thought to indicate deposition in more distal parts of the alluvial environment.

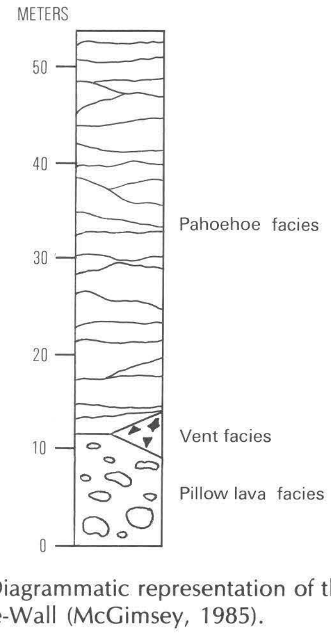


Figure 11. Diagrammatic representation of the Purcell Lava at Hole-in-the-Wall (McGimsey, 1985).

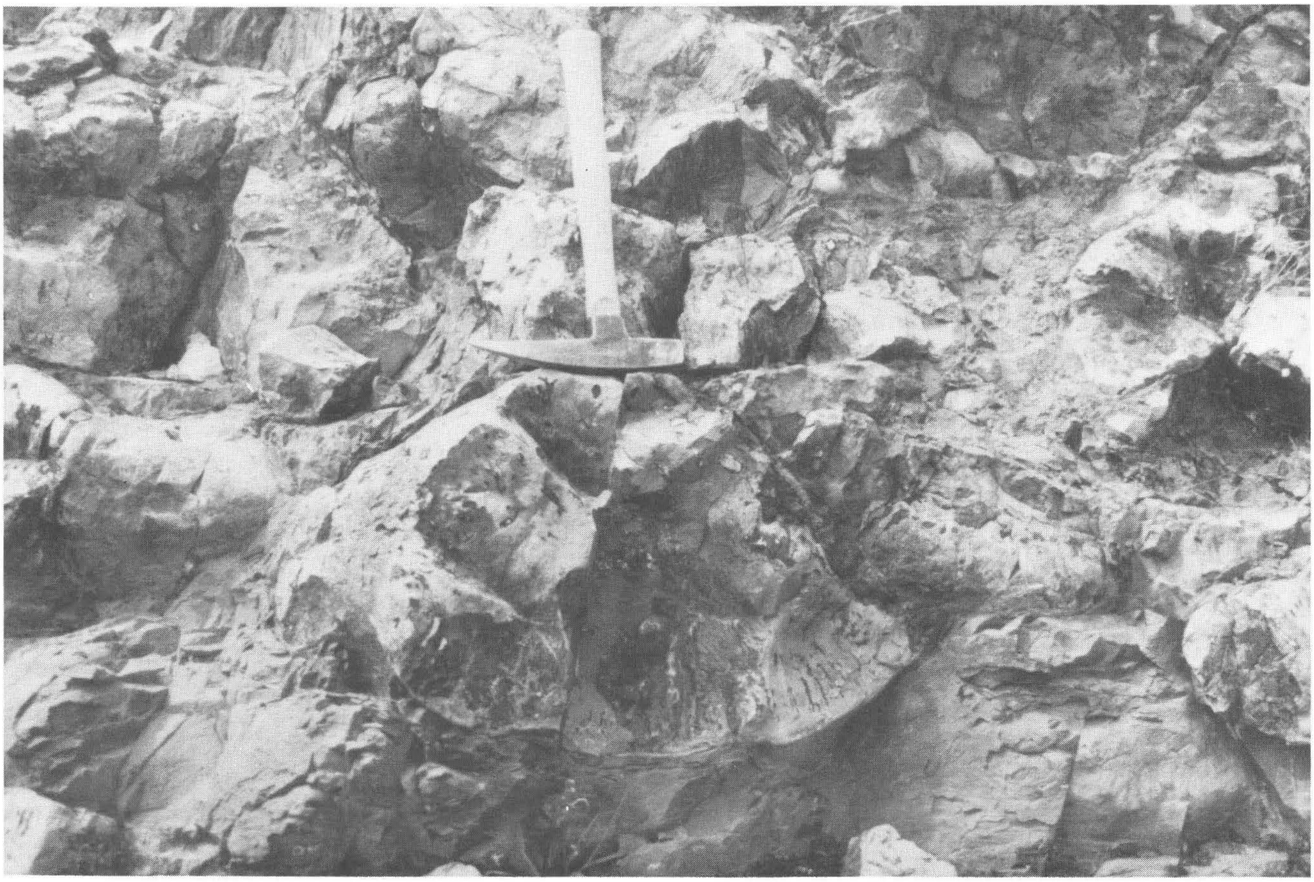


Figure 12. Large pillow in the pillow lava facies at the base of the Purcell Lava at Hole-in-the-Wall.

The Purcell Lava is interpreted to have been deposited in a peritidal environment. The lowermost lava flows (pillow facies) of the Purcell were extruded subaqueously (subtidal environment), and McGimsey (1985, p. 26) interpreted thickness of the pillow facies as indicating water depth that ranged from 9 to 15 m at the time of emplacement and probably during deposition of member 6. Subsequent lava flows were emplaced in a subaerial environment and formed positive, emergent areas during continued sedimentation of the Snowslip Formation in adjacent parts of the Belt basin. In some areas, upper surfaces of the last flows remained exposed long enough to oxidize before being inundated by marine waters.

Tectonic Setting

Deposition of the Snowslip Formation was preceded by a period of erosion, interrupted by the extrusion of the Purcell Lava, and punctuated by two episodes of fluvial sedimentation. These interruptions in the stratigraphic record of the Snowslip in Glacier National Park are interpreted as indicating an active period of tectonism.

Because of numerous dolomite clasts and broken oolites that are rimmed by hematite in the lowermost beds of member 1 of the Snowslip, we suggest that a period of uplift, exposure, and erosion followed the shoaling-upward phase of the Helena Formation and preceded the deposition of Snowslip sediments. The erosional event and influx of terrigenous material, which is most evident along the eastern margin (shelf) of the basin, was probably caused by increased basin subsidence, or uplift of source terrane, or both. On a regional scale, Harrison (1972) suggested that a major period of tectonic adjustment preceded deposition of the Missoula Group; his suggestion was based on a study of isopach maps and changes in basin geometry. Although no megascopic features that might suggest a disconformity at the contact between the Helena and Snowslip Formations are obvious, the contact is sharp and changes in lithofacies and depositional environment between the two are abrupt.

During deposition of member 6 of the Snowslip, a magmatic event resulted in the extrusion of the Purcell Lava, which we believe accompanied basin growth faulting in the northern part of the Belt basin. In Glacier

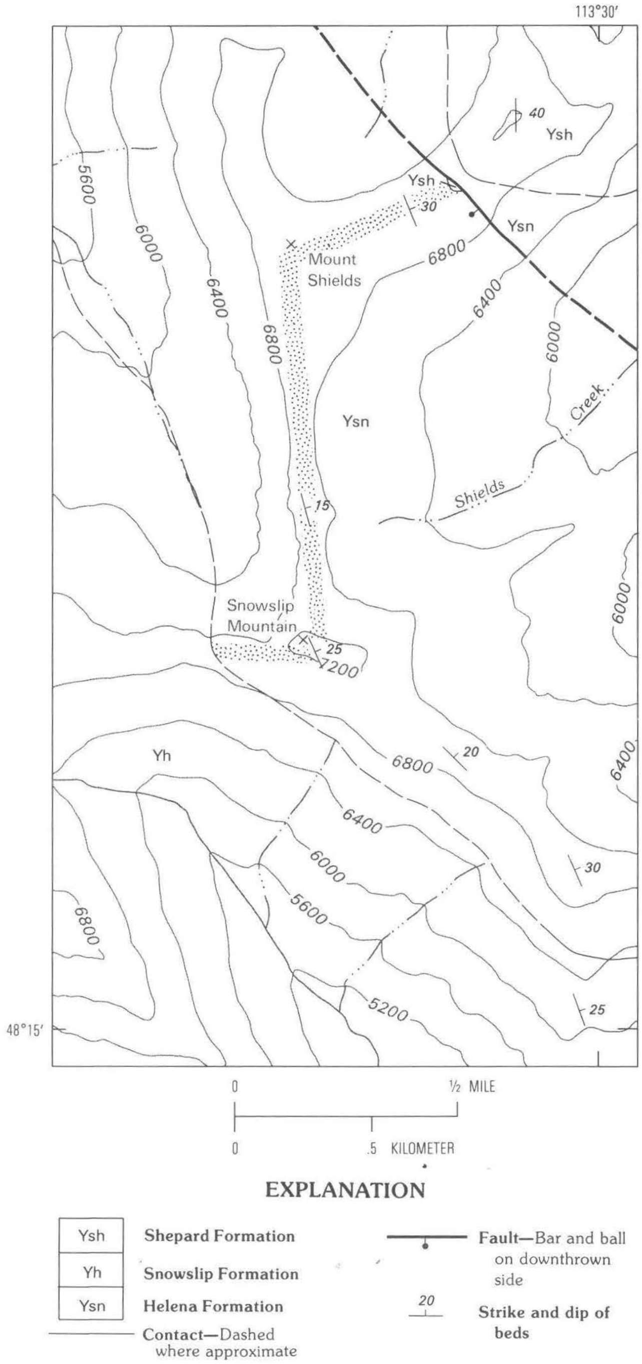


Figure 13. Geologic map showing the location of the type section of the Snowslip Formation (stippled) established by Childers (1963) in the southern part of Glacier National Park.

National Park, oxidation of the uppermost flows suggests that a diastemic period followed the emplacement of the lava in the Snowslip Formation. In parts of the northern Whitefish Range, west of Glacier National Park, uppermost flows are intercalated with member 6 lithofacies, overlain by beds of intraformational conglomerate, or overlain by the Shepard Formation (Whipple, 1984). Thus, locally (outside of Glacier National Park), an unconformity is present at the top of the Purcell Lava.

Members 3 and 5 of the Snowslip represent a rapid progradation of fluvial deposits into a peritidal setting. Events that caused this progradation were episodic and probably tectonically controlled. No unconformities between members 3 and 5 and adjacent members are evident in the sections studied, and members 3 and 5 are known to pinch out northwestward and westward from the Park (Whipple, unpublished mapping).

A polarity reversal that occurs at or near the base of the Snowslip Formation represents the first such reversal following a long period of normal polarity for the subjacent parts of the Belt Supergroup (Evans and others, 1975; Elston and Bressler, 1980) and forms a convenient magnetostratigraphic time line. This polarity event may correlate with a period of tectonic activity that we suggested at the close of Helena sedimentation.

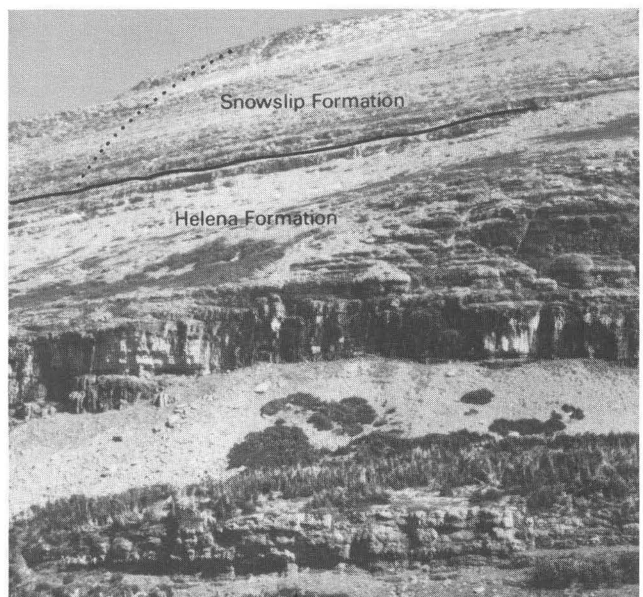


Figure 14. Lunch Creek measured section, looking east at the west-facing side of Piegan Mountain; member 5 at top of photo; dotted line is measured section.

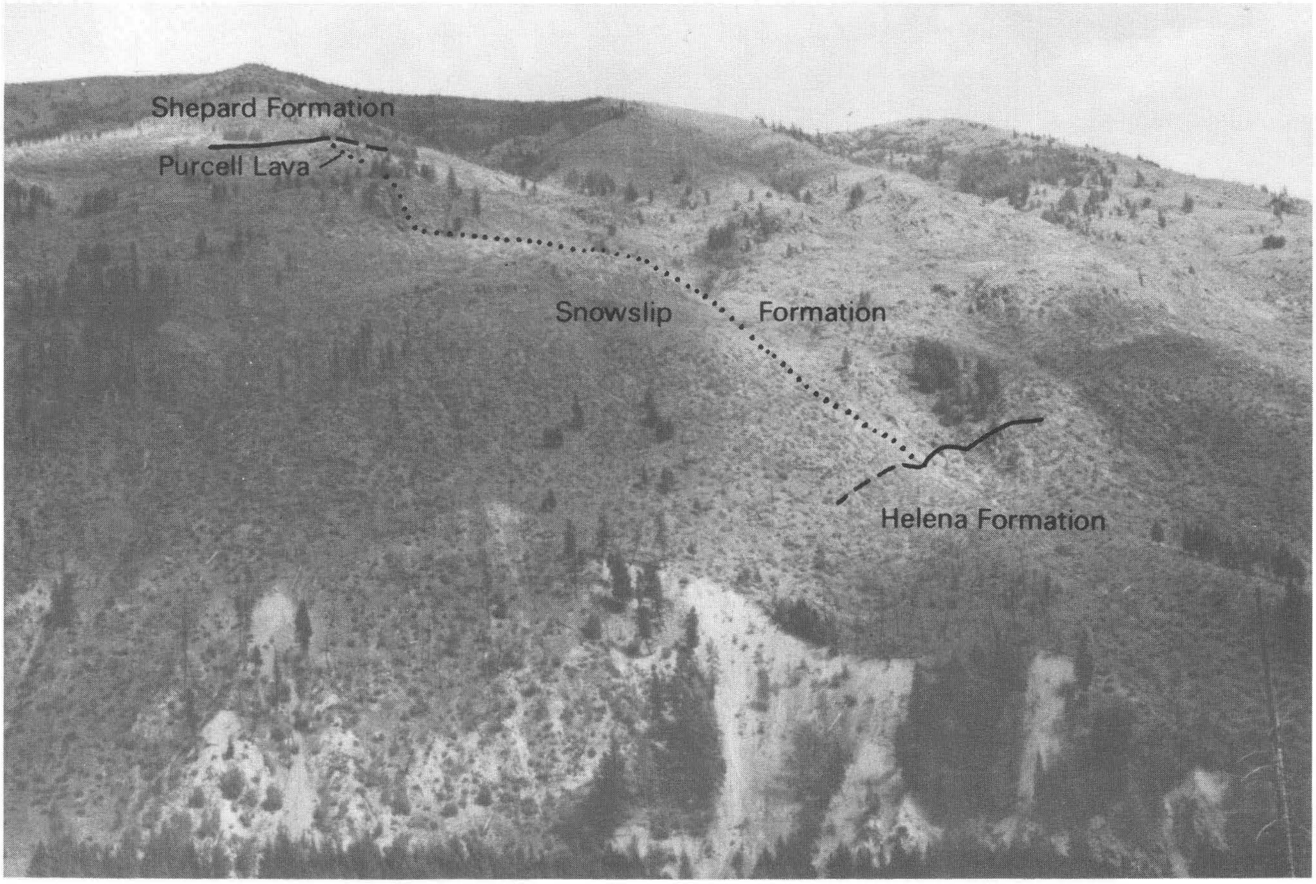


Figure 15. Huckleberry Ridge measured section, looking east. North Fork of Flathead River at toe of slope; dotted line is measured section.

Sedimentation

Only limited data are available to suggest provenance and sediment transport directions for the Snowslip Formation in Glacier National Park. Figure 22 is a ternary QmFLt diagram that shows inferred provenance for the suite of arenite samples from the four measured sections and from exposures along Going-to-the-Sun Road. The mean framework mode of detrital grains in the suite falls in the compositional field that is characteristic of sediments derived from recycled orogens (Dickinson and others, 1983). Within this field, the mode lies in the quartzose recycled subdivision, which denotes recycled sediments whose ultimate source was cratonic (Dickinson and others, 1983, p. 224). This interpretation is supported by the fact that many quartz grains in arenite samples of the Snowslip have inherited overgrowths (fig. 23), which is thought to indicate that the grains have been recycled (Sanderson, 1983).

Although the compositional data for construction of the provenance fields on the QmFLt diagram come largely from Phanerozoic rocks (Dickinson and others, 1983), the plots and interpretation of Snowslip samples suggest that the diagram is useful for determining provenance and tectonic setting of Proterozoic arenites. The plot of detrital framework modes for members 1, 3, and 5 shows a strong cratonic sediment source for members 3 and 5, whereas a mixed provenance is indicated for member 1 sediment. The mixed provenance of member 1, where at least part of the arenite composition is derived from carbonate rocks of the underlying Helena Formation, suggests that these sediments are multicyclic, had a cratonic source, and were recycled through platformal successions (Dickinson and Suczek, 1979, p. 2178).

Sediment transport direction and paleoslope for the Snowslip Formation can be determined from changes in grain size among sections, limited paleocurrent measurements, facies changes in the Purcell Lava, and changes in feldspar content. In members 3 and 5, decrease in grain size of arenite beds, decrease in stratigraphic thickness, and changes in facies of fining-upward sequences are interpreted as indicating that Snowslip strata of the Huckleberry Ridge and Hole-in-the-Wall sections were deposited downslope from the Lunch Creek and Snowslip

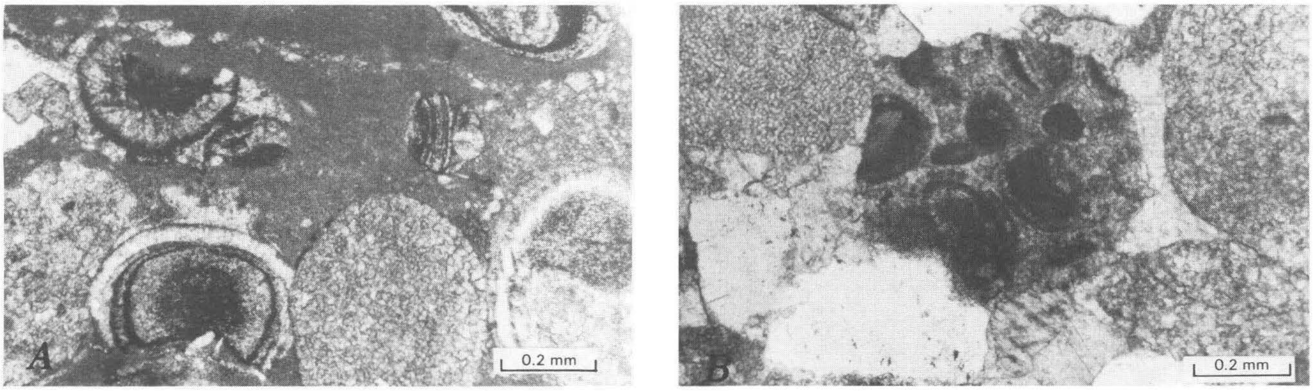


Figure 16. Photomicrographs (plain light) of ooliths in member 1 of the Snowslip Formation: *A*, Broken and deformed ooliths partially replaced and rimmed by hematite. *B*, Oolith aggregate spherule.

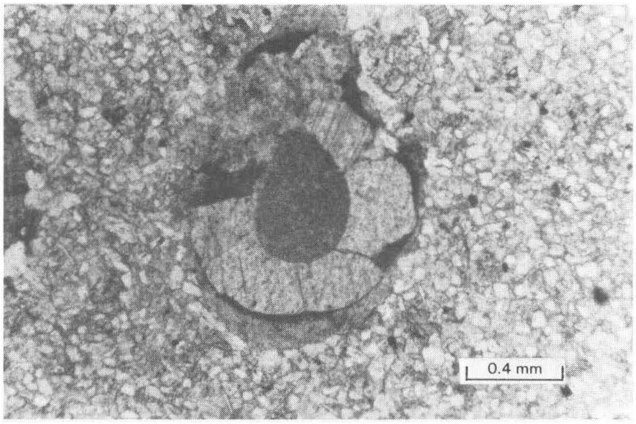


Figure 17. Photomicrograph (plain light) of an armored spherule showing armor of dolomite fragments, upper part of member 1, Lunch Creek section of the Snowslip Formation.

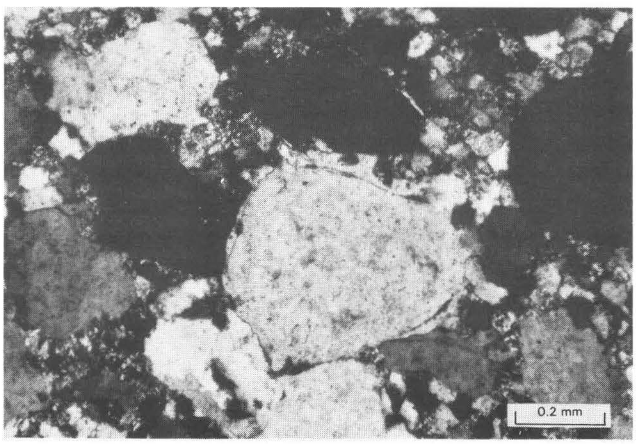


Figure 18. Photomicrograph (crossed nicols) of an abraded and impinged quartz overgrowth on quartz grain in member 3 of the Snowslip Formation, Huckleberry Ridge section.

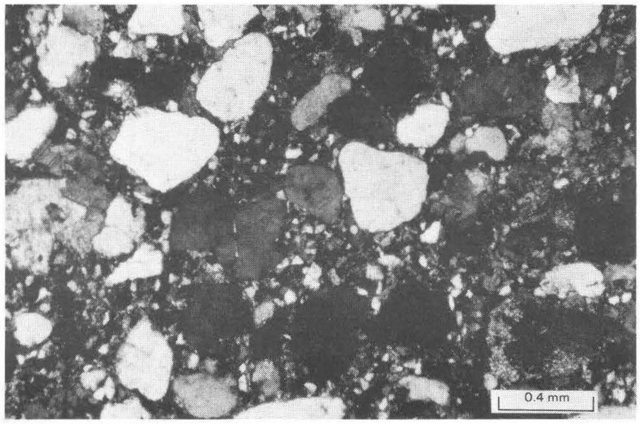


Figure 19. Photomicrograph (crossed nicols) of bimodal clast size in arenite bed of member 3, Hole-in-the-Wall reference section, which is interpreted to be the result of eolian processes.

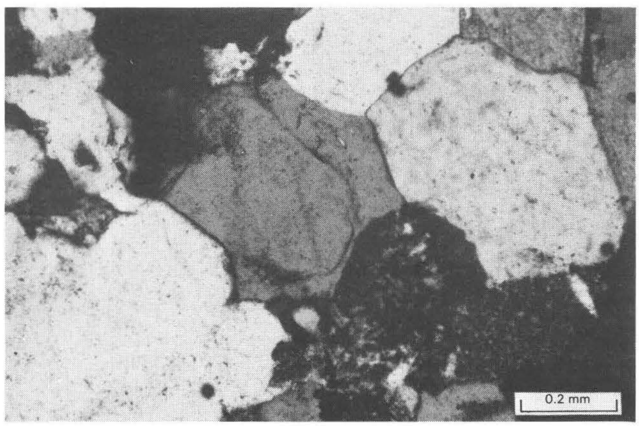


Figure 20. Photomicrograph (crossed nicols) of typical interlocking grain texture and quartz overgrowths in member 5 of the Snowslip Formation.

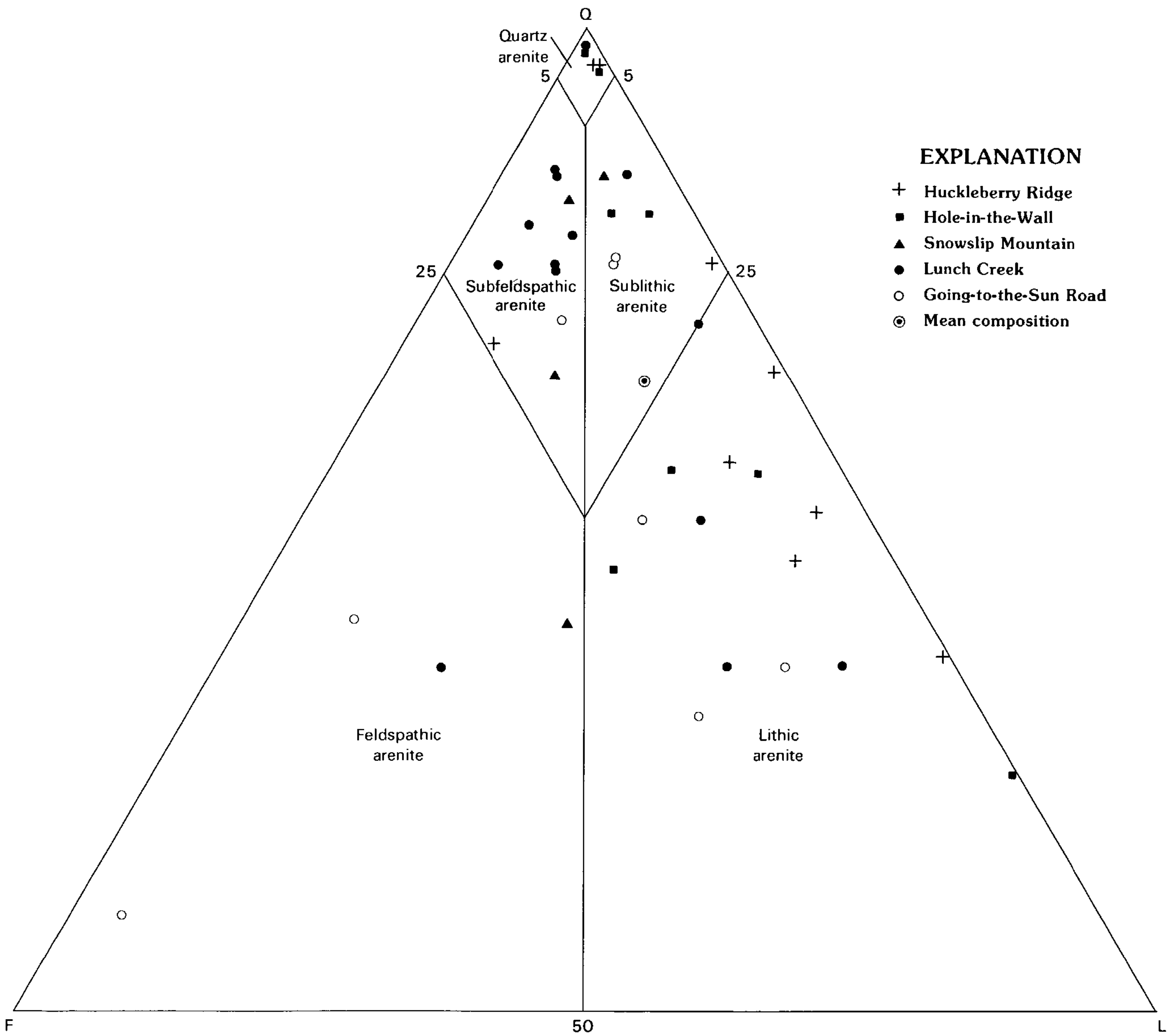


Figure 21. Ternary QFL diagram showing the compositional plots of 43 arenite samples from the Snowslip Formation in Glacier National Park. Samples with more than 25 percent carbonate framework grains are not included (modified from Pettijohn and others, 1973, p. 158, fig. 5-3). Q, quartz; F, feldspar; L, lithic fragments. Crosses, Huckleberry Ridge; solid squares, Hole-in-the-Wall; solid triangles, Snowslip Mountain; solid circles, Lunch Creek; open circles, Going-to-the-Sun Road; circle with dot, mean composition.

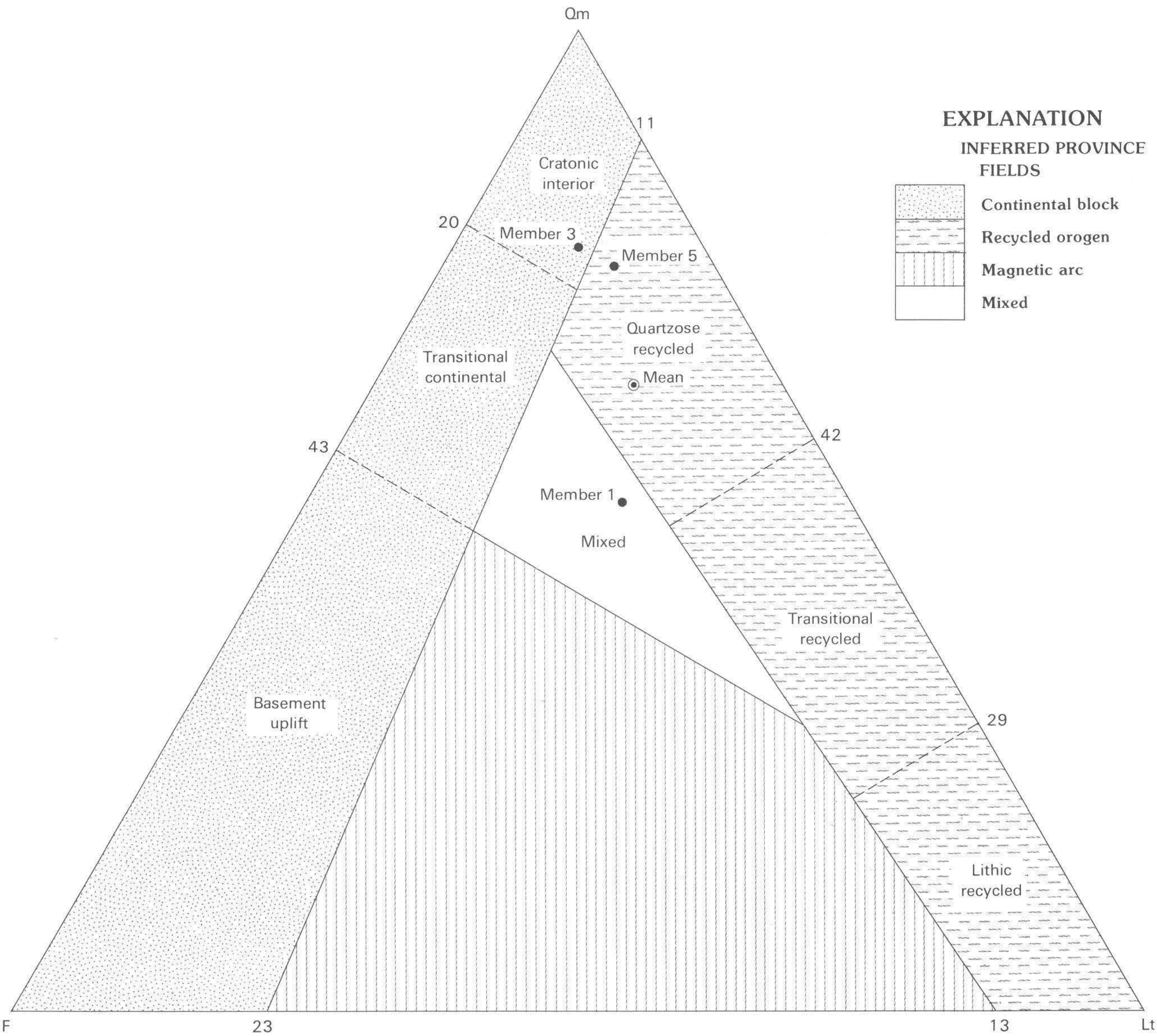


Figure 22. Ternary QmFLt diagram showing inferred provenance for terrigenous framework modes of members 1, 3, and 5 of the Snowslip Formation and the mean mode for a suite of 43 arenite samples from the Snowslip in Glacier National Park. Samples with more than 25 percent carbonate framework grains are not included. Numbers on sides of diagram are divisions in percent from nearest apical point (from Dickinson and others, 1983, p. 223, fig. 1). Qm, monocrystalline quartz; F, monocrystalline feldspar; Lt, lithic fragments.

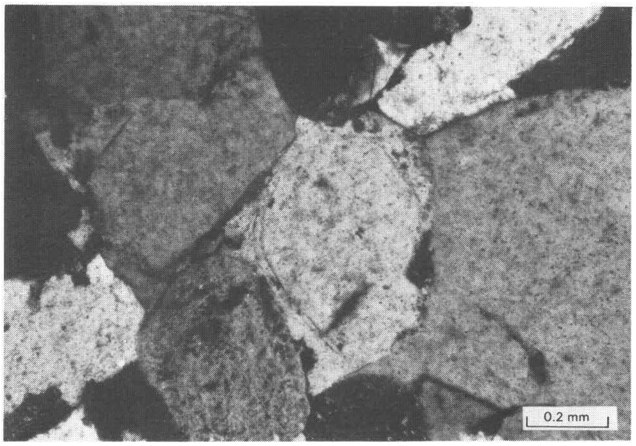
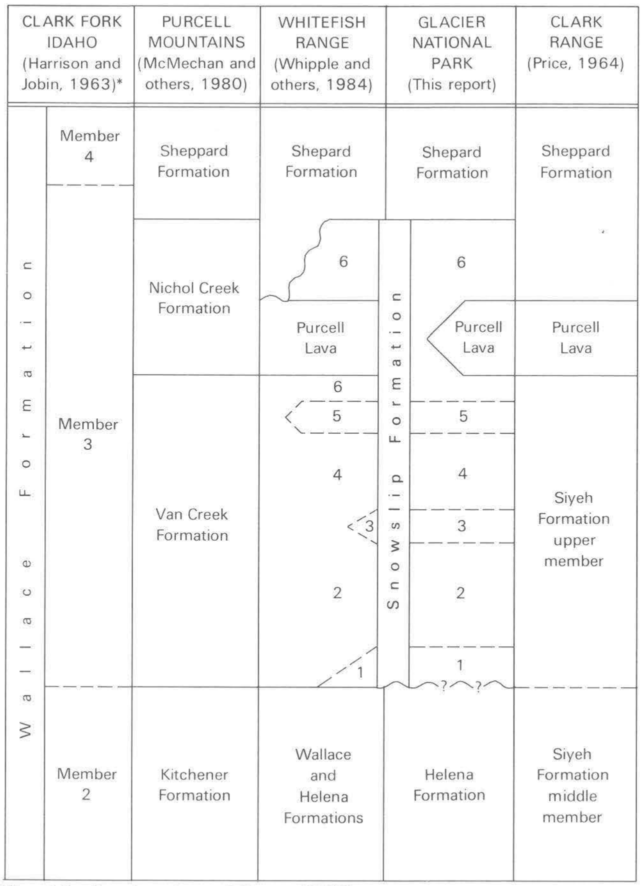


Figure 23. Photomicrograph (crossed nicols) of inherited quartz overgrowth (double overgrowth) in member 5 of the Snowslip Formation.



*Correlation from Lemoine and Winston (1968)

Figure 24. Regional stratigraphic correlation chart of the Snowslip Formation, northern part of the Belt basin.

Mountain sections. In this respect, sediment transport directions were primarily northwest with minor components to the west and southwest. Limited paleocurrent measurements of cross-bedded arenite units in members 1 and 5 show bimodal, bipolar directions about trends of 50° NW–SE and 83° NW–SE. Assuming that the thickness of the pillow lava facies of the Purcell Lava reflects water depth, emplacement of the lavas and synchronous deposition of sediments of member 6 in Glacier National Park must have occurred on a surface that sloped gradually downward to the northwest, west, and southwest (McGimsey, 1985, p. 27). Strata of the Snowslip observed north and east of Hole-in-the-Wall near Mount Rowe in Alberta, Canada (Cameron Lake area, fig. 2), were deposited downslope from Hole-in-the-Wall if the same criteria used above are applied.

Feldspar content may or may not reflect distance from source (Pettijohn and others, 1973; Blatt and others, 1972), but the small amounts of feldspar in the Hole-in-the-Wall and particularly the Huckleberry Ridge sections are consistent with the sediment transport direction being downslope to the northwest and west-southwest. That is, these two sections were further down the sediment-dispersal system and therefore have a diminished feldspar content. In summary, the principal direction of sediment transport for terrigenous clastics of the Snowslip Formation in Glacier National Park appears to have been northwest with minor components to the west and southwest.

Regional Correlation

The Snowslip Formation is recognized in many parts of the Belt basin outside Glacier National Park. Probable facies of the Snowslip have been identified in parts of southwest and west-central Montana (Mudge and others, 1982; Wallace and others, 1984) and northern Idaho (Burmester, 1985) (fig. 24). Stratigraphically equivalent units are known to occur in the Purcell Supergroup of southeast British Columbia and southwest Alberta (Price, 1964; McMechan and others, 1980). In the northern parts of the Whitefish Range and near Libby, Mont., the Snowslip rarely contains any red-bed sequences or carbonate, and arenite beds are few in number. In these areas, the Snowslip is composed of thinly laminated, dark-grey to green siltite and argillite. We suggest that this fine-grained, green-bed lithofacies of the Snowslip was deposited in deeper water than those lithofacies of the Snowslip in Glacier National Park and represents the coalescing of members 2, 4, and 6 as members 1, 3, and 5 pinch out basinward (see fig. 24). If this suggestion is correct, these facies changes would also indicate that the paleoslope was down to the northwest and west from the Park.

The Snowslip Formation is not recognized in the Purcell Supergroup of Canada. In southeast British Columbia, the Van Creek and Nichol Creek Formations are approximately equivalent to the Snowslip and Purcell Lava in stratigraphic position and closely resemble the green-bed lithofacies of the northern Whitefish Range (McMechan and others, 1980; Whipple, 1984). In the Clark Range of southwest Alberta, equivalent lithofacies of the Snowslip are called the upper part of the Siyeh Formation, which is overlain by the Purcell Lava (Price, 1964). In Waterton Lakes National Park, north of Cameron Lake (fig. 2), member 5 of the Snowslip Formation is easily recognized but is only 20–30 m thick, and member 3 is only a few meters thick. These equivalent lithofacies demonstrate the continued thinning of the Snowslip as well as the increase in interstratified green-bed lithofacies northwest from Glacier National Park.

Lastly, we agree with Lemoine and Winston (1986) that rock units mapped as the upper part of the Wallace Formation near Clark Fork, Idaho (lower part of Wallace 3 as described by Harrison and Jobin, 1963), are probably equivalent to the green-bed lithofacies of the Snowslip found elsewhere west and northwest of Glacier National Park.

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APPENDIX: REFERENCE SECTION

Reference Section

Hole-in-the-Wall reference section of the Snowslip Formation, Glacier National Park; section includes Purcell Lava and diabase sill (figs. 1 and 4)

[Section is just east of Boulder Pass in the north part of the Park; base of section at lat 48°57′53″ N., long 114°04′11″ W. Measured by James W. Whipple and James C. Sample]

Snowslip Formation (Middle Proterozoic); contact with overlying Shepard Formation conformable:

		Thickness Meters	Thickness Feet
Member 6:			
11.	Siltite and argillite couplets, grayish-green; wavy nonparallel lamination; locally calcareous; some beds of siltite as thick as 10 cm; interstratified white quartz arenite with thin, lenticular ripple cross-laminated beds less than 3 cm thick; mud-chip breccia, fluid-escape structures, and limonite stain abundant	8.1	26.6
10.	Siltite and argillite; pink, pale-purple, and grayish-green siltite and dark-red argillite; wavy discontinuous to wavy nonparallel lamination; siltite locally calcareous; mud-chip breccia and fluid-escape structures common	1.85	6.1
9.	Siltite and arenite; green to dark-green siltite and pink to light-orangish-brown-weathering calcareous arenite; arenite is very fine grained and ripple cross-laminated and forms broad cut-and-fill structures; color mottling occurs locally	1.45	4.8
8.	Siltite and argillite couplets; same as unit 11	5.3	17.4
7.	Purcell Lava; basalt	95.0	311.6
6.	Argillite, pale-green; abundant limonite stain; thinly laminated; interlaminated siltite and argillite couplets less than 1 cm thick; intensely deformed, some hornfels and quartz veinlets	5.2	17.1
5.	Diabase sill; irregular base; projects up and down section	4.6	15.1
4.	Argillite; same as unit 6	1.75	5.7
3.	Arenite, dark-red, lenticular; silicified red argillite clasts; mixed quartz and calcite cement; pyrite and chalcopyrite common (fig. 25)	.08	.3
2.	Argillite; same as unit 6	1.89	6.2
1.	Stromatolitic limestone, grayish-green; weathers orangish brown; laterally linked heads 30 cm across, 10 cm high; interstratified dark-brown cryptalgal limestone	.5	1.6
	Total thickness of member 6	26.12	85.7
	Total thickness of Purcell Lava	95.0	311.6
	Total thickness of diabase sill	4.6	15.1
Member 5; contact with overlying member 6 conformable:			
6.	Lithic arenite, pale-green to white, fine- to coarse-grained, poorly sorted; beds less than 10 cm thick; interstratified argillite and siltite; limonite stain common	3.8	12.5
5.	Lithic arenite and argillite, grayish-red (5 R 5/2) to dark-red; fining-upward cycles 15–20 cm thick (fig. 26); lithic arenite at base of cycle, very coarse to very fine grained, poorly sorted; beds are lenticular and cross-laminated. Dark-red argillite at top of cycle; wavy discontinuous lamination; raindrop impressions	17.1	56.1
4.	Lithic arenite and argillite; grayish-red to dark-red; fining-upward cycle; 40-cm-thick unit of arenite at base; remaining part interstratified arenite, siltite (5 R 5/2), and argillite (5 RP 5/2); ripple cross-lamination common in beds less than 5 cm thick, ripples draped by argillite; desiccation cracks, wrinkle marks, raindrop impressions, and mud-chip breccias common	6.8	22.3
3.	Lithic arenite and argillite; same as unit 4	3.52	11.5
2.	Lithic arenite and argillite; same as unit 4; lower beds of arenite grayish green and mottled	6.4	21.0
1.	Lithic arenite, grayish-green, gray, grayish-red, and pale-pink, very fine to fine grained; beds as much as 10 cm thick, ripple cross-laminated; interbedded thinly laminated, red and green siltite; minor argillite	2.2	7.2
	Total thickness of member 5	39.82	130.6
Member 4; contact with overlying member 5 conformable:			
6.	Siltite and argillite; greenish-gray (5 G 6/1) siltite and pale-grayish-olive (10 Y 5/2) argillite; rhythmic, wavy nonparallel fining-upward beds as much as 20 cm thick where siltite is 25 percent of bed thickness; siltite is locally calcareous and weathers light brown; syneresis cracks (fig. 27) and fluid-escape structures; pyritic and limonite stained	6.9	22.6
5.	Calcareous arenite, greenish-gray, very fine grained, ripple cross-laminated	.1	.3
4.	Dolomite, gray, brown-weathering; abundant syneresis cracks filled with sparry calcite, weathers to form miniature molartooth structures; thin bed of arenite at base	1.0	3.3
3.	Siltite and argillite; same as unit 6; interbedded brown-weathering dolomite occurs locally	55.7	182.7

Figure 25. Typical bedding style of member 6 showing red, mineralized arenite bed at level of hammer head.

	Thickness Meters	Thickness Feet
2. Stromatolitic limestone, pink to cream-colored; small irregular heads and cryptalgal laminae; minor interlaminated green argillite, thin deformed laminae	.8	2.6
1. Siltite and argillite; same as unit 6 ..	15.1	49.5
Total thickness of member 4 ...	79.6	261.1

Member 3; contact with overlying member 4 conformable:

	Thickness Meters	Thickness Feet
4. Siltite, grayish-red; interlaminated dark-red argillite; poorly developed fining-upward sequences less than 2 m thick; mud-chip breccia and desiccation cracks common (fig. 28)	7.0	23.0
3. Siltite and argillite, grayish-green; wavy nonparallel couplets as much as 4 cm thick; siltite locally calcareous	3.8	12.5
2. Arenite and siltite; light-gray arenite and grayish-green to dark-green siltite; fining-upward cycles with argillite (5 RP 5/2) at top; arenite beds ripple cross-laminated, lenticular, and less than 10 cm thick; cycles are less than 2 m thick; mud-draped ripples, desiccation cracks, and fluid-escape structures common	5.73	18.8
1. Quartz arenite, white to pinkish-gray (5 YR 8/l), fine- to medium-grained, well-sorted; cross-laminated at base with green mud-chips on foresets; lenticular; grades upward into unit 2	.07	.2
Total thickness of member 3 ...	16.6	54.4

Member 2; contact with overlying member 3 conformable:

	Thickness Meters	Thickness Feet
8. Siltite and argillite; greenish-gray (5 G 6/l) siltite and pale-grayish-olive (10 Y 5/2) argillite; siltite locally calcareous and weathers brown; wavy nonparallel couplets as much as 4 cm thick; interbedded calcareous, very fine to fine grained arenite beds as thick as 10 cm and ripple cross-laminated; syneresis cracks, fluid-escape structures, and mud-chip breccias common (fig. 29); pyritic and locally stained by limonite	2.1	6.9

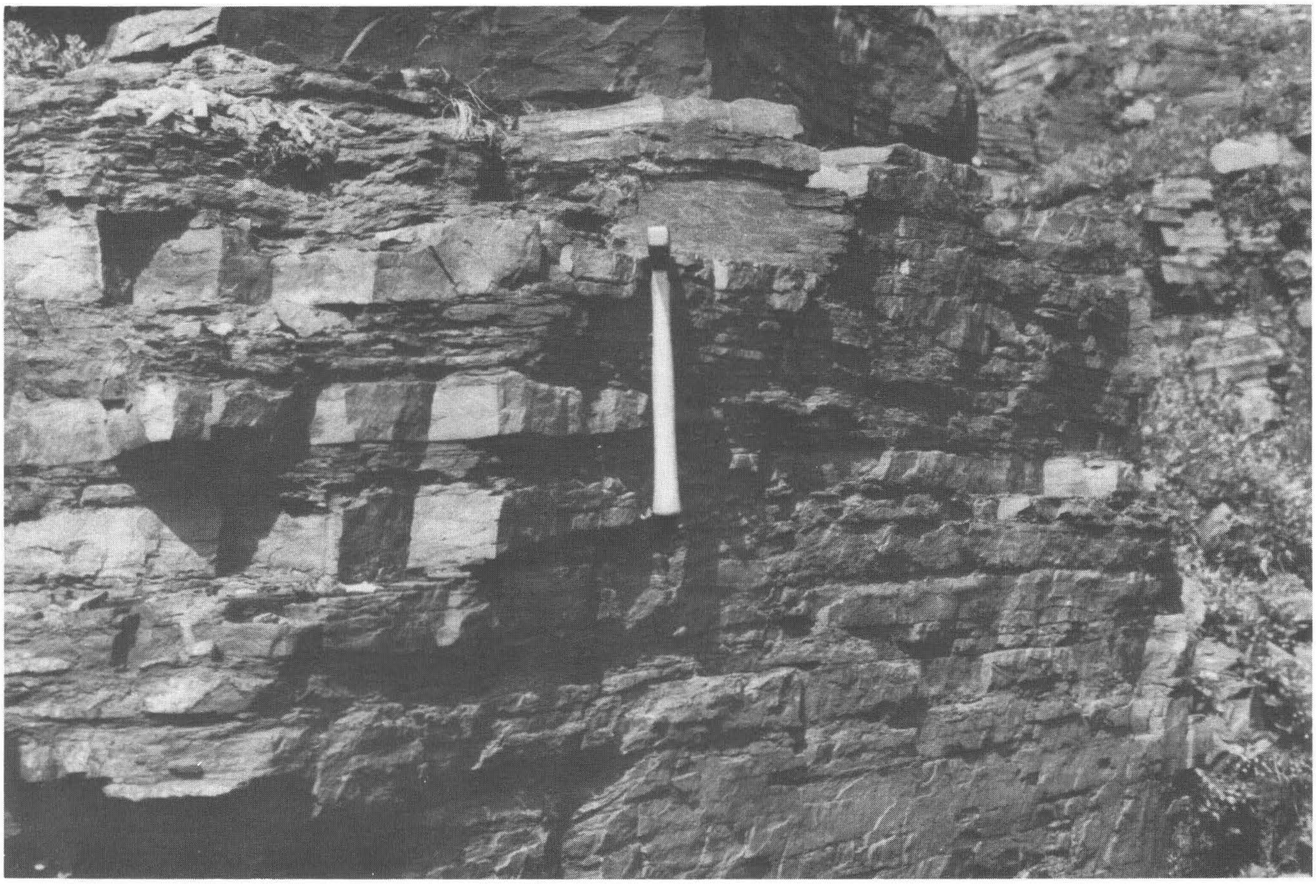

Figure 26. Incomplete fining-upward sequences in unit 5, member 5 of the reference section of the Snowslip Formation.

Figure 27. Syneresis cracks on bedding plane surface, typical of members 2, 4, and 6 of the Snowslip Formation, Glacier National Park; knife is 8 cm long. Photo by O.B. Raup.

Figure 28. Desiccation cracks and traces of fluid-escape structures on bedding plane surface, typical of members 1, 3, and 5 of the Snowslip Formation, Glacier National Park. Photo by O.B. Raup.

		Thickness Meters	Thickness Feet
7.	Stromatolitic limestone, pink to gray; small laterally linked heads and cryptalgal laminae (fig. 30)	.15	.5
6.	Siltite and argillite; same as unit 8, less arenite; some siltite beds as thick as 20 cm; cryptalgal lamination local	45.95	150.7
5.	Stromatolitic limestone; same as unit 7	.25	.8
4.	Siltite and argillite; same as unit 8 ..	.8	2.6
3.	Stromatolitic limestone, pink to gray; laterally linked heads 10 cm high; underlain by mud-clast conglomerate, elongate limestone and green calcareous argillite clasts as long as 5 cm, supported by coarse-grained lithic arenite; pyritic	.4	1.3
2.	Siltite and argillite; same as unit 8 ..	18.9	62.0
1.	Stromatolitic limestone; same as unit 7	1.3	4.3
	Total thickness of member 2 ...	69.85	229.1
	Member 1; contact with overlying member 2 conformable:		
6.	Siltite and lithic arenite; interlaminated grayish-green to moderate-red (5 R 5/4) siltite and pale-reddish-purple (5 RP 6/2) to medium-gray (N 5) arenite; locally calcareous; bleaching and mottling of rock color common; lenticular arenite laminae less than 5 mm thick; some interlaminated dark-red argillite; abundant mud-chip breccia; mud-draped ripples and desiccation cracks common	6.8	22.3
5.	Siltite, greenish-gray (5 G 6/1), calcareous; some interlaminated, poorly sorted, coarse-grained, calcareous lithic arenite; all beds weather light brown; fluid-escape structures, syneresis cracks, and abundant mud-chip breccia present	4.4	14.4
4.	Siltite and argillite, pale-green (10 G 6/2); thin wavy nonparallel to wavy discontinuous couplets less than 10 mm thick; locally calcareous; some fluid-escape structures and mud-chip breccia present	1.4	4.6
3.	Siltite and lithic arenite; same as unit 6; beds of arenite 3 cm thick or less; much bleaching of colors along joints and on bedding surfaces	12.61	41.4
2.	Oolitic arenite, medium-gray (N 5) to light-pinkish-gray, calcareous, ripple cross-laminated	.1	.3
1.	Siltite and argillite; grayish-green to tan-weathering, calcareous siltite and pale-pink argillite; wavy discontinuous lamination; syneresis cracks, mud-chip breccia, and fluid-escape structures common	.6	2.0
	Total thickness of member 1 ...	25.91	85.0
	Total thickness of the Snowslip Formation	257.9	845.9
	Total thickness of Purcell Lava	95.0	311.6
	Total thickness of diabase sill ..	4.6	15.1

Helena Formation (Middle Proterozoic); not measured; contact with overlying member 1 of the Snowslip Formation probably disconformable.

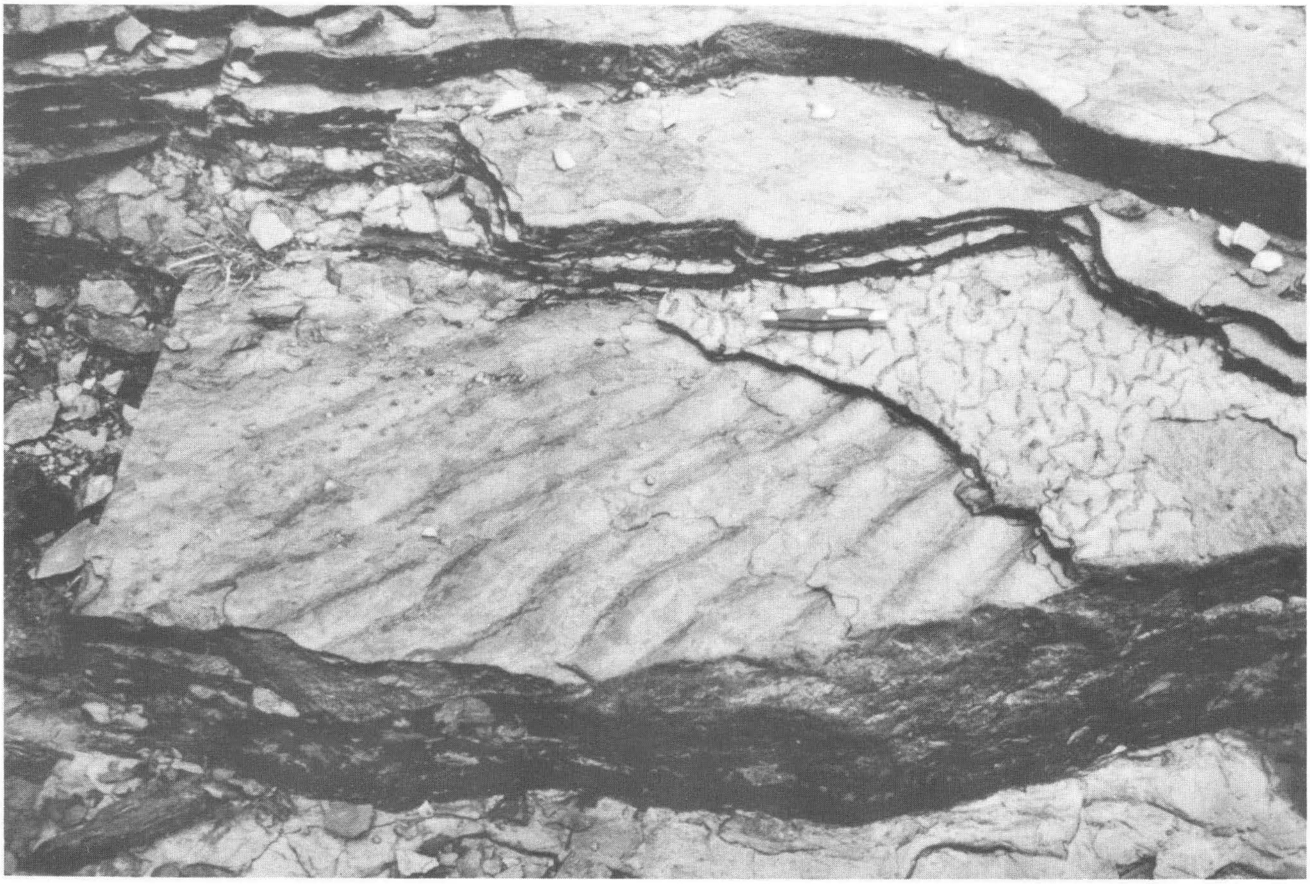

Figure 29. Syneresis cracks and wave-generated ripple marks on bedding plane surfaces, typical of members 2, 4, and 6 of the Snowslip Formation, Glacier National Park; knife is 8 cm long. Photo by O.B. Raup.

Figure 30. Pink stromatolitic limestone, typical of members 2 and 4 of the Snowslip Formation, Glacier National Park; knife is 8 cm long. Photo by O.B. Raup.

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