Table Mountain Quartzite and Moose Formation (new names) and Associated Rocks of the Middle Proterozoic Belt Supergroup, Highland Mountains, Southwestern Montana

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Table Mountain Quartzite and Moose Formation (new names) and Associated Rocks of the Middle Proterozoic Belt Supergroup, Highland Mountains, Southwestern Montana

By J. Michael O'Neill

BELT SUPERGROUP IN THE HIGHLAND MOUNTAINS AND PROBABLE EQUIVALENT ROCKS IN THE PIONEER AND ANACONDA RANGES, SOUTHWESTERN MONTANA
J. Michael O'Neill and Robert C. Pearson, Editors

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CONTENTS

FIGURES

Table Mountain Quartzite and Moose Formation (new names) and Associated Rocks of the Middle Proterozoic Belt Supergroup, Highland Mountains, Southwestern Montana

By J. Michael O'Neill

ABSTRACT

Sedimentary rocks of Belt age (Middle Proterozoic) in the Highland Mountains of southwestern Montana are exposed in an elongate east-trending zone that extends almost completely across the range. Strata of the Belt Supergroup are composed mainly of lower Belt rocks and Ravalli Group rocks overlain successively by middle Belt carbonate rocks, which pinch out westward in the range and a thin sequence of Missoula Group quartzite. Striking lateral facies changes in all these sedimentary rocks are accompanied by thickening of the succession toward the central part of the range. Major facies changes are present across northwest- to north-trending faults that are the northward continuation of conspicuous northwest-trending faults that cut basement rocks to the south. These faults extended into the Belt Basin in Middle Proterozoic time and acted as growth faults during deposition of Belt sediments. Belt-age rocks were deposited in northwest-trending, fault-bounded half grabens or structural blocks outlined by these growth faults; these structural blocks step down eastward and outline a large, composite northwest-trending graben, herein called the Highland graben, that is manifested as a Middle Proterozoic paleovalley along this part of the southern margin of the Belt Basin. Facies relationships among rocks within the graben show that lower Belt rocks and the Greyson Shale of the Ravalli Group are laterally gradational and were deposited simultaneously. The lower Belt deposits, represented by the LaHood Formation, the newly named Moose Formation and Table Mountain Quartzite, and the Newland Formation are subaerial to near-shore deposits that interfinger with subaqueous calcareous muds of the Newland Formation, which, in turn, grade laterally into laminated silty muds of the Greyson Shale of the Ravalli Group that were deposited farther from shore. Variations in stratigraphic thickness and hanging-wall onlap of these lower Belt strata suggest syndepositional fault activity, widening of the graben during Belt deposition, and a gradual transition from subaerial to subaqueous deposition through lower Belt time. Crossbedded, argillaceous siltstone and sandstone of the Spokane Formation were deposited uniformly above the Greyson Shale. The western margin of the graben was subaerially exposed in middle Belt time. Carbonate bank deposits of the Helena Formation interfinger with calcareous argillite of the Empire Formation in and near the central part of the graben but pinch out to the west in the Highland Mountains and thin to the east. Younger alluvial conglomerate and fluvial sandstone of the Missoula Group were deposited on the older strata. The main depositional center for these younger rocks was also along the graben axis, and the younger rocks thin to a few tens of meters to the west.

INTRODUCTION

In southwestern Montana rocks of the Middle Proterozoic Belt Supergroup are exposed along an east-trending structural zone that marks the southern margin of the Helena embayment of the Belt depositional basin (fig. 1). The lithology and general stratigraphic relations of rocks in the Helena embayment were first summarized by Ross in 1963; however, details of the stratigraphy of most of these rocks along the southern margin of the embayment are still not well known because of stratigraphic and structural complexities and poor exposures.

In this report I briefly review the history of nomenclature of Belt-age rocks of the Helena embayment and apply embayment nomenclature, with some minor revisions and important additions, to rocks of the Belt Supergroup in the Highland Mountains. The revised nomenclature of Middle Proterozoic sedimentary rocks is modified from informal nomenclature used in recently completed mapping of the Dillon 1°×2° quadrangle (Ruppel and others, 1993).

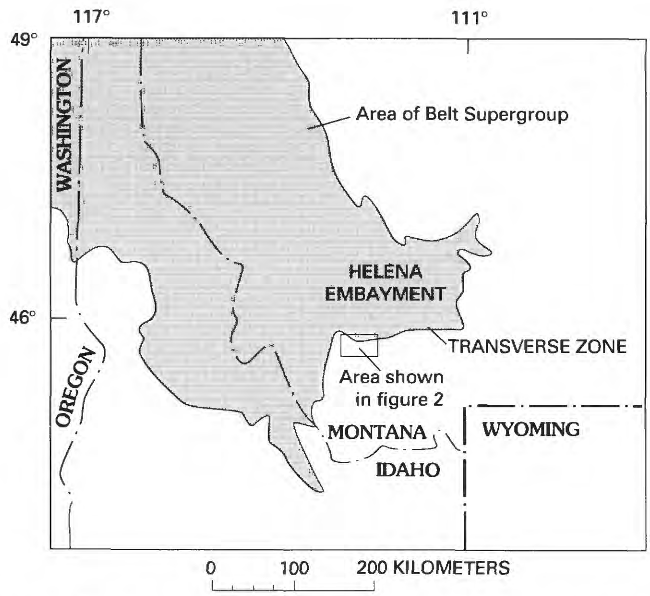


Figure 1. Index map showing location of study area, extent of Belt Supergroup rocks, and location of Helena embayment of the Belt Basin, northwestern United States.

MIDDLE PROTEROZOIC REGIONAL GEOLOGIC SETTING

The Belt Basin of the northern Rocky Mountains is an elongate northwest-trending depositional trough that began to form about 1.5 Ga (Harrison, 1972; Obradovich and others, 1984). The oldest deposits in the northern part of the basin consist of deep-water turbidites (Harrison and others, 1974; Cressman, 1984, 1985, 1989) that are locally intruded by mafic sills. The Crossport C sill in the western part of the basin, dated 1.43 Ga (Zartman and others, 1982), places a minimum age on the oldest sedimentary rocks in the basin (Obradovich and others, 1984). Approximately coeval with sill emplacement was intrusion of a series of northwest-trending diabasic dikes into cratonic rocks directly south of the Helena embayment (Koehler, 1973, Wooden and others, 1978); two episodes of dike emplacement are recognized in the Tobacco Root Mountains and Ruby Range, east and southeast, respectively, of the Highland Mountains (fig. 2*A*). Dike emplacement along fractures in cratonic rocks adjacent to the Belt Basin coincided with the early part of the basin's tectonic evolution (Wooden and others, 1978; Schmidt and Garihan, 1986). Similar mafic dikes intruded Early Proterozoic cratonic rocks of the Highland Mountains (Duncan, 1976; Garihan and others, 1981; O'Neill and others, 1988; O'Neill and Schmidt, 1989).

Rocks deposited in the Helena embayment are separated from cratonic rocks to the south by the low-angle Camp Creek fault zone in the Highland Mountains (McMannis, 1963; O'Neill and others, 1986) and by right-lateral, oblique-slip thrust faults of the Southwest Montana transverse zone farther to the east along the northern edge of the Tobacco Root Mountains (Schmidt and O'Neill, 1982) (fig. 2*A*). Along this zone sedimentary rocks of the Belt Supergroup consist of a basal conglomeratic and arkosic facies of the LaHood Formation. The angular and extremely coarse nature of clasts in the LaHood and the geographic restriction of the unit to areas directly adjacent to cratonic rocks suggest a steep, perhaps structurally controlled, east-trending southern margin to the Belt Basin in this area (McMannis, 1963; Harrison and others, 1974; Schmidt and Garihan, 1986). The Southwest Montana transverse zone consists of a series of younger east-trending faults that show characteristic right-reverse slip. The transverse zone is inferred to have been superimposed along an older zone of concealed high-angle faults of the Middle Proterozoic Willow Creek fault zone of Robinson (1963); the entire zone of older faults, coarse sedimentary debris, and younger thrust and oblique-slip faults can be traced for more than 100 km eastward from the Highland Mountains (Schmidt and O'Neill, 1982).

Sedimentary rocks of Belt age in the Highland Mountains crop out along an elongate east-trending zone that extends almost completely across the range; the zone is about 25 km long and as wide as 8 km (fig. 2*A*). The sedimentary rocks are in fault contact on the south with cratonic basement rocks, are overlain by or structurally juxtaposed against Paleozoic sedimentary rocks on the north, and are intruded by the Boulder batholith on the east. This sedimentary succession is composed mainly of lower Belt rocks and Ravalli Group rocks, overlain, in part, by middle Belt carbonate rocks below a thin succession of Missoula Group quartzite. Striking lateral facies changes in all of these sedimentary rocks (fig. 2*B*) are accompanied by an overall thickening of the succession from about 1,000 m on the west to more than 3,000 m in the central part of the range. The major facies changes coincide with northwest- to north-trending faults that are the northward continuation of conspicuous northwest-trending faults that cut basement rocks to the south. These faults extended into the Belt Basin in Middle Proterozoic time and acted as growth faults during deposition of Belt sediments. The formations described in this report were measured in four northwest-trending step grabens or structural platforms outlined by northwest-trending faults. The structural platforms are designated, from west to east, the Moose Creek, Soap Gulch, Camp Creek, and Table Mountain blocks (fig. 2*B*). Maximum subsidence was centered in the Table Mountain block and defines a northwest-trending structural graben that was the locus of a Middle Proterozoic paleovalley during deposition along this part of the southern margin of the Belt Basin. Measured stratigraphic sections extend from the top of the LaHood Formation to the base of the Middle Cambrian Wolsey Shale and include the Middle Cambrian Flathead Quartzite. The entire LaHood was not measured in the field because of generally poor exposures in the area; the Flathead is included in these sections because of the local difficulty in the Highland Mountains in differentiating between quartzite of the uppermost Missoula Group and quartzite of the basal Flathead (McMannis, 1963; Smedes, 1967).

PREVIOUS WORK

Published reports on the geology of the Belt Supergroup in the Highland Mountains are few. Sahinen (1939) was apparently the first to describe Belt sedimentary rocks in this area, and McMannis (1963) later outlined the general stratigraphic relationships of Belt strata in the Highland Mountains in his discussion of the LaHood Formation along the southern margin of the Belt Basin. Thorson (1984) described the lower Belt sequence in the range and outlined basic stratigraphic relationships among these lower Belt units. The entire sequence of rocks in the range was briefly described by O'Neill and others (1986) and O'Neill (1989).

STRATIGRAPHIC NOMENCLATURE

Nomenclature for Middle Proterozoic sedimentary rocks exposed in western Montana was first summarized by Ross (1963) in his seminal paper on the "Belt Series." Modifications to that nomenclature were made by Harrison (1972, fig. 5), and stratigraphic relations and correlations among major subdivisions within the Belt Supergroup proposed by Harrison are mostly followed in this report (fig. 3). The Belt Supergroup of western Montana is divided into four distinct sequences, from lowest to highest, lower Belt rocks, Ravalli Group, middle Belt carbonate rocks, and Missoula Group. All these sequences are present and generally well exposed in the Highland Mountains.

Lower Belt rocks in the Highland Mountains are, from oldest to youngest, the LaHood Formation, Moose Formation and Table Mountain Quartzite (new names), and Newland Formation. These rocks are overlain by the Greyson Shale and Spokane and Empire Formations of the Ravalli Group. Middle Belt carbonate rocks are represented by a westward-thinning tongue of the Helena Formation. The uppermost Belt sequence, the Missoula Group, consists of a thin sequence of interbedded quartzite, argillite, and conglomerate that have been mapped as lithologic units in the central part of the Highland Mountains (O'Neill and others, 1995) but were not divided into formations. All Belt-age rocks in the Highland Mountains show significant lateral facies and thickness changes from east to west. The major changes are across north- to northwest-trending high-angle faults that are the northward continuation of prominent structures in cratonic rocks directly to the south. Facies relationships between formations of the lower Belt and the Greyson Shale are laterally gradational from graben margin to graben axis, and the various units were deposited simultaneously. The lower Belt deposits represent subaerial to near-shore sediments that interfinger laterally with subaqueous calcareous mud of the Newland Formation, which, in turn, grades into laminated silty mud of the Greyson Shale farther from shore. Variations in thickness and hanging-wall onlap of the lower Belt strata suggest syndepositional fault activity, widening of the graben during Belt deposition, and a transition from alluvial and fluvial to subaqueous deposition through time.

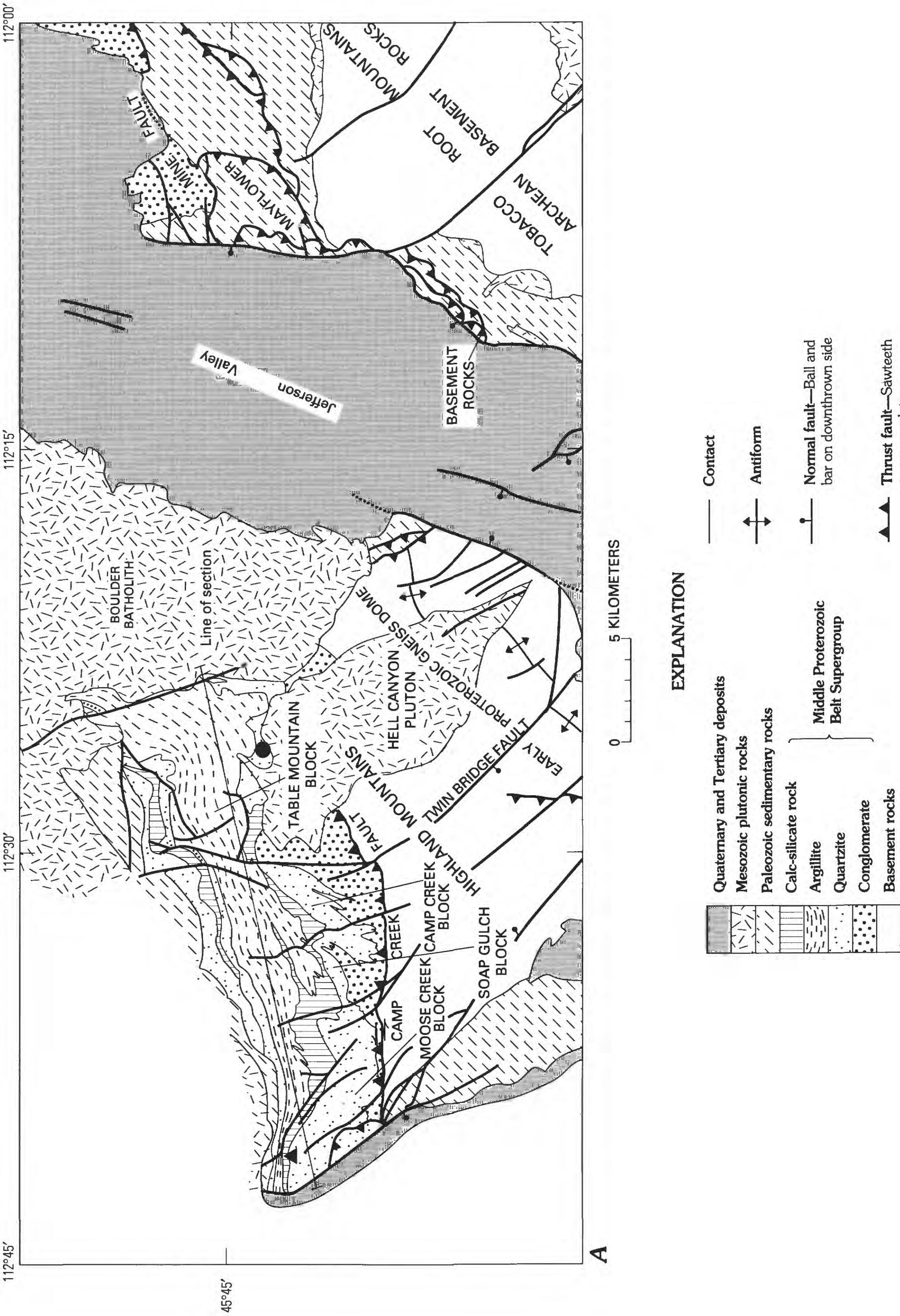
Lithologic terminology for fine-grained sedimentary rocks of the Belt Supergroup commonly has been restricted to the terms argillite, siltite, and quartzite in lieu of shale, siltstone, and sandstone (J.E. Harrison, U.S. Geological Survey, oral commun., 1993). This restricted terminology is applied because of the ubiquitous, low-grade, burial metamorphic aspect of most of the supergroup. In the Highland Mountains the Belt Supergroup, although never deeply buried, shows contact metamorphism from plutons of the Boulder batholith that grades from albite-epidote-hornfels to hornblende-hornfels facies, depending on proximity to adjacent plutons. Because of the variable contact metamorphic grade, from unmetamorphosed to strongly porphyroblastic and recrystallized, the terms argillite, siltite, and quartzite are used for all rocks in order to avoid confusion regarding lithology.

LOWER BELT ROCKS

LAHOOD FORMATION

The LaHood Formation, the name proposed by Alexander (1955) for the coarse facies of the Belt Supergroup that Ross (1949, 1963) named the North Boulder Group, is well exposed in the Highland Mountains. The type locality of the LaHood is near the small community of LaHood at the northwest corner of the Tobacco Root Mountains, about 25 km east of LaHood outcrops in the Highland Mountains. Because the type locality includes only the upper part of the formation, McMannis (1963, p. 409) amended the formation description to "include all dominantly coarse Belt strata along the southern margin of the central Montana embayment of the Belt geosyncline***Arbitrarily the name applies where Belt strata consists of less than 75 percent of fine-grained rocks and greater than 25 percent of coarse arkosic debris."

The LaHood Formation in the Highland Mountains crops out in a narrow east-trending zone that separates the finer grained overlying Belt strata to the north from crystalline basement rocks to the south. The formation was deposited directly on Early Proterozoic crystalline basement rocks; this unconformity is now the locus of the Camp Creek fault. The formation consists of cobble to boulder conglomerate and breccia, quartz-pebble conglomerate, arkose, and


112°00'
112°15'
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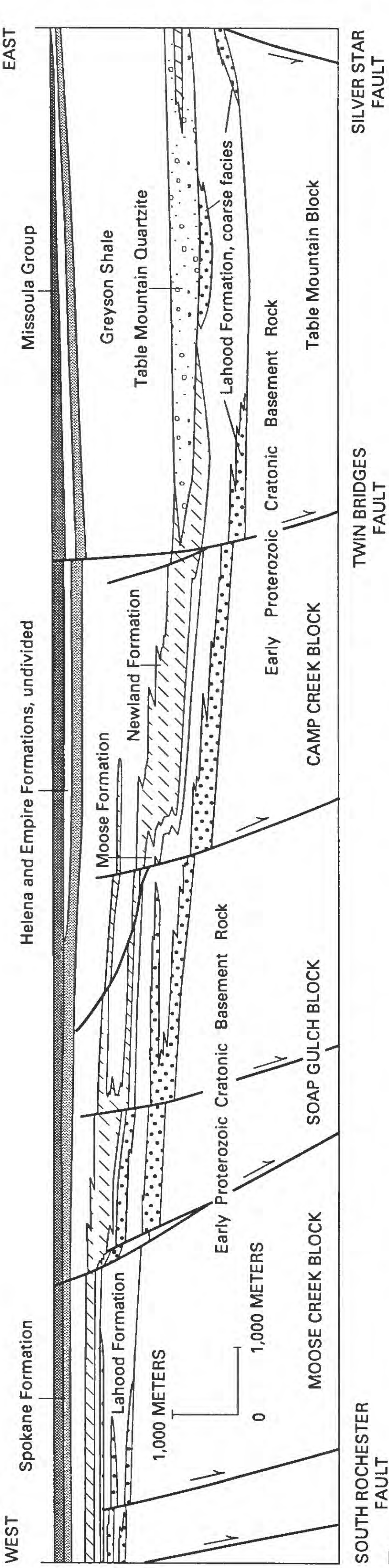
A
MAYFLOWER
MINE
FAULT
TOBACCO
ROOT
MOUNTAINS
ARCHEAN
BASEMENT
ROCKS
Jefferson
Valley
BASEMENT
ROCKS
BOULDER
BATHOLITH
Line of section
PROTEROZOIC GNEISS DOME
HELL CANYON
PLUTON
TABLE MOUNTAIN
BLOCK
HIGHLAND MOUNTAINS
FAULT
TWIN BRIDGE FAULT
EARLY
CAMP CREEK
BLOCK
CAMP
CREEK
MOOSE CREEK
BLOCK
SOAP GULCH
BLOCK
0
5 KILOMETERS
EXPLANATION
Quaternary and Tertiary deposits
Mesozoic plutonic rocks
Paleozoic sedimentary rocks
Calc-silicate rock
Argillite
Quartzite
Conglomerate
Middle Proterozoic
Belt Supergroup
Basement rocks
Contact
Antiform
Normal fault—Ball and bar on downthrown side
Thrust fault—Sawteeth on upper plate



B

Figure 2. Map and cross section showing geology of study area, southwestern Montana. *A*, Generalized lithofacies map of the Highland Mountains and the northwestern part of the Tobacco Root Mountains; map units of the Belt Supergroup sedimentary rocks are lithofacies units and do not everywhere reflect individual formations within the supergroup; location of type sections of the Table Mountain Quartzite (solid circle) and the Moose Formation (solid triangle) are also shown. *B*, Diagrammatic cross section showing stratigraphic relations of Belt Supergroup across the Highland Mountains and relation of depositional units to underlying basement structural blocks.

coarse- to medium-grained argillaceous lithic quartzite; in the western part of the outcrop belt the formation includes minor fine- to medium-grained quartzite. Subordinate argillite and siltite are locally interlayered with these rocks.

The thickness of the LaHood Formation is not known precisely. Faint bedding in the coarse clastic facies and poor exposure of intervals of thinly bedded quartzite, siltite, and argillite preclude measurement and detailed description of the formation in the Highland Mountains. The estimated thickness, based on map measurements of the LaHood directly west of the Twin Bridges fault, is about 1,300 m (O'Neill and others, 1995).

LITHOLOGIC DESCRIPTION

The LaHood Formation in the Highland Mountains can be divided into two sedimentary packages. Coarse-grained conglomeratic alluvial deposits interlayered with subaerial and subaqueous quartzite dominate the formation west of the Twin Bridges fault (fig. 2*A*), whereas well-bedded quartz and lithic pebble and boulder conglomerate, coarse-grained lithic quartzite containing rip-up clasts of dark-gray siltite-argillite of probable subaqueous debris flow origin, and minor fluvial conglomerate characterize the formation in the Table Mountain block east of the fault.

In the package west of the Twin Bridges fault, poorly bedded to massive, cobble to boulder conglomerate is preferentially located at or near the base of the sequence. The conglomerate is thickest at the intersections of the Camp Creek fault with each of the northwest-trending faults that cut the crystalline basement rocks to the south; the conglomerate thins northeastward, away from the fault intersections (fig. 2*A*). Clasts in the conglomerate (fig. 4*A*) consist of biotite and quartzofeldspathic gneiss that probably was derived from Precambrian cratonic rocks now exposed directly south of the Camp Creek fault. Clasts are generally subangular to subrounded and are as long as about 0.5 m (fig. 4). Matrix consists of sand, granules, and pebbles and commonly is grayish green to brown.

Conglomerate lenses become finer grained (fig. 4*B*) and pinch out laterally to the northeast, where they grade successively into fine- to coarse-grained quartzite, siltite, and silty argillite. These finer grained distal facies show abundant cut-and-fill structures, load casts, soft-sediment folds (figs. 5*A*, *B*), and, locally, in the most distal parts, upward-fining Bouma sequences (fig. 5*C*) typical of turbidite deposits.

Rocks of the LaHood directly overlying the basal conglomeratic facies are generally poorly exposed; however, the uppermost LaHood is well exposed below the type section of the Moose Formation, west of the Twin Bridges fault. The approximately 125 m of the LaHood measured in this area can be divided into two units. The lower 108 m is a clastic sequence that fines upward from beds of lithic-pebble conglomerate to beds of argillaceous siltite and silty argillite.

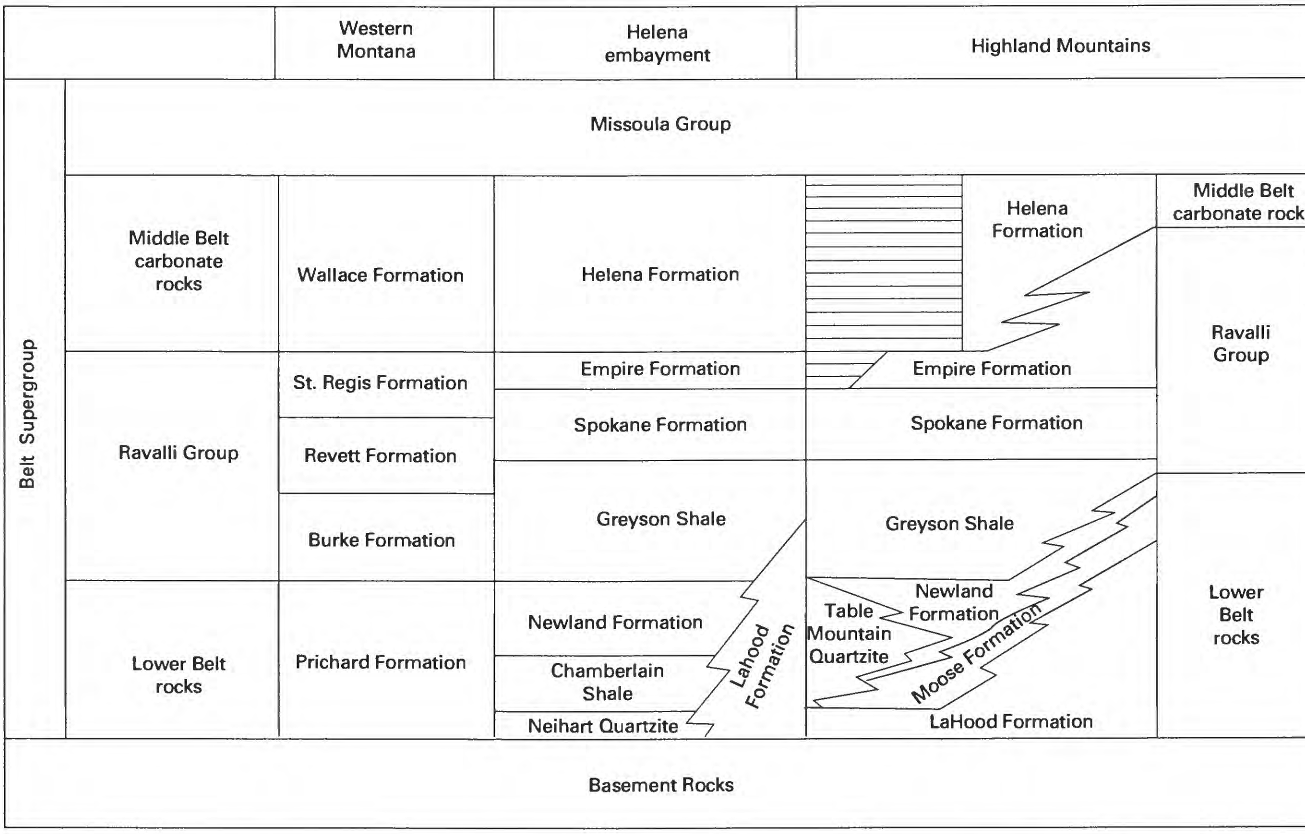


Figure 3. Correlation of Belt Supergroup units in western Montana and the Helena embayment (Harrison, 1972) and units exposed in the Highland Mountains.

The beds range from less than 0.5 to as much as 7 m in thickness and internally each fines upward. The base of each bed is marked by granule to pebble conglomerate that grades upward into coarse quartz-rich quartzite. Almost all upward-fining beds are capped by dark-gray silty argillite. These upward-fining beds are distinct and generally do not grade into overlying and underlying beds. Most bedding contacts are planar but locally define lens-shaped channel deposits.

The upper 17 m of the LaHood Formation consists of an overall upward-coarsening clastic sequence. Beds in the lower part are characterized by upward-coarsening silty argillite to very fine grained quartzite 0.2–0.5 cm thick. The upper part is channel quartzite that coarsens upward from medium to coarse sand in beds that have irregular, wavy tops.

FACIES

A distinctively different succession of the LaHood strata is only present in the Table Mountain block, east of the Twin Bridges fault. In this area, LaHood strata consist mainly of thick-bedded to massive, locally conglomeratic, coarse-grained lithic arenite and quartzite. The quartzite is poorly sorted and commonly encloses floating granules and pebbles of subrounded lithic clasts (fig. 6*B*). Lenses of lithic cobble conglomerate are present in the quartzite. These lenses rarely exceed 3 m in thickness, and they are locally associated with rip-up clasts and lenses of intraformational conglomerate (fig. 6*A*). More commonly, the quartzite contains lenses of upward-fining quartz-pebble conglomerate less than 20 cm thick. The best exposures of the coarse-grained quartzite are directly east of the Twin Bridges fault, in a triangle-shaped area bounded on the east by the Hell Canyon pluton, a satellite of the Boulder batholith (fig. 2*A*).

In the Highland Mountains the LaHood Formation is overlain by the Moose Formation except in the central part of the Table Mountain block, where well-rounded pebble and cobble conglomerate of the LaHood is overlain by the Table Mountain Quartzite (fig. 2*B*).

MOOSE FORMATION

The Moose Formation is the name herein applied to a thin sequence of argillite and siltite that overlies the

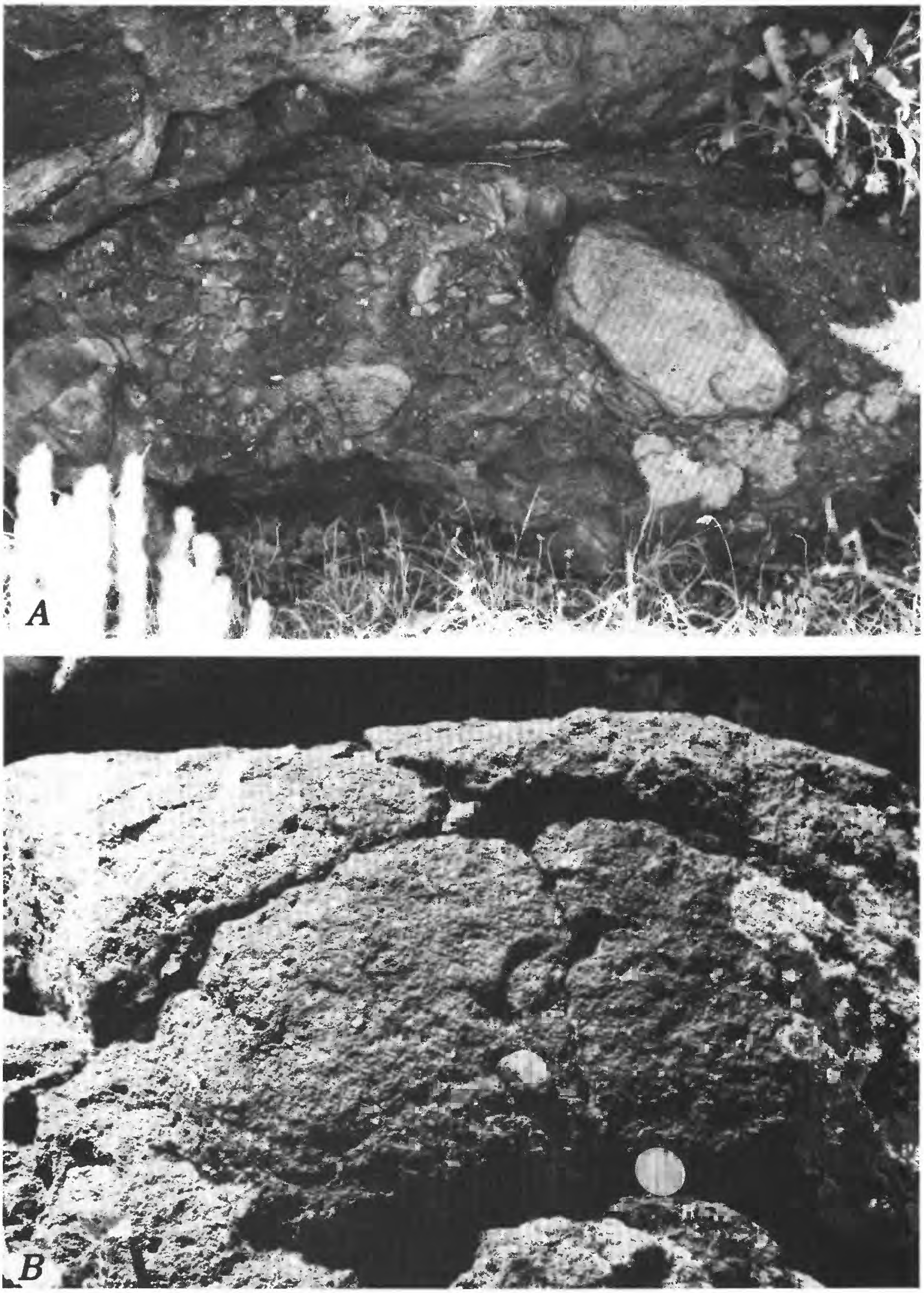


Figure 4. Coarse conglomerate facies of LaHood Formation. Outcrop along Camp Creek on the southeast side of King and Queen Hill, Wickiup Creek 7½-minute quadrangle. *A*, Boulder and cobble conglomerate; the long axis of the boulder right of center is 0.45 m. *B*, Granule and pebble conglomerate, a lateral northeasterly facies of the boulder and cobble conglomerate. Quarter in lower part of photograph is shown for scale.

LaHood Formation and underlies the Newland Formation in the western part of the Highland Mountains. These rocks were assigned to the Prichard Formation by Thorson (1984) and to the Chamberlain Shale by Ruppel and others (1983), and they were described but not named by Ruppel and others (1993). Although the Prichard Formation of the western Belt Basin is in part a stratigraphic correlative of the Moose of the Highland Mountains (fig. 3), the nearest outcrops of unquestioned Prichard Formation are about 150 km west-northwest of the Highland Mountains, and the Prichard is generally restricted to sedimentary successions commonly more than 6 km thick (Cressman, 1989) in that part of the basin where Helena embayment nomenclature is not applied.

The Chamberlain Shale nomenclature is also not used for these rocks. The Moose and Chamberlain occupy the same stratigraphic position below the Newland Formation (fig. 3) but in vastly different parts of the Helena embayment. The Chamberlain, a 500-m-thick black argillite that was deposited directly above the Neihart Quartzite, is restricted to the Little Belt Mountains, 150 km northeast of the Highland Mountains, and is lithologically different from the thin silty argillite and siltite of the Moose Formation.

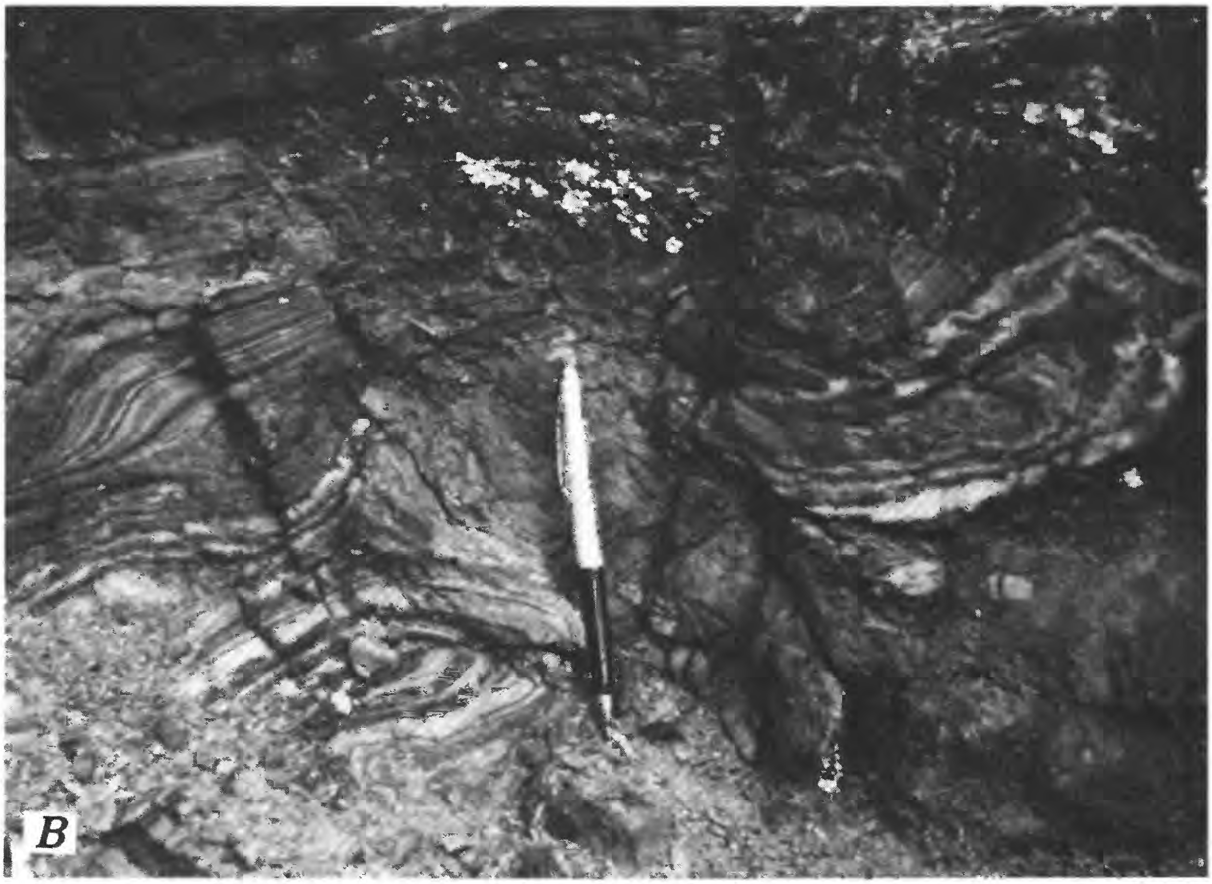
A separate nomenclature for lower Belt rocks has generally been used in the geographically isolated Helena embayment (fig. 3). I prefer to continue that tradition but establish a new formation name for a geographically isolated unit, unique in its stratigraphic and sedimentologic significance, that may or may not be a facies of either the Prichard Formation or the Chamberlain Shale. Thus, the names Prichard and Chamberlain are not used and the name Moose is applied to the fine-grained clastic rocks below the Newland and above the LaHood in the Highland Mountains along the southern margin of the Helena embayment of the Belt Basin.

Figure 5 (above and facing page). Bedding character of finer grained facies of the LaHood Formation. *A*, Thin- to medium-bedded quartzite and argillaceous siltite. Quarter in central part of photograph is shown for scale. *B*, Soft-sediment folds in interlayered quartzite, siltite, and silty argillite. Pencil is shown for scale. *C*, Typical Bouma sequence in distal parts of LaHood Formation. Quarter is shown for scale. Photographs (*A*) and (*B*) are of exposures along Soap Gulch near its confluence with Left Fork Soap Gulch, Melrose 7½-minute quadrangle. Photograph (*C*) is of an exposure on the lower slopes, southeast side of King and Queen Hill, Wickiup Creek 7½-minute quadrangle.

TYPE LOCALITY AND TYPE SECTION

The type locality of the Moose Formation (solid triangle, fig. 2*A*) is along the north side of Moose Creek, for which the unit is named, and the access road to the Humbug Spires Primitive Area. Moose Creek drains the western part of the Highland Mountains and empties into the Big Hole River about 10 km north of Melrose, Montana. The type locality is on Bureau of Land Management lands, adjacent to Deerlodge National Forest, near the line between secs. 26 and 27, T. 1 S., R. 9 W.; a graphic type section of the Moose Formation is shown in figure 7. The thickness of the Moose Formation is at least 48 m at the type section, and, similar to all other formations of Belt age in the Highland Mountains, it thickens eastward; at Camp Creek, 11 km away, the formation is about 85 m thick (fig. 7).

At the type section, the Moose Formation is separated from pebbly quartzite of the underlying LaHood Formation by a small north-dipping oblique-slip shear zone. Both the bedding and the shear zone dip north, and the angle between the two planar features is about 30°. The shear zone cannot be traced laterally; hence, the amount of stratigraphic section missing, although not known, is probably not large. The lower 9 m of the Moose consists mainly of even to wavy parallel-laminated, argillaceous siltite containing 1-cm-thick silty, less commonly crossbedded, sand-filled channels. The upper 39 m consists mainly of even- to wavy-laminated, medium-gray platy argillaceous siltite and dark-gray silty argillite enclosing very fine grained quartzite lenses 0.5 cm



A Basal sands of overlying turbidity flow

C(?) and D Fine-grained pelagic sediments cap flow

B Fine-grained sandstone deposited in lower and upper flow regimes

A Upward-fining coarse- to fine-grained sandstone

Rapid deposition

Base of turbidity flow

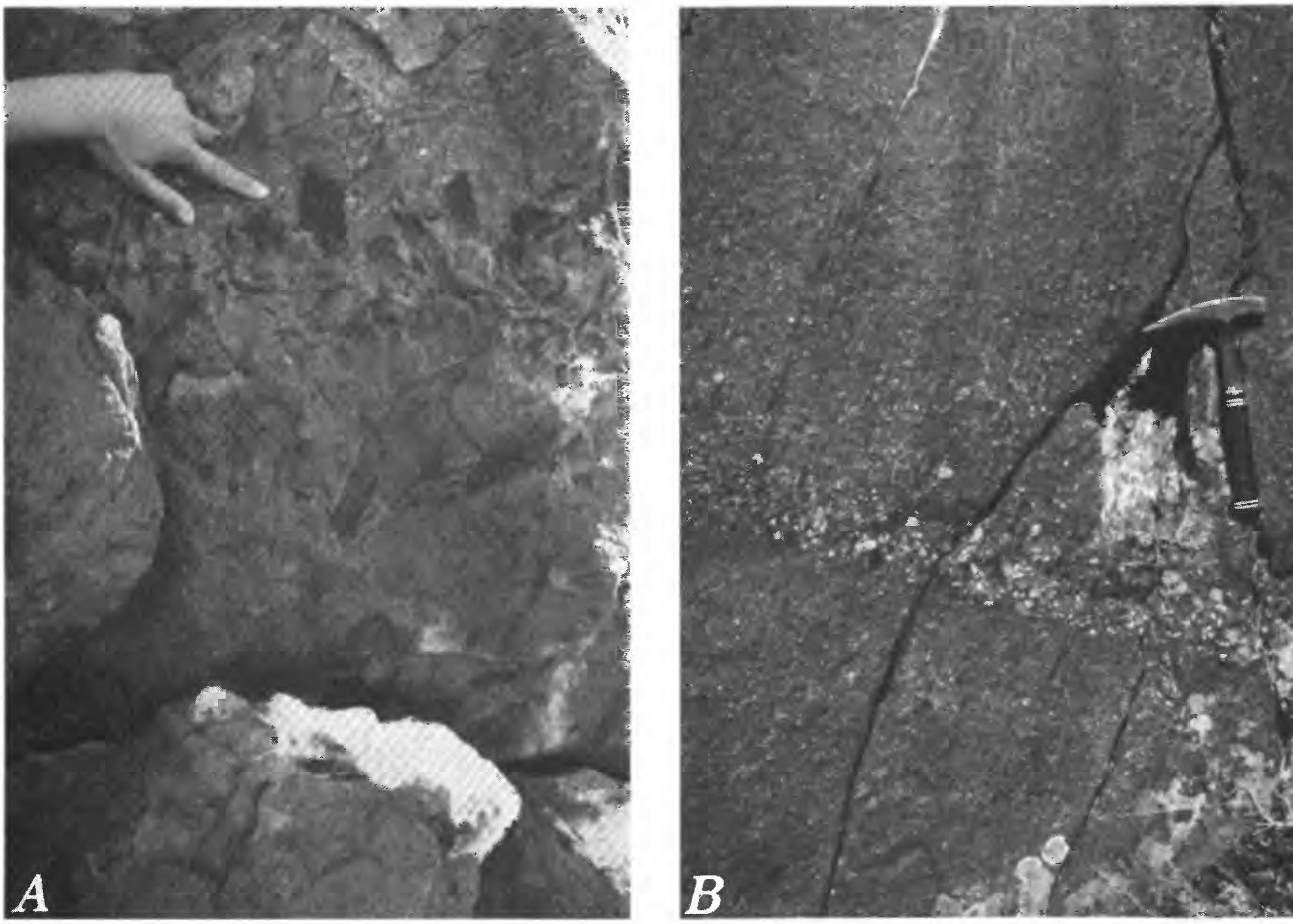


Figure 6. Facies of the LaHood Formation east of the Twin Bridges fault, 0.5 km south of Sawmill Gulch, Wickiup Creek 7½-minute quadrangle. *A*, Floating clasts of lithic pebbles and cobbles and angular clasts of argillite and siltite adjacent to hand in coarse-grained quartzite. *B*, Coarse lithic quartzite containing abundant lithic granules and thin lenses of quartz-rich pebble conglomerate; note floating boulder of quartzofeldspathic gneiss behind hammer.

thick. Minor soft-sediment slumps and rare ripple marks are also present.

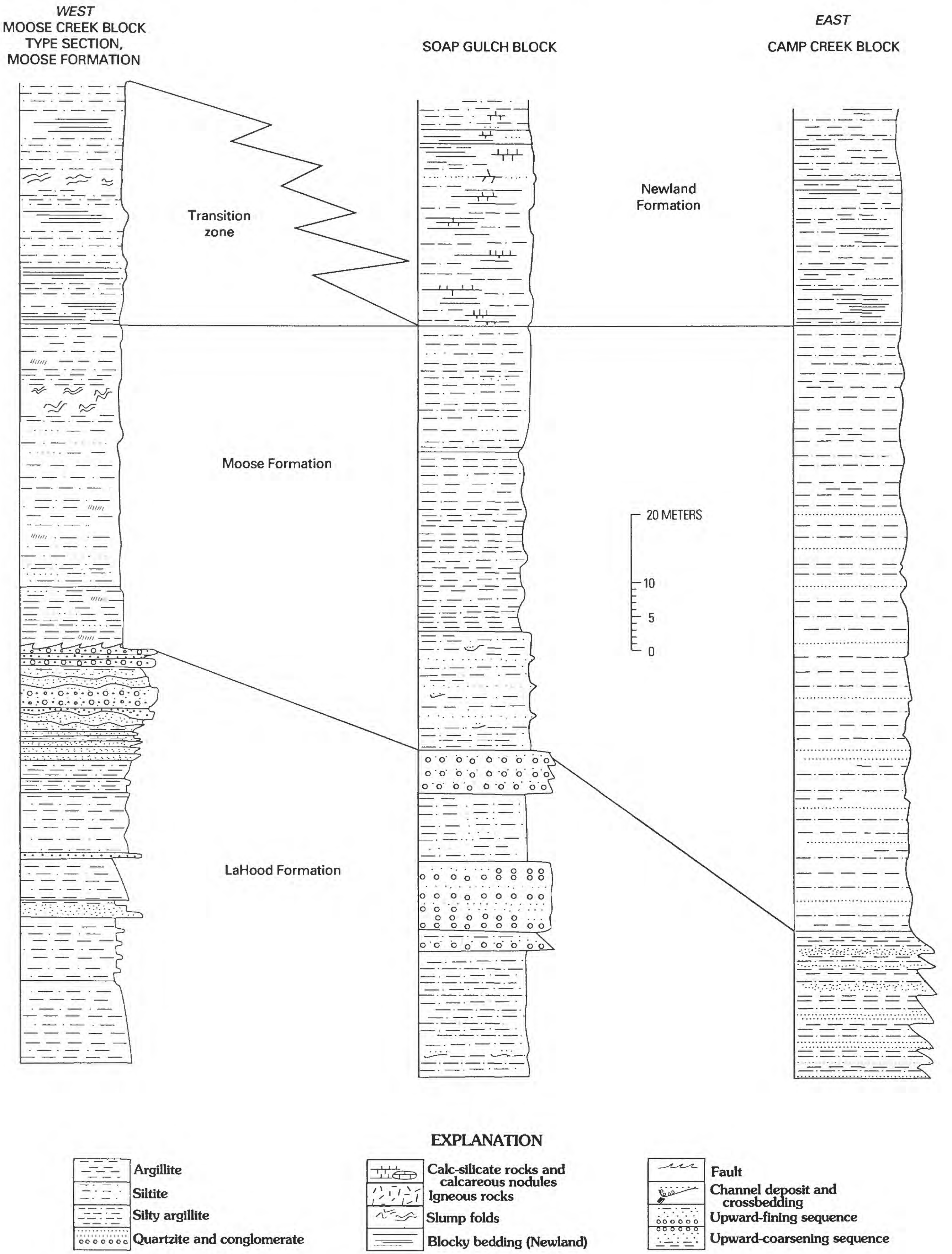
CONTACTS WITH ADJACENT UNITS

At the type section, basal parallel-laminated silty argillite of the Moose Formation is in fault contact with arkosic quartzite and conglomerate of the LaHood Formation. The contact is abrupt and is marked by a fault breccia that dips about 60° northward. The upper contact of the Moose Formation is placed at the first occurrence of Newland-like beds that mark the base of the transition zone; the zone is gradational into calcareous, blocky bedded silty argillite of the Newland Formation. The transition zone is 34.5 m thick and composed of dark-gray argillaceous siltite and thin siltite lenses interlayered with medium-gray argillaceous siltite beds typical of the Newland. The beds representative of the Newland are 1–2 cm thick, internally homogeneous and structureless, and separated by even-parallel argillaceous siltite lamellae.

FACIES

The Moose Formation thickens eastward, across the Soap Gulch block, to about 90 m in the Camp Creek block.

Figure 7 (facing page). Stratigraphic correlation of sections of the Moose Formation at the type section (secs. 26, 27, T. 1 S., R. 9 W.) and in the Soap Gulch and Camp Creek blocks to the east. Locations of type section and the Soap Gulch and Camp Creek blocks are shown in figure 2.


WEST
MOOSE CREEK BLOCK
TYPE SECTION,
MOOSE FORMATION
SOAP GULCH BLOCK
EAST
CAMP CREEK BLOCK
Transition zone
Newland Formation
Moose Formation
LaHood Formation
20 METERS
10
5
0
EXPLANATION
Argillite
Siltite
Silty argillite
Quartzite and conglomerate
Calc-silicate rocks and calcareous nodules
Igneous rocks
Slump folds
Blocky bedding (Newland)
Fault
Channel deposit and crossbedding
Upward-fining sequence
Upward-coarsening sequence

At Camp Creek the lower 61 m consists mainly of argillaceous siltite and minor thin interbeds of argillite and fine-grained quartzite. The uppermost 29 m lacks the thin interbeds of quartzite.

Only a thin sliver of the Moose Formation was recognized to the east in the Table Mountain block. In this area, the normal stratigraphic position of the Moose, as well as part of the overlying Newland, is occupied by the Table Mountain Quartzite.

TABLE MOUNTAIN QUARTZITE

TYPE LOCALITY AND TYPE SECTION

The type locality of the Table Mountain Quartzite is along the south side of East Peak, 1.6 km east of Table Mountain, the highest peak in the Highland Mountains. This locality (solid circle north of the Hell Canyon pluton, fig. 2*A*) is in the Deerlodge National Forest and crosses the line between secs. 14 and 23, T. 1 S., R. 7 W. A graphic section of the type Table Mountain Quartzite is shown in figure 8. In the type locality area, the Table Mountain Quartzite underlies the highest peaks of the Highland Mountains and is recognized by its distinctive white color that contrasts markedly with the red argillite and siltite of the Greyson Shale that underlies the other high peaks of the range.

The formation was named for the conspicuous white quartzite exposed on Table Mountain; however, the type locality is on East Peak because the entire formation is best exposed in the south-facing glacial cirque carved into the southern face of the peak. The Table Mountain Quartzite is about 528 m thick at the type section, but the unit pinches out to the west and thins to the east where it is cut out by the Rader Creek and Donald plutons of the Boulder batholith. The Table Mountain can be divided into two informal members: a lower quartzite member 262 m thick consisting mainly of massive, thick-bedded, cliff-forming white quartzite and an upper argillaceous quartzite member 266 m thick consisting of thin-bedded, upward-fining quartzite interlayered with minor siltite and argillite (fig. 8). At the type section, the lower quartzite member consists of three units: a lower unit, A, and upper unit, C, of thick-bedded quartzite separated by an interval (unit B) of thin-bedded quartzite, siltite, and argillite (see fig. 8). Three small faults are present in the lower quartzite member but probably do not cut out much of the section. The lowermost 80 m of unit A is poorly exposed and consists of fine- to medium-grained quartzite that rests directly on lithic pebble to cobble conglomerate of the LaHood Formation. Overlying this poorly exposed quartzite is about 100 m of thick-bedded to massive, cliff-forming orthoquartzite composed of very fine grained to medium-grained, subrounded quartz grains. Bedding in the orthoquartzite ranges from 1 to more than 5 m in thickness; layering in these massive beds is locally defined by seams and lamellae of heavy-mineral concentrates. The base of the orthoquartzite is associated with thin seams of purplish-gray, very fine grained argillaceous quartzite and intraformational (mudchip) conglomerate. The uppermost 15 m of the orthoquartzite is thin- to thick-bedded, tan to yellowish-white quartzite.

Unit A is overlain by about 45 m of interlayered quartzite and argillaceous quartzite and siltite (unit B) in beds 5–50 cm thick (fig. 8). The lower beds of unit B consist of upward-fining, medium- to fine-grained, well-sorted quartzite that locally fills small channels cut into beds of argillaceous quartzite and siltite. The upper contacts of the channel fill are sharp and abrupt. Unit B is in sharp contact with the overlying 37-m-thick, massive white quartzite of unit C, which is similar to the white cliff-forming quartzite in the lower part of the section (unit A).

The upper argillaceous quartzite member of the Table Mountain Quartzite consists predominantly of thin-bedded quartzite interlayered with minor conglomerate, argillaceous and silty quartzite, siltite, and argillite; the contact with the underlying quartzite member is sharp. The member can be divided into two parts (see fig. 8). The lower part, unit A, contains numerous well-developed upward-fining cyclical units 1–2 m thick. Characteristically the cycles consist of four parts, each grading successively upward into the next part (fig. 9): (1) basal conglomerate of clasts of the underlying argillaceous quartzite, (2) poorly sorted coarse- to fine-grained quartzite, (3) well-sorted medium-grained orthoquartzite, and (4) a sequence of interlayered argillaceous quartzite and clean, white to pink quartzite in beds as thick as 5 cm that grades upward into gray, laminated argillaceous quartzite. The upper part (unit B) of the member is 166 m thick and contains numerous partial cycles commonly consisting of upward-fining medium-grained orthoquartzite overlain by thin-bedded argillaceous quartzite (parts 3 and 4 of the entire cycle). In the uppermost 50 m of unit B, these partial cyclic deposits are characterized by numerous soft-sediment folds and slumps.

A lens at least 5 m thick of intraformational conglomerate and slump breccia, which is not present at the type section, is poorly exposed in a glacial cirque on the northwest side of Table Mountain. The conglomerate is mostly covered by talus and glacial moraine but can be traced along strike for 0.5 km. It is composed of rounded to subangular boulders of quartzite as much as 0.5 m across. The unit is near the top of the lower quartzite member of the Table Mountain Quartzite.

A similar, areally restricted slump breccia containing clasts as much as 5 m across is present in the Greyson Shale that overlies the Table Mountain Quartzite and is also restricted to the glacial cirque on the northwest side of Table Mountain. The restricted areal extent and the large size of the slump blocks within the Table Mountain Quartzite and the overlying Greyson Shale suggest that the breccias reflect localized syndepositional tectonism.

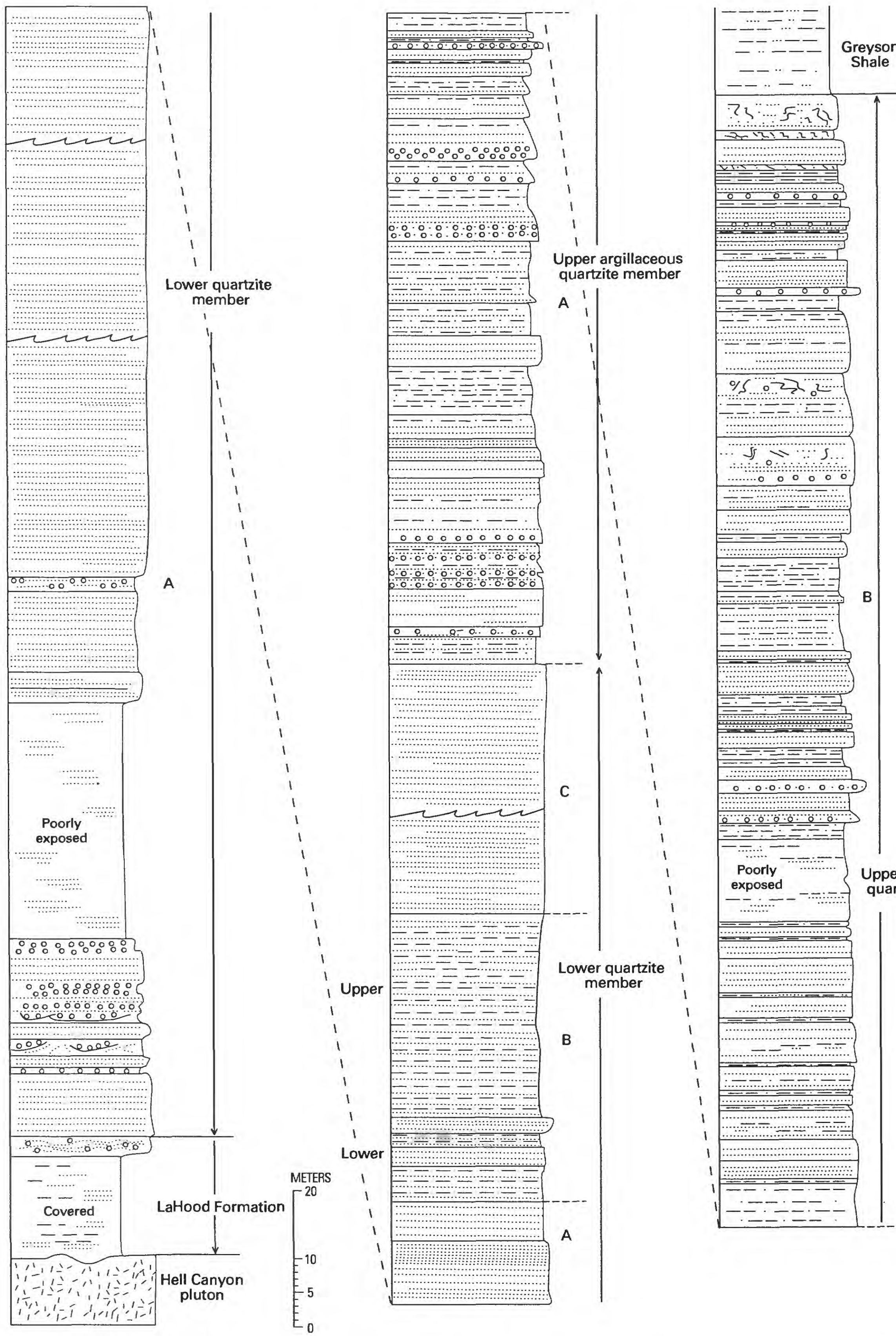


Figure 8. Stratigraphic section of the Table Mountain Quartzite at the type section (secs. 14, 23, T. 1 S., R. 7 W.) on East Peak. Informal upper and lower members are divided into units A, B, and C, as discussed in text. Lithologic explanation is given in figure 7.

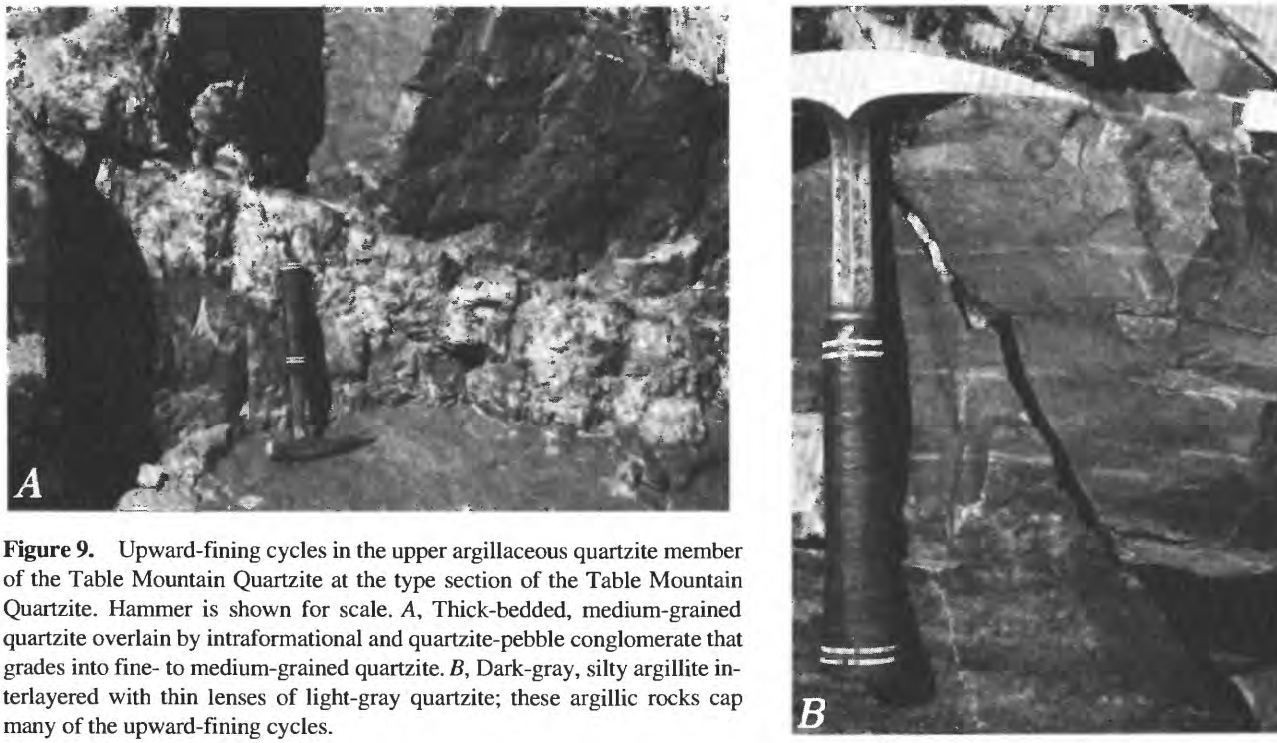


Figure 9. Upward-fining cycles in the upper argillaceous quartzite member of the Table Mountain Quartzite at the type section of the Table Mountain Quartzite. Hammer is shown for scale. *A*, Thick-bedded, medium-grained quartzite overlain by intraformational and quartzite-pebble conglomerate that grades into fine- to medium-grained quartzite. *B*, Dark-gray, silty argillite interlayered with thin lenses of light-gray quartzite; these argillic rocks cap many of the upward-fining cycles.

CONTACTS WITH ADJACENT UNITS

At the type section the Table Mountain Quartzite lies conformably on lithic, pebble to cobble conglomerate of the LaHood Formation. The top of the Table Mountain Quartzite is placed at the top the highest white quartzite bed below the Greyson Shale. West of the type section the Table Mountain interfingers with the Newland Formation. East of the type section the Table Mountain Quartzite rests directly on pebble conglomerate of the LaHood, contains a tongue of the Newland in the middle as well as 28 m below the top of the formation, and is overlain by the Greyson Shale.

FACIES

The Table Mountain Quartzite pinches out to the west of the type area and is not present west of the Twin Bridges fault (fig. 2*B*). On the unnamed peak 2 km directly west of Table Mountain, the formation is 240 m thick, less than half the thickness at the type section at East Peak 2 km to the east. On the unnamed peak, the quartzite rests conformably on the Newland Formation. Here the quartzite is white and medium to thick bedded, similar to the lowermost quartzite at the type section but including a greater argillaceous component. The Table Mountain Quartzite is also overlain by thin-bedded argillite and siltite of the Newland Formation.

East of the type section the formation has been intruded by plutons of the Boulder batholith. At the easternmost exposures adjacent to the batholith, the quartzite rests directly on conglomerate of the LaHood. The formation, poorly exposed in this area except for the lowermost 30 m, is about 320 m thick. The exposed lowermost beds consist of medium-bedded, fine- to medium-grained channel-fill quartzite and laminated to massive, tabular quartzite. Beds are commonly separated by thin argillaceous seams or laminated argillaceous quartzite. Cyclical deposits, similar to those in the upper part of the Table Mountain at the type section, are rare. The lowermost part of the section is overlain by 100 m of mostly covered section that is interpreted from float to include an unknown percentage of white to pink, fine- to coarse-grained quartzite. Beds probably are 1 m or less thick. A 60-m-thick tongue of Newland Formation is 120 m below the top of the Table Mountain in this area, and thin Newland-like beds are also present in the uppermost 30 m. The upper contact with the Greyson Shale is abrupt.

NEWLAND FORMATION

The Newland Formation of the Highland Mountains is similar mainly in its bedding character to the Newland Formation at its type locality near Newlan Creek in the Little Belt Mountains and to a complete section along Deep Creek at the south end of the Big Belt Mountains (M.W. Reynolds, oral commun., 1988). In the Little Belt Mountains, the Newland consists of alternating limestone and argillite, and the amount of limestone increases upward (Ross, 1963, p. 69). Many of the limestone beds in the Big Belt Mountains are finely layered and may represent mat stromatolites.

Figure 10. Flaggy bedding character of typical Newland Formation. Quarter inset in fracture in right-central part of photograph is shown for scale. Outcrop along dirt road on the south side of Moffet Mountain, Wickiup Creek 7½-minute quadrangle.

LITHOLOGIC DESCRIPTION

The partial section of the Newland Formation that overlies the Moose Formation at its type section illustrates the general lithology of the Newland in the Highland Mountains. There the Newland consists of almost 150 m of mainly medium gray, flaggy weathering siltite in beds 2–3 cm thick (fig. 10). Individual beds are homogeneous and without internal structure or layering and are separated from adjacent beds by even-parallel laminae of lighter colored siltite. About 6 m above its base, the Newland in a 7.5-m-thick interval is less flaggy and more argillaceous and contains numerous small silty and sandy channel fills and climbing ripples similar to the Moose Formation. At 52 m above the base, there is a local decrease in bed thickness and an increase in slightly wavy laminae; bedding character is similar to that of the overlying Greyson Shale. The upper 40 m of the Newland Formation shows bedding typical of the Newland at its type locality in the Little Belt Mountains.

CONTACTS WITH ADJACENT UNITS

At the Moose Creek locality, the lower contact of the Newland is gradational over a 34.5-m-thick transition zone above the Moose Formation. The base of the Newland is placed at the base of the lowest, laterally continuous flaggy argillaceous siltite that displays typical Newland bedding. At the Soap Gulch and Camp Creek localities, the contact with the Moose Formation is sharp.

At the Moose Creek locality, the upper contact of the Newland is abrupt, marked by thin-bedded black argillite of the Greyson Shale. The lowermost Greyson does contain several very calcareous beds, but they are herein included in the Greyson. Hydrothermally altered limestone beds mark the top of the Newland at the Soap Gulch locality. At the Camp Creek locality, interlayered Greyson Shale and flaggy bedded Newland form a transition zone more than 225 m thick; the contact between the two formations is placed at the base of this transition zone. At Table Mountain, a similar, but more arenaceous, 160-m-thick transition zone is present between the two formations.

FACIES

The Newland Formation, which is only 150 m thick at Moose Creek in the western part of the Highland Mountains, thickens eastward to more than 350 m at the Camp Creek locality (fig. 2*B*). The Newland Formation at the Moose Creek locality is laterally equivalent to the upper part of the Newland at Soap Gulch, and this part of the formation pinches out eastward from Soap Gulch by interfingering with and grading laterally into the Greyson Shale. The lower part of the Newland at the Soap Gulch locality is laterally equivalent to the upper part of the Newland at Camp Creek. Eastward, the upper part of the Newland interfingers with and pinches out into the Greyson Shale of the Table Mountain locality; the middle part of the Newland at the Camp Creek locality interfingers with and lies beneath the Table Mountain Quartzite. Farther to the east, a tongue of the Newland is present within the Table Mountain Quartzite.

RAVALLI GROUP

GREYSON SHALE

The Greyson Shale, named for 915 m of dark-gray to greenish-gray argillite exposed in the southwestern part of the Big Belt Mountains in the vicinity of Deep Creek (Walcott, 1899), is, with the probable exception of the LaHood Formation, the thickest formation of the Belt Supergroup in the Highland Mountains. The Greyson, only 220 m thick at Moose Creek, thickens dramatically eastward to about 1,260 m in the Table Mountain block. The mainly interlayered silty argillite and siltite of the western outcrop area become more lithologically diverse to the east. At Camp Creek the formation includes several calcareous beds, interpreted to be eastward-thinning tongues of the Newland, as well as distinctive calcareous, coarse-grained quartzite. In the Table Mountain block the middle part of the formation contains a thick sequence of upward-fining layers, some of which are capped by calcareous argillite.

LITHOLOGIC DESCRIPTION AND FACIES

In the Moose Creek block the lowermost 36 m of the Greyson is characterized by interlayered flaggy dark-gray argillite, platy argillaceous siltite, and 0.1–0.25-m-thick beds of medium-gray silty limestone and associated limestone nodules. The calcareous beds, restricted to the bottom 10 m of the Greyson, are included in this formation because they are interlayered with dark-gray argillite that lacks the blocky bedding of the underlying Newland. The remaining 26 m consists of dark-gray, noncalcareous, wavy bedded, silty argillite containing at least one 2-cm-thick limestone lens. The overlying 27 m consists mainly of dark-gray argillaceous siltite that has flaggy Newland-like bedding. These rocks are in turn overlain by dark-gray, platy, even-parallel-laminated silty argillite characteristic of much of the Greyson elsewhere in the Highland Mountains. The uppermost 84 m of the formation is mostly covered; float consists of Greyson-like argillite, thin-bedded siltite, and very fine grained quartzite. This interval probably represents a transition zone between the Greyson and the overlying Spokane Formation.

To the east, in the Soap Gulch block, the Greyson is about 350 m thick. The formation, although poorly exposed in the lower part, consists of two units: a lower 170 m of dark- to medium-gray, even-parallel-laminated silty argillite displaying rare Newland-like bedding and an upper 180 m of dark-gray, locally silty argillite characterized by extensive soft-sediment deformation manifested mainly as isoclinal folds that have amplitudes of as much as 2 m (fig. 11).

In the Camp Creek block, the Greyson is 876 m thick and represents the most lithologically diverse part of the formation. The lowermost 160 m consists of dark-gray, even-parallel-laminated argillaceous siltite and silty argillite enclosing wispy lenses of tan siltite; a 0.5-m-thick calcareous quartzite is present near the top of this interval. Strata in the bottom 40 m locally show the flaggy bedding of the Newland. Upsection is about 180 m of light-to dark-gray, olive-green, or tan, laminated to nonlaminated silty argillite; soft-sediment folds are common in the upper part. Two thin beds of calcareous siltite to very fine grained quartzite in the upper 40 m of this part of the Greyson probably are eastward-thinning tongues of the upper Newland Formation in the Soap Gulch block.

Above the 180-m-thick silty argillite unit is about 330 m of mainly siltite and argillaceous siltite that contain conspicuous beds, generally less than 0.5 m thick, of tan, medium- to coarse-grained, grain-supported quartzite. Associated silty argillite commonly contains wispy, discontinuous lenses, generally less than 1 cm thick and 15 cm long, of very fine grained quartzite that locally forms climbing ripples. The uppermost Greyson, almost 200 m thick, consists of laminated silty argillite containing minor thin quartzite lenses.

To the east, in the Table Mountain block, the Greyson is 1,260 m thick and consists of three distinctive parts. The lower part is 210 m thick and mainly argillaceous, laminated siltite. The middle part, 550 m thick, consists mainly of upward-fining cyclic deposits and includes two 50–60-m-thick, dark-gray argillite intervals that display well-developed soft-sediment deformation features. Cyclic deposits in the lower portion of the middle part consist of four components: (1) even-parallel-laminated, very fine grained quartzite to siltite that grades upward into (2) silty argillite containing thin, wispy sand lenses that, in turn, grades into (3) dark-gray argillite locally capped by (4) calcareous argillite. Each cycle is no thicker than about 20 m. Cycles in the upper portion of the middle part are also composed of four components but lack calcareous argillite. The components of these cycles are (1) a basal medium-grained quartzite commonly associated with intraformational conglomerate overlain by (2) thick-bedded, very fine grained quartzite and siltite containing even-parallel microlaminae of quartzite-siltite couplets. Component 2 grades upward into (3) 2–5-cm-thick

Figure 11. Soft-sediment folds in laminated Greyson Shale. Hammer is shown for scale. Outcrop along ridge extending westward from Negro Mountain, Wickiup Creek 7½-minute quadrangle.

beds of microlaminated quartzite and siltite couplets associated with dense, unlaminated siltites and is overlain by (4) massive to thick-bedded silty argillite. These cycles in the upper portion of the middle part range in thickness from 2 to 16 m.

The upper part of the Greyson in the Table Mountain block is 500 m thick and mainly dark gray to black argillite; locally it contains beds of sandy to silty argillite showing numerous soft-sediment folds.

SPOKANE FORMATION

The Spokane Formation was named for an incomplete section of deep-red arenaceous argillite in the Spokane Hills on the west side of the Big Belt Mountains (Walcott, 1899). The deep red colors displayed by the Spokane Formation in much of the Helena embayment are a major criterion for recognition. In the Highland Mountains, contact metamorphism of Belt-age rocks in the vicinity of the Boulder batholith, albeit weak, has modified the colors of the formation to hues of gray and green. The Spokane is the only formation that was deposited uniformly across the Highland Mountains; however, the formation is somewhat thicker and lithologically more variable in the Camp Creek block.

LITHOLOGIC DESCRIPTION

The Spokane Formation, 172 m thick at the Moose Creek locality, is mainly siltite containing local argillaceous and arenaceous intervals. The poorly exposed lower 34 m is the coarsest part of the formation and consists of medium-gray silty quartzite and thin interbeds of brownish-red thin-bedded siltite. The overlying 134 m is mostly siltite that contains thin argillaceous intervals, minor soft-sediment slump structures, and, locally, crossbeds and cut-and-fill structures where it is arenaceous. The uppermost 10 m is composed of interlayered argillite-siltite couplets enclosing even-parallel-laminated siltite beds as thick as 20 cm.

The Spokane thins slightly to the east, to 152 m, at the Soap Gulch locality. As at Moose Creek, the lower part is

Figure 12. Spokane Formation showing wavy-parallel laminated quartzite grading upward into nonlaminated arenaceous siltite. Pencil is shown for scale. Outcrop on ridge on the west side of Spring Creek cirque, Pipestone Pass 7½-minute quadrangle.

coarsest; it consists of 12 m of irregularly layered, blocky to platy, light-gray siltite and laminated, medium- to light-gray siltite interlayered with light-colored argillaceous to arenaceous siltite that commonly shows well-developed cross-stratification. Beds are as thick as 3–5 cm. The overlying 38 m consists mainly of thin-bedded siltite that locally includes layers of argillaceous siltite and minor fine-grained pinkish-white quartzite. The upper 102 m is mainly siltite but includes argillaceous to silty quartzite beds as thick as 6 m.

The Spokane is thickest, 220 m, in the Camp Creek block; to the east in the Table Mountain block it is 134 m thick. In both blocks the formation is mainly greenish-gray argillaceous siltite containing millimeter- to centimeter-thick intervals of lenticular, tan, very fine grained quartzite beds that thin and thicken along strike and tannish-white, nonlaminated arenaceous siltite to very fine grained quartzite that contains wavy-parallel laminations where argillaceous (fig. 12). Quartzite lenses 0.5–2 m thick composed of medium subrounded grain-supported quartz grains are also present and, in the Camp Creek block, are more common and thicker in the upper part of the Spokane Formation. All quartzite lenses pinch out to the west in the central part of the Soap Gulch block and thin eastward in the Table Mountain block.

CONTACTS WITH ADJACENT UNITS

The lower contact of the Spokane Formation across the Highland Mountains is generally well defined and abrupt and is placed on top of the uppermost laminated silty argillite of the Greyson Shale and below platy to thick bedded, medium-gray to greenish-gray siltite of the Spokane.

The Spokane Formation at the Moose Creek locality is unconformably overlain by quartzite and argillite of the Missoula Group; the position of the contact is occupied by a thin mafic sill of probable Cretaceous age. Above the mafic sill is a 6-m-thick medium-gray, poorly sorted, medium-grained quartzite interpreted to represent the base of the Missoula Group. The contact between the two formations, if viewed from several kilometers distance, appears slightly discordant; the underlying Spokane dips to the northeast at a slightly greater angle than that of the overlying Missoula

Group. At the Soap Gulch locality, the upper contact of the Spokane is placed on top of the highest argillaceous siltite, which is overlain by a thick succession of 1-m-thick blocky, irregularly bedded, dark-gray to greenish-gray argillaceous quartzite of the Missoula Group. In the central part of the Soap Gulch block the Spokane is overlain by complexly interlayered strata of the Empire and Helena Formations. In the Camp Creek block, the Spokane is overlain by rocks of the Empire Formation, here a distinctive dark-gray to black, thick-bedded argillite that contains conspicuous lenses of white calcareous quartzite. In the Table Mountain block the uppermost argillaceous siltite of the Spokane is overlain by blocky, greenish-gray argillite containing light-colored blebs of calcareous sandstone of the Empire Formation.

FACIES

Unlike the older formations of the Belt Supergroup, the Spokane Formation does not interfinger with adjacent sedimentary units. Contacts with underlying and overlying formations are abrupt and relatively well defined. The most significant facies change in the Spokane is the presence in the Camp Creek block of clean, light-colored quartzite beds that thin and pinch out to the east and west.

EMPIRE FORMATION

The Empire Formation, the uppermost formation of the Ravalli Group and typically a greenish-gray, siliceous argillite in the central part of the Helena embayment (Walcott, 1899; Ross, 1963), consists of dark-gray, black, and greenish-gray, thick-bedded argillite in the Highland Mountains. In the Soap Gulch block the formation is interlayered with the Helena Formation of the middle Belt carbonate sequence, and both the Empire and Helena pinch out westward in the block; neither is present in the Moose Creek block.

LITHOLOGIC DESCRIPTION

The Empire Formation is not well exposed in the Highland Mountains. In the Table Mountain block, the formation consists of 16.5 m of weakly laminated, dark-gray argillite containing tan to white wispy blebs of calcareous sand; the formation directly underlies cyclic, upward-fining, calcareous clastic deposits of the Helena Formation. In the Camp Creek block the Empire is mostly covered, and the upper and lower contacts are not exposed. In the central part of the Soap Gulch block, the formation is intimately interlayered with the Helena Formation, and both units together are less than 10 m thick. Farther to the west, in the Soap Gulch block, a 1.5-m-thick dark-gray argillite containing white, wispy quartzite lenses may represent the westernmost extent of the Empire Formation. In this area argillite of the Empire rests directly on a 4-m-thick dark-greenish-gray argillaceous quartzite that is underlain by siltite typical of the Spokane Formation; the argillite is overlain by quartzite assigned to the Missoula Group.

MIDDLE BELT CARBONATE ROCKS

HELENA FORMATION

The Helena Formation was named for prominent exposures of calcareous rocks near Helena, Montana, that consist mainly of impure bluish-gray to gray limestone interbedded with minor gray, green, and purple siliceous shale (Walcott, 1899). In the Highland Mountains the Helena is close to the southern margin of, and locally intruded by, plutons of the Boulder batholith; consequently, in this area the Helena is commonly a hornfelsed calc-silicate rock that weathers a distinctive pale greenish gray to pale green.

LITHOLOGIC DESCRIPTION

The Helena Formation is thickest, 172 m, in the Table Mountain block. The formation thins to 56 m westward in the Camp Creek block and pinches out farther to the west in the central part of the Soap Gulch block. The formation also thins to the east of the Table Mountain block. The formation, best exposed in the Table Mountain block, consists mainly of clastic to carbonate rocks in cyclic units that range in thickness from less than 10 cm to as much as 5 m. Not all cycles are well developed or complete, and one or more components may be missing. Each cycle has three major components: (1) a lower light-colored, very fine grained to medium-grained, wavy-parallel-laminated quartzite that fines upward, (2) a medial dark-gray weakly laminated argillaceous siltite that may contain very fine grained quartzite lenses, and (3) an upper purplish-gray to greenish-gray calcareous argillite (now calc-silicate rock). The argillite may contain vugs that are elongate parallel to bedding, or it may be well laminated (stromatolitic?) and contain numerous water-expulsion structures. Some well-laminated calcareous intervals are capped by thin purplish-gray silty argillite containing mud cracks filled by fine sand; locally the upper argillaceous parts of the cycles include intraformational conglomerate that may signal onset of the overlying upward-fining sand of the next cycle. The lower part of the formation includes intervals as thick as 9 m of dark-gray argillite enclosing tannish-white, very fine grained quartzite lenses that look like the underlying Empire Formation. The cyclic aspect of the Helena decreases upsection but not uniformly. In the Table Mountain block, the uppermost 20 m contains cyclical deposits, but the underlying 35 m consists mainly of interlayered purplish-gray silty argillite and minor tan and medium- to light-gray, very fine grained to medium-grained quartzite. The top of the formation is placed at the top of the highest clastic-carbonate cycle.

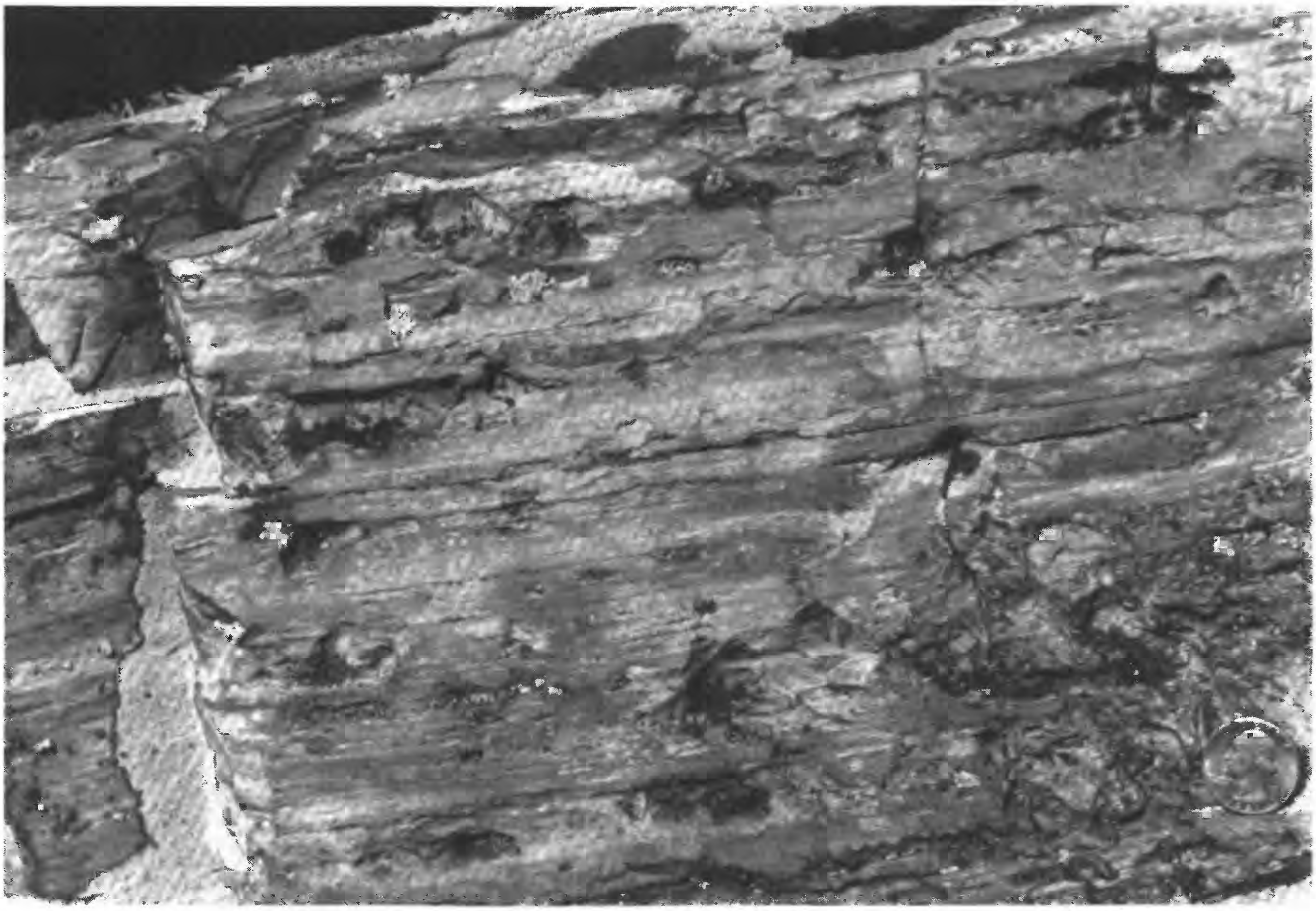


Figure 13. Helena Formation showing laminated beds containing vugs aligned along bedding planes. Quarter is shown for scale. Outcrop directly south of Gold Hill, Butte South 15-minute quadrangle.

To the west, in the Camp Creek block, the Helena Formation is not well exposed and is locally intruded by granitic rocks related to the Boulder batholith. The formation consists of pale-green, laminated, vuggy weathering calc-silicate rock (fig. 13) that includes centimeter-scale argillite to laminated calcareous argillite cycles and thin, horizontal calcareous pods. Locally, mud cracks (synoresis? cracks) are preserved in the calcareous argillite layers. In the Camp Creek block, the basal Helena grades laterally into or is interlayered with dense, green to dark-gray-green, locally laminated rocks that contain wispy, white calc-silicate lenses generally less than 3 cm thick (Empire? Formation). The Helena is clearly and intimately interlayered with the Empire Formation farther to the west in the Soap Gulch block; both formations pinch out westward and were apparently not deposited in the Moose Creek block.

CONTACTS WITH ADJACENT UNITS

In the Highland Mountains, the Empire and Helena Formations were not mapped separately (O'Neill and others, 1995) because in all places rocks typical of both formations are interlayered. Consequently, the lower contact of the Helena Formation, drawn at the base of the first clastic-to-carbonate cycle in laminated, vuggy calc-silicate rock, is not easy to map. The upper contact is placed at the top of the highest clastic-carbonate cycle and is generally abrupt. Argillic rocks of the Missoula Group present above this horizon generally lack the purplish-gray and greenish-gray colors typical of the Helena argillite; rather, they tend to be reddish gray to gray and silty to sandy. To the west, in the Camp Creek and Soap Gulch blocks, the Helena is overlain by a conspicuously laminated fine- to medium-grained argillaceous quartzite of the Missoula Group.

FACIES

Thick-bedded cyclical deposits of the Helena Formation in the Table Mountain block give way to thin-bedded cycles and calcareous argillite to the west in the Camp Creek block. The Helena and Empire Formations are intimately interlayered farther to the west, and in the Soap Gulch block both formations pinch out completely.

MISSOULA GROUP

Red and green argillite and siltite and pink to gray quartzite of the Missoula Group are present across much of western Montana (Ross, 1963); maximum thickness of these rocks exceeds 5,000 m (Wallace and others, 1984). The Missoula Group is well exposed 20 km directly west of the Highland Mountains in the Pioneer Mountains (Zen, 1988; Ruppel and others, 1993) where it is mostly allochthonous and is represented by more than 1,000 m of argillite, quartzite, and minor conglomerate. In sharp contrast, Missoula Group rocks in the Highland Mountains are in depositional contact with underlying Belt strata but are very thin, a maximum of 168 m thick in the Table Mountain block and only 16 m thick to the west in the Moose Creek block (fig. 14). Strata assigned to the Missoula Group in the Highland Mountains are composed mainly of quartzite and interlayered argillite and siltite. Isolated conglomerate is also present.

LITHOLOGIC DESCRIPTION AND FACIES

The Missoula Group is represented by a 16-m-thick sequence of interlayered quartzite and argillite in the Moose Creek block. The lower 6.2 m of the sequence is marked by beds of upward-coarsening, medium-gray, medium-grained quartzite. Beds are poorly layered in the lower part of the 6.2 m but grade upward into light-gray, coarse-grained, well-layered quartzite; the upper part is poorly sorted, consisting mainly of coarse- to granule-size grains. The lower 6.2 m of quartzite grades upward into 1.5 m of ripple-crosslaminated argillaceous siltite that, in turn, grades into a 1-m-thick fine- to medium-grained quartzite. A dark-gray argillite about 1 m thick separates the underlying quartzite and minor siltite from the remaining 6.3 m of the Missoula Group along sharp upper and lower contacts. The uppermost 4 m of Missoula is composed of at least six distinct, generally upward fining, coarse- to medium-grained beds that locally show cut-and-fill and climbing-ripple structures.

To the east, in the Soap Gulch block, rocks assigned to the Missoula Group aggregate 62 m in thickness. The base of the Missoula Group is placed at the top of a 1.5-m-thick dark-gray argillite of the Empire Formation (?) that encloses thin, wispy, white quartzite lenses. The lower 2 m of the Missoula Group strata consists of dark-gray, laminated, very fine grained, argillaceous quartzite and is overlain by a 1-m-thick, pinkish-white, poorly sorted, fine- to coarse-grained quartzite somewhat similar to the upward-coarsening quartzite near the base of the group at the Moose Creek locality. The overlying 30 m consists of interlayered dark-gray, thin-bedded (10–20 cm) argillaceous quartzite and argillite. The argillite commonly contains thin, white to pinkish-white, quartz-rich cut-and-fill and lenticular laminae less than 1 cm thick. The remainder of the group consists of argillaceous siltite and very fine grained quartzite containing lenses of clean, white to pink quartz grains.

At the Camp Creek locality, the Missoula Group is 148 m thick. The lower unit of quartzite is a coarsening-upward sequence at least 46 m thick that is intruded by biotite granite. This lower unit is unique to the Camp Creek block and consists of laminated, poorly sorted, very fine grained quartzite containing floating, coarse quartz grains. Laminae are defined by parallel, alternating layers 1–3-mm thick of light-colored clean quartzite and dark-gray argillaceous quartzite. Overlying this lower unit of quartzite is a 16-m-thick section of thin-bedded, white, commonly poorly sorted, very fine grained to coarse-grained quartzite that is present as channel fill and as individual beds as thick as 10 cm. This 16-m-thick unit is capped by a 1–2-m-thick, light- to dark-banded, locally vuggy, calcareous argillite. The remainder of the succession is similar to the interlayered quartzite-argillite sequence in the Soap Gulch and Moose Creek blocks. The quartzite is typically cream to white and locally shows well-developed centimeter-scale crossbeds, upward-fining sequences, and ripple marks.

The thickest section of the Missoula Group in the Highland Mountains is in the Table Mountain block and consists of at least 168 m of interbedded conglomerate, quartzite, and argillite. The rocks of the group are coarsest along the western margin of the block, directly adjacent to the Twin Bridges fault, consist of mainly pink to greenish-gray quartzite and minor argillite, and are capped by a pebble to cobble conglomerate; however, these rocks are present mostly as float and could not be adequately measured and described. A section was measured along the west side of Spring Creek, about 2,000 m east of the Twin Bridges fault (O'Neill and others, 1995), and the following description is taken from that section.

At Spring Creek, the base of the Missoula Group is marked by 4 m of red to gray, massive silty argillite overlain by about 44 m of thin-bedded (10–30 cm), tan to gray, very fine grained to fine-grained quartzite, siltite, and argillaceous siltite and minor dark-gray argillite near the top. At about 22 m above the base of the group is 6 m of white, fine- to medium-grained feldspathic quartzite. The lower 48 m of fine-grained rocks is overlain by about 16 m of even- to uneven-parallel-laminated, very fine grained quartzite that is similar to the laminated quartzite at the base of the Missoula Group to the west in the Camp Creek block. The succeeding 55 m consists of alternating greenish-gray, very fine grained to fine-grained argillaceous quartzite and light-gray and pinkish-white to white feldspathic quartzite and orthoquartzite that contain well-developed oscillation and asymmetric ripple marks in the uppermost 5 m. The next higher 27 m is mostly covered but shows argillite, siltite, and minor white quartzite float. The uppermost Missoula Group consists of 10 m of massive to weakly crosslaminated, fine- to medium-grained nonfeldspathic quartzite in beds 30–60 cm thick.

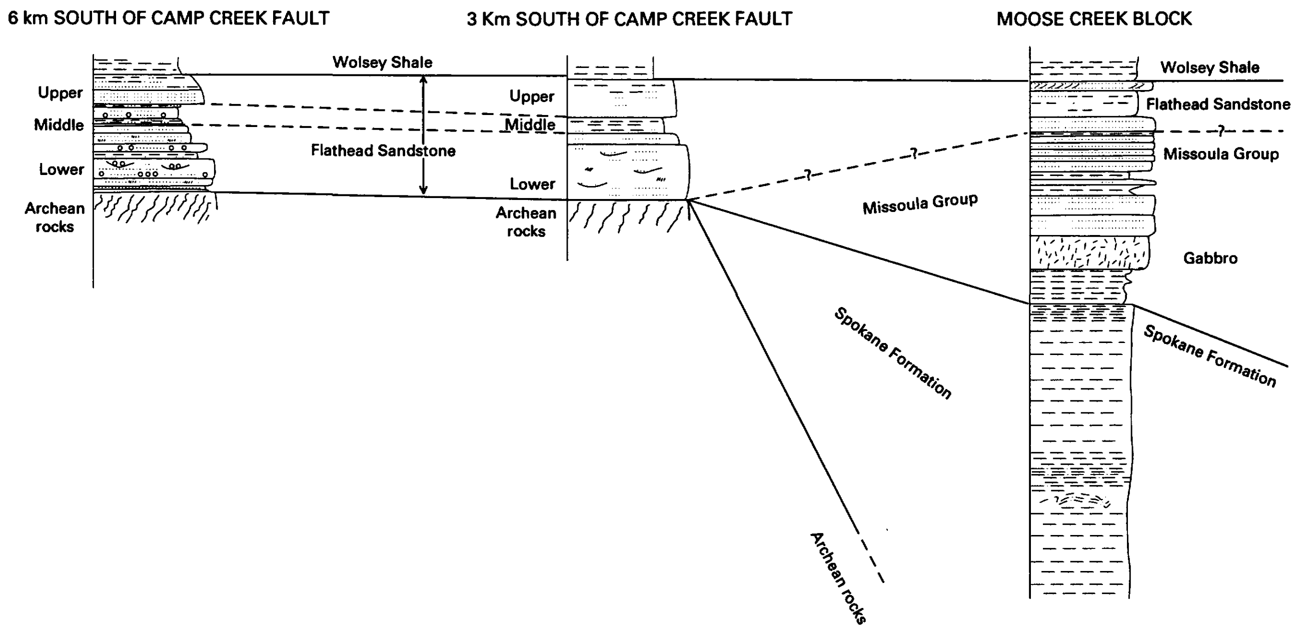


Figure 14 (above and facing page). Stratigraphic sections of the Middle Cambrian Flathead Sandstone and the underlying Belt Supergroup in the Highland Mountains. Lithologic explanation is given in figure 7.

CONTACTS WITH ADJACENT UNITS

The lower contact of the Missoula Group is generally sharp and is drawn at the top of the highest lithologic unit characteristic of the underlying formation. In the Moose Creek block the contact is drawn at the top of the highest Spokane-like siltite. In the Soap Gulch block to the east, the contact is placed at the top of a 1.5-m-thick dark-gray argillite containing wispy white quartzite lenses of the Empire Formation(?); farther to the east, the contact is drawn at the top of calc-silicate rocks of the Helena Formation.

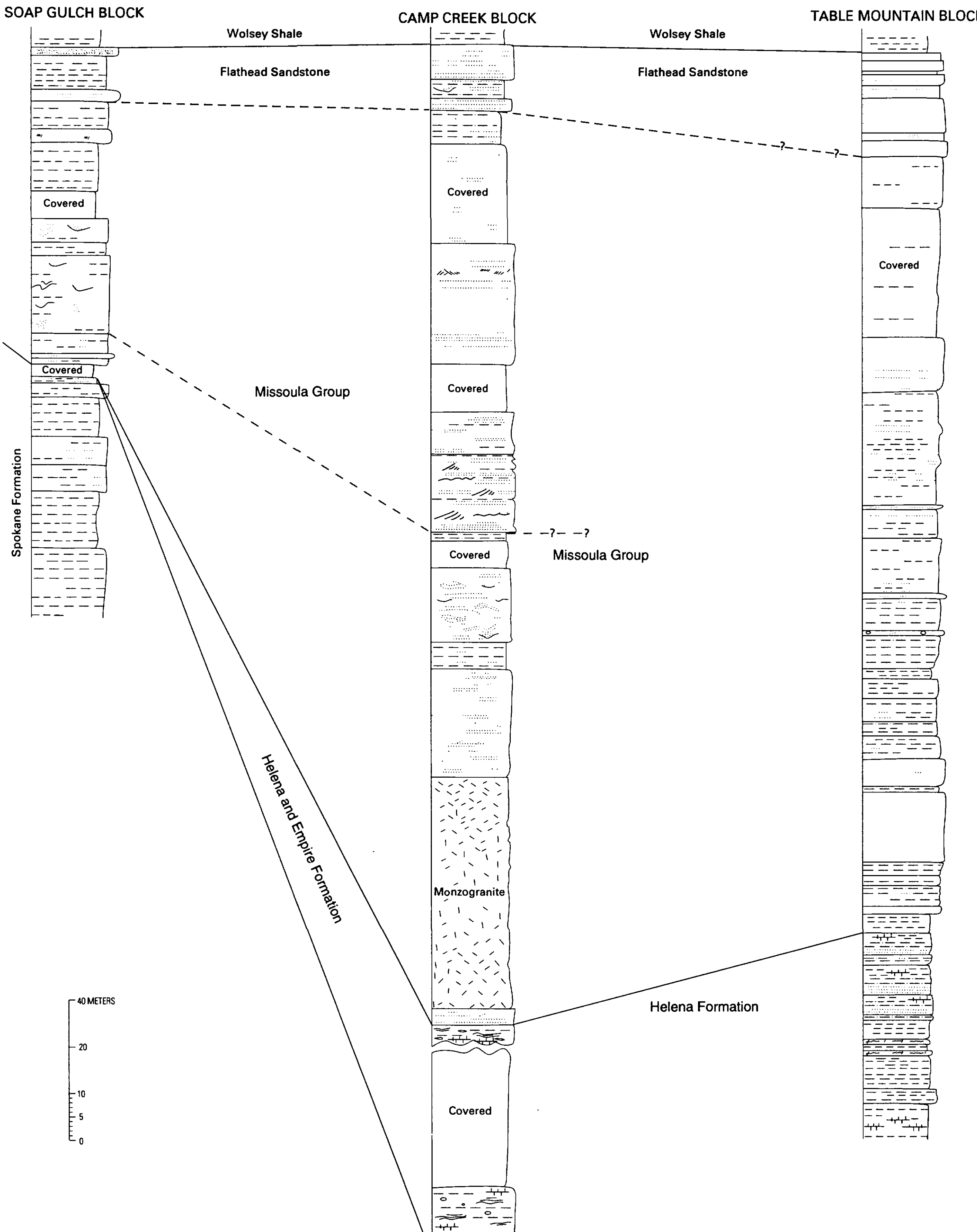
MIDDLE CAMBRIAN ROCKS

In parts of southwestern Montana it is difficult to distinguish between the uppermost clastic deposits of the Missoula Group and those of the overlying Middle Cambrian Flathead Sandstone (Don Winston, University of Montana, oral commun., 1988). In the Highland Mountains the upper contact of the Missoula Group with the Flathead Sandstone is also tenuous. Directly south of the exposures of the Belt Supergroup in the range, but still within the mountains, the Flathead rests unconformably on Early Proterozoic basement rocks (fig. 2*A*). The Flathead was measured at two locations in this area, and the sections are included in the correlation diagram of figure 14; one section is 6 km south of the Camp Creek fault, and a second section is about 3 km south of the fault. The Flathead Sandstone south of the Belt exposures is a tripartite unit; the upper and lower parts consist of orange-tan to reddish-orange feldspathic sandstone interlayered with minor conglomerate, siltstone, and shale; they are separated by a medial, weakly resistant part of mainly shale and siltstone. The Flathead is about 20 m thick in both measured sections.

Everywhere in the Highland Mountains where Belt sedimentary rocks are preserved a similar but thinner tripartite sequence of the Flathead underlies the Middle Cambrian Wolsey Shale. Sandstone beds in the upper and lower parts of this sequence are commonly well sorted, white, fine grained, and nonfeldspathic and lack conglomerate. The top of the Missoula Group is everywhere drawn at the base of the lowermost sandstone unit interpreted as the Flathead Sandstone.

TECTONICS AND SEDIMENTATION

Sedimentary rocks of Belt age (Middle Proterozoic) in the Highland Mountains are exposed in an elongate east-trending zone that extends almost completely across the range. Rocks of the Belt Supergroup are separated from the underlying basement on the south by the Camp Creek fault; they are overlain by or structurally juxtaposed against Paleozoic sedimentary rocks on the north; they are intruded by the Boulder batholith on the east; and they are truncated by Neogene basin and range faults on the west. This Belt Supergroup sedimentary succession is composed mainly of lower Belt and Ravalli Group rocks overlain by different formations in different structural blocks. Striking lateral facies changes are present in all of these sedimentary rocks (fig. 2), and these changes are accompanied by an overall thickening of the succession toward the central part of the range. The


SOAP GULCH BLOCK
CAMP CREEK BLOCK
TABLE MOUNTAIN BLOCK
Wolsey Shale
Wolsey Shale
Flathead Sandstone
Flathead Sandstone
Covered
Covered
Covered
Covered
Covered
Covered
Covered
Missoula Group
Missoula Group
Spokane Formation
Helena and Empire Formation
Monzogranite
Helena Formation
40 METERS
20
10
5
0

formations are thinnest and best exposed in the west where the entire succession is about 1,000 m thick; the thickness increases to more than 3,000 m in the central part of the range. Major facies changes are present across northwest- to north-trending faults that are the northward continuation of conspicuous northwest-trending faults that cut basement rocks to the south. These faults extended into the Belt Basin in Middle Proterozoic time and acted as growth faults during deposition of the Belt sediments. Belt-age rocks were deposited in northwest-trending half grabens or structural blocks outlined by these growth faults. These structural blocks are designated, from west to east, the Moose Creek, Soap Gulch, Camp Creek, and Table Mountain blocks (fig. 2*B*). Stratigraphic relations preserved across these structural blocks outline a large northwest-trending graben, herein called the Highland graben, that is manifested as a Middle Proterozoic paleovalley along this part of the southern margin of the Belt Basin. Facies relationships among rocks within the graben show that lower Belt and Ravalli Group rocks are laterally gradational and were deposited simultaneously. The lower Belt deposits represent subaerial to near-shore deposits that interfinger with subaqueous calcareous muds that, in turn, grade laterally into Ravalli Group laminated silty muds deposited farther from shore. Variations in stratigraphic thickness and hanging-wall onlap of these lower Belt strata suggest syndepositional fault activity, widening of the graben during Belt deposition, and a gradual transition from subaerial to subaqueous deposition through time.

Faults that outline the Highland graben were overlapped by subaerial deposits of the LaHood Formation that graded downslope into subaqueous deposits. These basal deposits can be divided into two sedimentary sequences: (1) interlayered coarse conglomeratic alluvial gravel, fluvial deposits, and minor distal, subaqueous quartzite west of the Table Mountain block and (2) well-bedded quartz-pebble conglomerate and coarse lithic quartzite of probable subaqueous debris flow origin and minor fluvial stream deposits within the Table Mountain block in the central part of the graben.

As the central part of the paleovalley eventually became completely submerged, deltaic sands were deposited above the fluvial and shallow-water debris-flow sandstone and conglomerate. These sands, the Table Mountain Quartzite, pinch out to the east and west. The quartzite can be divided into two informal members: the lower 230 m consists mainly of massive, thick-bedded, cliff-forming white quartzite, and the upper 260 m consists of thin-bedded, upward-fining quartzite interlayered with minor siltite and argillite. The upper member includes numerous upward-fining cyclical deposits that are 1–2 m thick and best developed in the lower 100 m of the section.

Alluvium of the LaHood Formation continued to be shed during and after the deposition of the Table Mountain Quartzite to the west from the higher, uplifted margins of the graben. The alluvium interfingers downslope with submarine, locally turbiditic deposits that, in turn, grade laterally into mud and silt of the Moose Formation. Similarly, the Moose Formation grades laterally into the Newland Formation. Farther basinward, the calcareous Newland gives way to thick accumulations of finely laminated mud, silt, and sand of the Greyson Shale. As subsidence within the graben progressed, the strandline of the Belt sea migrated landward, and the various lithofacies being deposited in the graben also shifted landward, overlapping all previously deposited sediments. As a result, and in spite, of lateral facies changes within the graben, the well-established and known normal stratigraphic succession of the Belt Supergroup of the Helena embayment was maintained.

Although the Newland Formation is only 150 m thick in the western part of the Highland Mountains, it thickens eastward to more than 350 m at Camp Creek. The entire Newland Formation exposed in the Moose Creek block is temporally equivalent to only the upper part of the Newland in the Soap Gulch block. The upper part of the Newland at Soap Gulch pinches out eastward, interfingering with and grading into the Greyson Shale. The lower part of the Newland at Soap Gulch is temporally equivalent to the upper part of the Newland in the Camp Creek block. The upper part of the Newland at Camp Creek interfingers with and pinches out into the Greyson Shale in the Table Mountain block, and the lower part of the Newland at Camp Creek interfingers with the Table Mountain Quartzite.

The Greyson Shale exposed in the Highland Mountains is the thickest Belt formation in the range. The unit is almost 220 m thick on the west at Moose Creek and thickens dramatically eastward to about 1,260 m in the Table Mountain block. The mainly interlayered silty argillite and siltite to the west becomes more lithologically diverse to the east. At Camp Creek, the formation includes several calcareous layers as well as distinctive, coarse, calcareous quartzite beds. In the Table Mountain block, the middle part of the formation contains a thick sequence of numerous upward-fining sedimentary cycles, each capped by limestone.

As subsidence slowed in the Highland graben, cross-bedded, argillaceous silt and sand of the Spokane Formation were deposited uniformly above the Greyson Shale; the Spokane is somewhat thicker (135 m) and coarser grained in the Camp Creek and Table Mountain blocks along the graben axis than farther to the west.

The Moose Creek block along the western margin of the graben was subaerially exposed in middle Belt time. In the Soap Gulch block, carbonate bank deposits of the Helena Formation interfinger with calcareous argillite of the Empire Formation; both formations pinch out to the west and were not deposited in the Moose Creek block. The Empire and overlying Helena Formations are in normal stratigraphic order in the Table Mountain block in the central part of the range, where they have a combined thickness of about 200 m. Both units thin eastward, away from the graben axis.

Younger alluvial conglomerate and fluvial sand of the Missoula Group covered all the older deposits. The main depositional center for these younger rocks was also in the Table Mountain block along the graben axis, and these rocks include thick, medium-grained, white to pink quartzite, minor argillite, and an uppermost angular quartz-pebble conglomerate that is restricted to the Table Mountain block. The Missoula Group has a maximum thickness of 155 m but thins to less than 30 m on the west.

Belt Supergroup rocks of the Highland Mountains are in fault contact with Early Proterozoic crystalline rocks to the south (fig. 2*A*). The contact is marked by the Camp Creek fault, a low-angle thrust fault that has been interpreted, on the basis of inference, as having a significant component of right-lateral slip (see, for example, Ruppel and Lopez, 1984). Reverse-slip movement on the Camp Creek fault is indicated by south-directed shears and folds within the fault zone. The interpretation of right-slip is based mostly on regional tectonic necessity: the need to find a link between the foreland fold and thrust belt of extreme southwestern Montana (Ruppel and Lopez, 1984) and the huge, thin-skinned detachments within the Helena embayment that are northeast of the Highland Mountains (Woodward, 1981; Schmidt and O'Neill, 1982). That the Camp Creek fault is not this major tectonic link is indicated by the structural continuity of high-angle faults in the basement rocks of the southern part of the Highland Mountains that acted as growth faults during deposition of the overlying Belt sediments; this structural continuity indicates that displacement on the Camp Creek fault is minor. O'Neill and others (1990) argued that the overthrusts of extreme southwestern Montana and adjacent Idaho and the thin-skinned detachments of the Helena embayment are tectonically linked by the postulated northeast-trending Dillon cutoff. The cutoff is a zone of basement-involved thrust faults that passes beneath the Jefferson Valley, directly east of the Highland Mountains (fig. 2*A*), and continues southwestward into extreme southwestern Montana. In this interpretation, the Highland Mountains are allochthonous; basement rocks within the range are a part of the foreland fold and thrust belt and were thrust northeastward in concert with the overlying sedimentary rocks. High-angle faults in basement rocks of the southern part of the range curve gently westward into the Camp Creek fault, become incorporated within the fault zone, and then continue northward, curving into the Belt sedimentary succession. The gentle westward bending of these fault zones suggests a left-lateral strike-slip component on the Camp Creek fault. The Camp Creek fault probably is simply a displacement transfer zone, best interpreted as a tectonic detachment at the base of the Belt Supergroup; basement rocks in the footwall were detached from the overlying Belt sedimentary rocks and were thrust northeastward beneath them during the formation of the Cordilleran frontal fold and thrust belt (fig. 15). There is no evidence in the Highland Mountains for a major, east-trending, Middle Proterozoic basin-margin fault similar to that postulated along the southern part of the Helena embayment farther to the east (Robinson, 1963; Schmidt and Garihan, 1986).

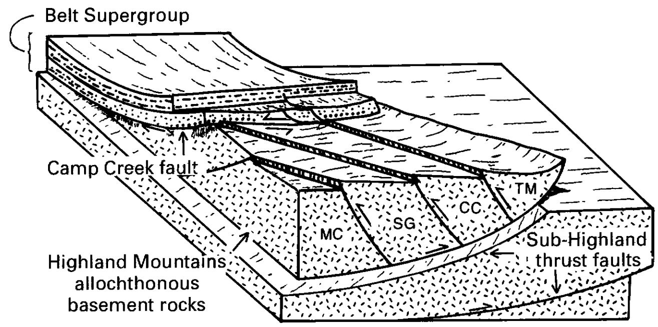


Figure 15. Structural relationship between crystalline basement rocks of the Highland Mountains and the overlying Belt Supergroup. The two rock groups are separated by the Camp Creek fault, a left-lateral, oblique-slip thrust fault. The allochthonous basement rocks were detached from the overlying Belt Supergroup along an unconformity and transported to the northeast, beneath the sedimentary cover rocks. MC, Moose Creek block; SG, Soap Gulch block; CC, Camp Creek block; TM, Table Mountain block.

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

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

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

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

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

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

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

Catalogs

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