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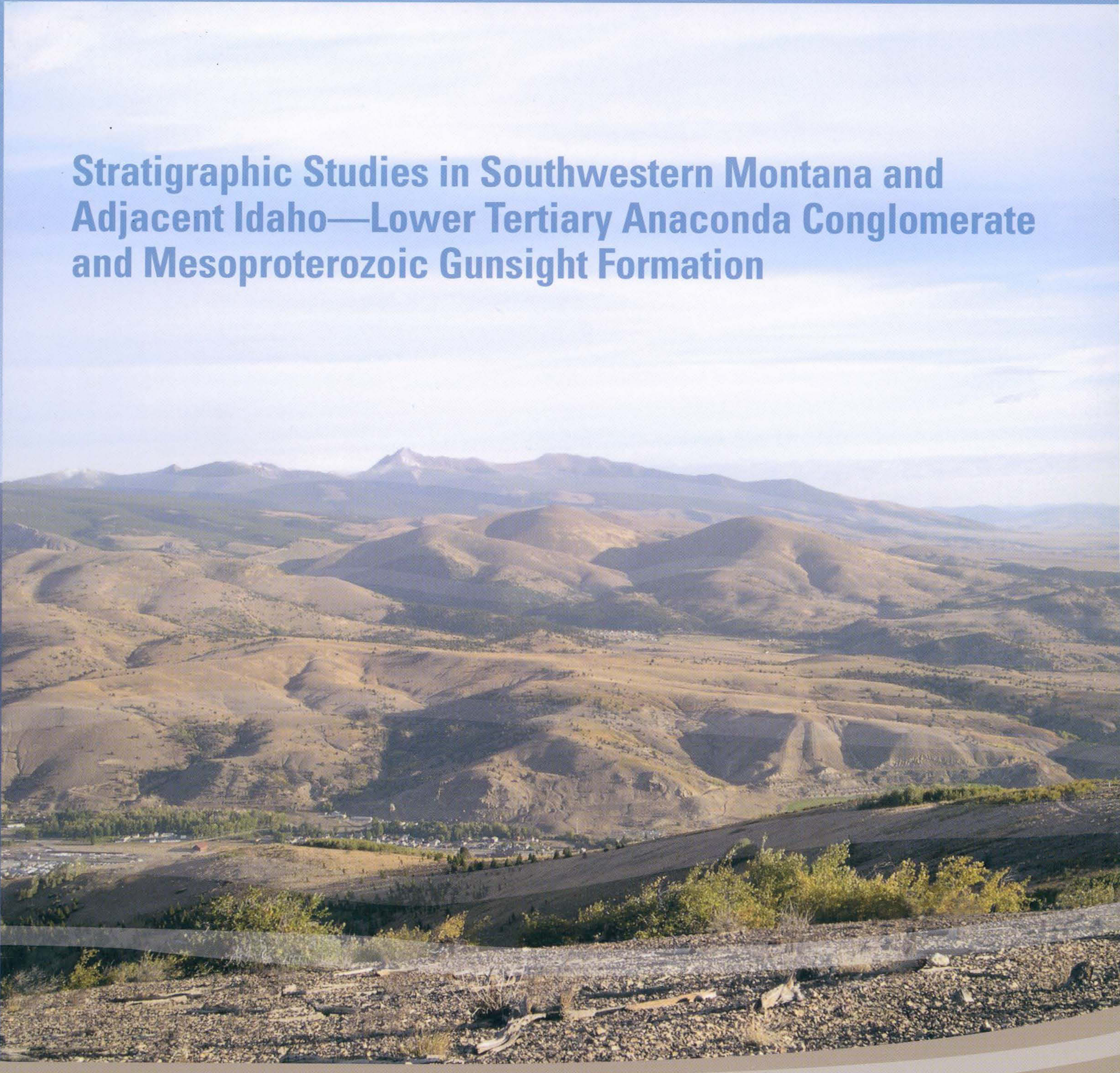
Stratigraphic Studies in Southwestern Montana and Adjacent Idaho—Lower Tertiary Anaconda Conglomerate and Mesoproterozoic Gunsight Formation



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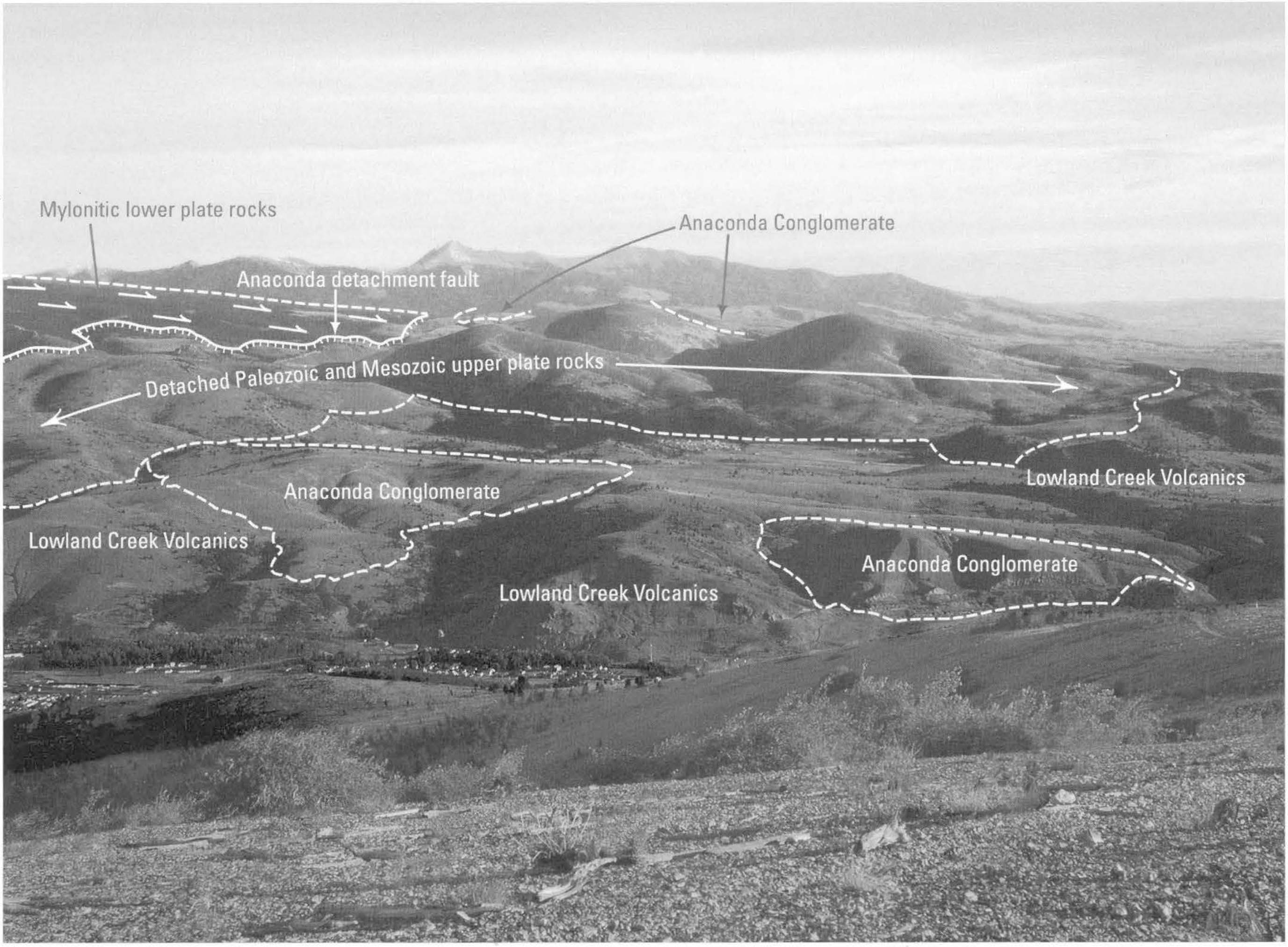

Cover and above. Anaconda Conglomerate and Lowland Creek Volcanics rest unconformably on detached upper plate rocks of the Anaconda metamorphic core complex. View to north. Anaconda townsite along Warm Springs Creek in middle foreground. Short-dashed lines are approximate contacts.

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Chapter A

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Chapter B

Alluvial Facies, Paleocurrents, and Source of the Mesoproterozoic Gunsight Formation, East-Central Idaho and Southwestern Montana

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Stratigraphic character and tectonic significance of the Anaconda Conglomerate in southwestern Montana

Professional Paper 1700

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Syntectonic Anaconda Conglomerate (New Name)—A Stratigraphic Record of Early Tertiary Brittle-Ductile Extension and Uplift in Southwestern Montana

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Abstract

The Anaconda Conglomerate, a new name applied to discontinuous exposures of lower Tertiary coarse conglomeratic deposits along the eastern margins of the Anaconda and Flint Creek Ranges, is a syntectonic sedimentary rock unit related to the formation of the Anaconda metamorphic core complex. The conglomerate, which ranges from coarse sedimentary breccia to poorly sorted boulder-to-pebble, well-rounded conglomerate interlayered with lenses of sandstone and siltstone, attains a maximum exposed thickness of 650 feet. Pebbles, cobbles, and boulders in the sedimentary breccia are derived solely from the detached upper, unmetamorphosed plate of the core complex. Fluvial and alluvial conglomeratic rocks were derived mainly from the upper plate rocks but locally contain sparse metamorphosed lower plate clasts.

The formation lies unconformably on Mesoproterozoic, Paleozoic, and Mesozoic sedimentary rocks of the underlying detachment; the age of the underlying rock is controlled by the structural aspects of the tectonically detached carapace of the core complex. The conglomerate is interlayered with lower Eocene Lowland Creek Volcanics and is overlain by upper Eocene and Oligocene Renova Formation of the Tertiary Bozeman Group where the conglomerate is exposed in adjacent valleys; at higher elevations and in the mountains, the conglomerate is locally overlain by glacial till.

Introduction

Sedimentary deposits of Tertiary and Quaternary age are widespread in southwestern Montana. Most of these deposits are confined to intermontane basins that first formed in the Eocene; Neogene basin-range structures are superimposed on the earlier basins and now restrict the distribution of these generally poorly consolidated sedimentary deposits throughout the region. The Tertiary deposits in these basins belong to the Bozeman Group (Robinson, 1963), which, in the study area, consists of two formations—the older Renova Formation and the overlying Sixmile Creek Formation. The Tertiary conglomeratic deposits in the vicinity of the Anaconda and Flint Creek Ranges (fig. 1) have been previously recognized as well, but their stratigraphic position and relationship to the Bozeman Group deposits have been unclear. The first descriptions of these conglomerates were provided by Emmons and Calkins (1913) in their discussion of the geology of the Philipsburg 30′ quadrangle that includes the Anaconda and Flint Creek Ranges; subsequent studies, mainly in the form of theses (for example, Csejtey, 1963; Noel, 1956; Mutch, 1960), have described similar deposits from isolated areas within and adjacent to the Philipsburg quadrangle.

Current geologic framework studies in the Anaconda and Flint Creek Ranges have revealed that these isolated conglomerates are syntectonic deposits related to the formation of the lower Tertiary Anaconda metamorphic core complex (O'Neill and others, 2004). The conglomerates are restricted to areas above and adjacent to the core complex; they were shed from detached, upper plate rocks of the core complex and deposited in structural troughs and grabens developed in the cataclasized, highly extended tectonic carapace. The purpose of this report is to document the presence of lower Tertiary sedimentary rocks, older than the known Bozeman Group, and to bring attention to the fact that these newly named earlier strata are related to significant and previously unrecognized tectonic events in southwestern Montana.

Geologic Setting

Southwestern Montana is underlain, in part, by crystalline basement rocks of mainly Archean ancestry. These basement rocks are complexly overprinted by younger tectonic features related to the Paleoproterozoic continental assembly of the North American craton (O'Neill and Lopez, 1985; O'Neill, 1999). Superimposed on the crystalline basement is the Mesoproterozoic Belt basin in which as much as 50,000 ft of mainly clastic subaqueous to subaerial sedimentary deposits has accumulated (Ross and others, 1963). This heterogeneous Precambrian basement assemblage of amphibolite-grade gneissic rocks and overlying greenschist facies metasediments of the Belt Supergroup became the semistable cratonic shelf margin of North

America from Neoproterozoic through Paleozoic time. Mesozoic rocks, mainly clastic continental interior basinal deposits, rest unconformably on the shelf-margin, carbonate-rich sequence. All these sedimentary rocks were caught up in Sevier thrust belt deformation throughout western Montana, and in the southwest were additionally deformed by the broadly coeval Laramide basement-cored uplifts (Schmidt and Perry, 1988). Plutonism in the form of large batholithic complexes, the Boulder and Idaho batholiths and related volcanic rocks, accompanied Late Cretaceous tectonic events (Robinson and others, 1968). Early Tertiary plutonism followed the igneous events of the Late Cretaceous and is conspicuously aligned in a northeasterly trend controlled in large part by the continental suture zone that formed in the Paleoproterozoic (O'Neill and Lopez, 1985; O'Neill and others, 2002). By Eocene time, much of southwestern Montana consisted of seemingly isolated basins that were depocenters of fine-grained fluvial to lacustrine sediments rich in volcanoclastic detritus (Robinson, 1963). Late Tertiary time saw the inception of basin-range extensional faulting that continues today.

Low-angle faults are common in southwestern Montana, and their genetic relationship to thin-skinned tectonic development of the Sevier overthrust belt is universally recognized. However, in an area encompassing the Anaconda and Flint Creek Ranges of southwestern Montana, mylonitic low-angle faults characteristically place younger on older rocks. This area, named the Anaconda metamorphic core complex (AMCC) by O'Neill and others (2004), is the manifestation of early Tertiary brittle-ductile crustal extension superimposed on the complexly deformed Archean to Mesozoic rocks of the region (fig. 2).

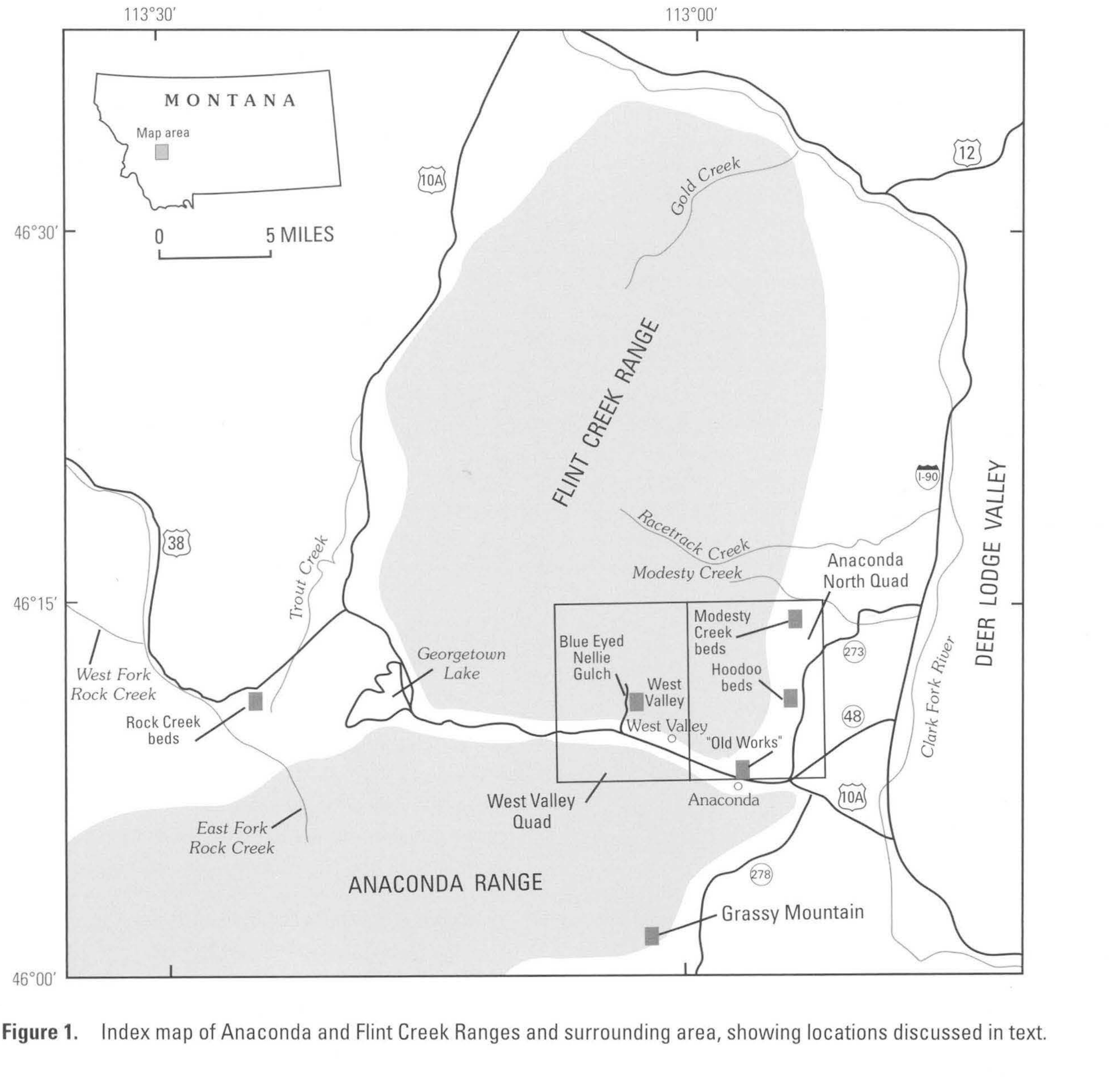


Figure 1. Index map of Anaconda and Flint Creek Ranges and surrounding area, showing locations discussed in text.

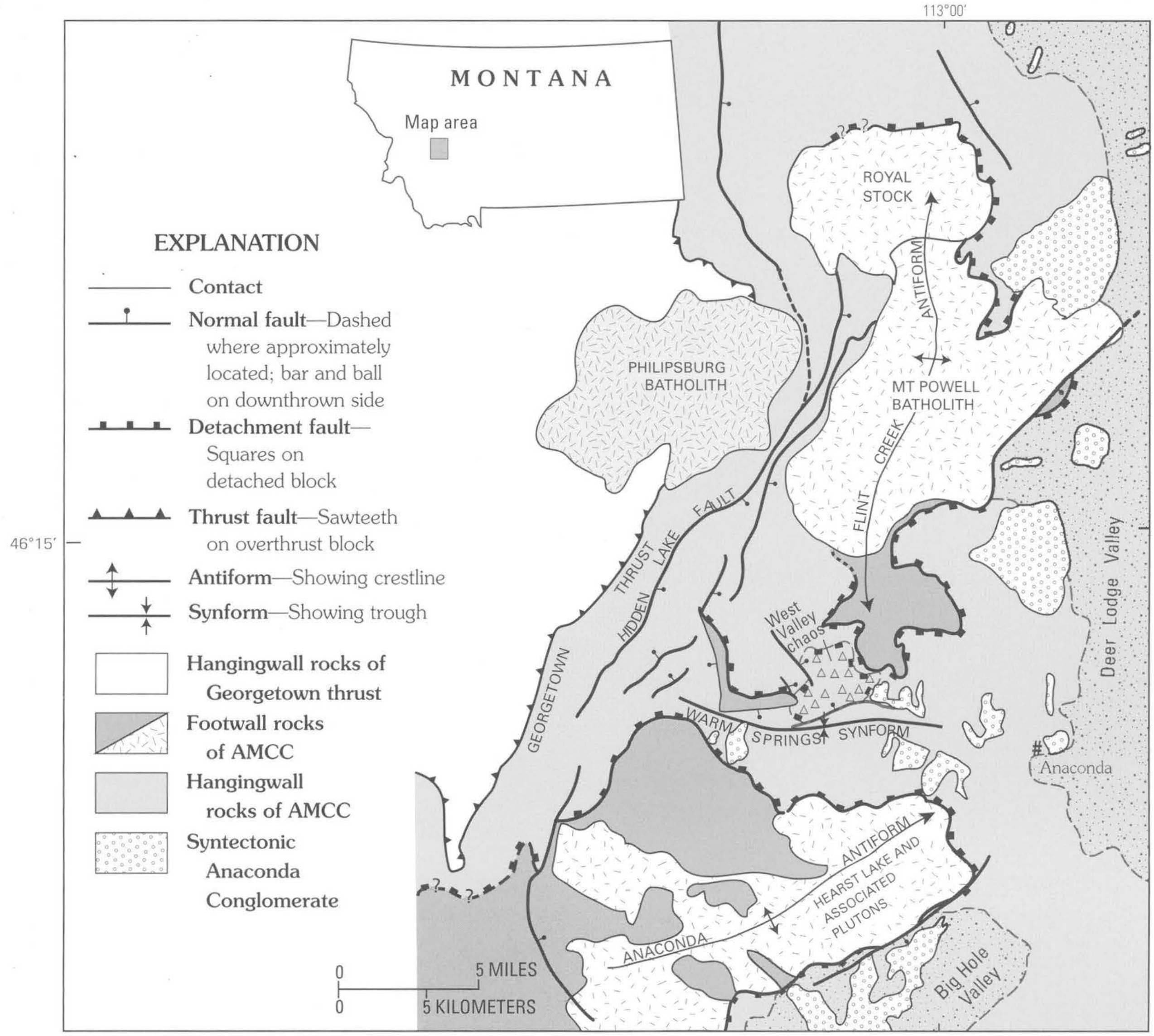


Figure 2. Generalized geologic map of the Anaconda metamorphic core complex (AMCC) showing location and distribution of syntectonic deposits of the Anaconda Conglomerate.

Name and Distribution

The herein named Anaconda Conglomerate is composed of both (1) coarse proximal sedimentary breccia deposited adjacent to and on top of highly distended and cataclasized Paleozoic through Mesozoic sedimentary rocks of the Anaconda metamorphic core complex, and (2) more distal coeval sedimentary conglomerate, grainstone, sandstone, siltstone, and lacustrine beds deposited in positions away from the structural axis of the complex (fig. 2). The formation is a syntectonic sedimentary deposit that is temporally and spatially related to the formation of the core complex. Most of the rocks were derived from erosion of the detached upper plate and in many places are confined to structural grabens and half-grabens formed during extension. The Anaconda Conglomerate is named for discontinuous exposures at and west of the townsite of Anaconda, where it is locally preserved on the flanks of the Anaconda and Flint Creek Ranges, and best exposed in a structural trough, the Warm Springs synform and the inset West Valley chaos directly west of Anaconda. Rocks of similar age, lithology, and stratigraphic position mainly underlie large areas along the eastern flanks of the Flint Creek and Anaconda Ranges. Exposures are characteristically patchy and do not occur as bold, continuous exposures that allow the designation of a type section; rather, a type locality for the conglomerate is herein designated as extending from the town of Anaconda westward, to the townsite of West Valley in the Anaconda North and West Valley 7½′ quadrangles, southwestern Montana (figs. 1, 2).

Figure 3. Outcrop of the "earlier gravels" of Emmons and Calkins (1913). Clasts are predominantly angular pebbles and cobbles, consist exclusively of unmetamorphosed Paleozoic sedimentary rocks, and are randomly oriented. Coin in center for scale. These gravels rest directly on the upper plate of the core complex and were derived from adjacent rocks.

Lithology and Thickness at the Type Locality

Trough of the Warm Springs Synform

The base of the Anaconda Conglomerate is exposed in the Warm Springs synform along the northeast flank of the Anaconda Range. The synform is a structural sag defined by the opposing dips of the core complex detachment and separates the Flint Creek and Anaconda antiforms of the AMCC on the north and south, respectively (fig. 2). The conglomerate preserved in the synform was first recognized by Emmons and Calkins (1913, p. 134–135) and described by them as "earlier gravels."

On the north slope of Anaconda Range, Emmons and Calkins described the deposits as "chiefly composed of well rounded pebbles and boulders of sandstone***locally attaining a diameter of 2 feet and of unmetamorphosed (carbonate) rocks***which are smaller and decomposed much more readily. Thin sandy beds have locally been observed in the gravels" (p. 134–135). Logging roadcuts recently cut in this area reveal scattered exposures of 1–2 m thick clast- to matrix-supported angular to subangular limestone and quartzite pebble conglomerate (fig. 3). Interbedded in the conglomerate are thin lenses of granule to very small pebble conglomerate, 2.5–4 in. thick, and discontinuous lenses of siltstone and silty sandstone beds as much as 6 in. thick. In other roadcuts the conglomerate consists mostly of angular, white and gray limestone pebbles in a sandy matrix consisting almost exclusively of limestone.

Near the town of Anaconda, similar conglomeratic rocks were also described by Csejtey (1963), who informally called them the Anaconda beds from what was then called the "old Mill site." Csejtey (1963, p. 41–48) described the beds, which he estimated to be as much as 2,500 ft thick, as follows:

> The Anaconda beds are a sequence of unconsolidated fluvial sedimentary rocks, namely: conglomerates, wackes, siltstones, a very small amount of shale, kaolinitic siltstone, some bentonite, and some beds of lignitic shale and impure lignitite [this report, fig. 4].

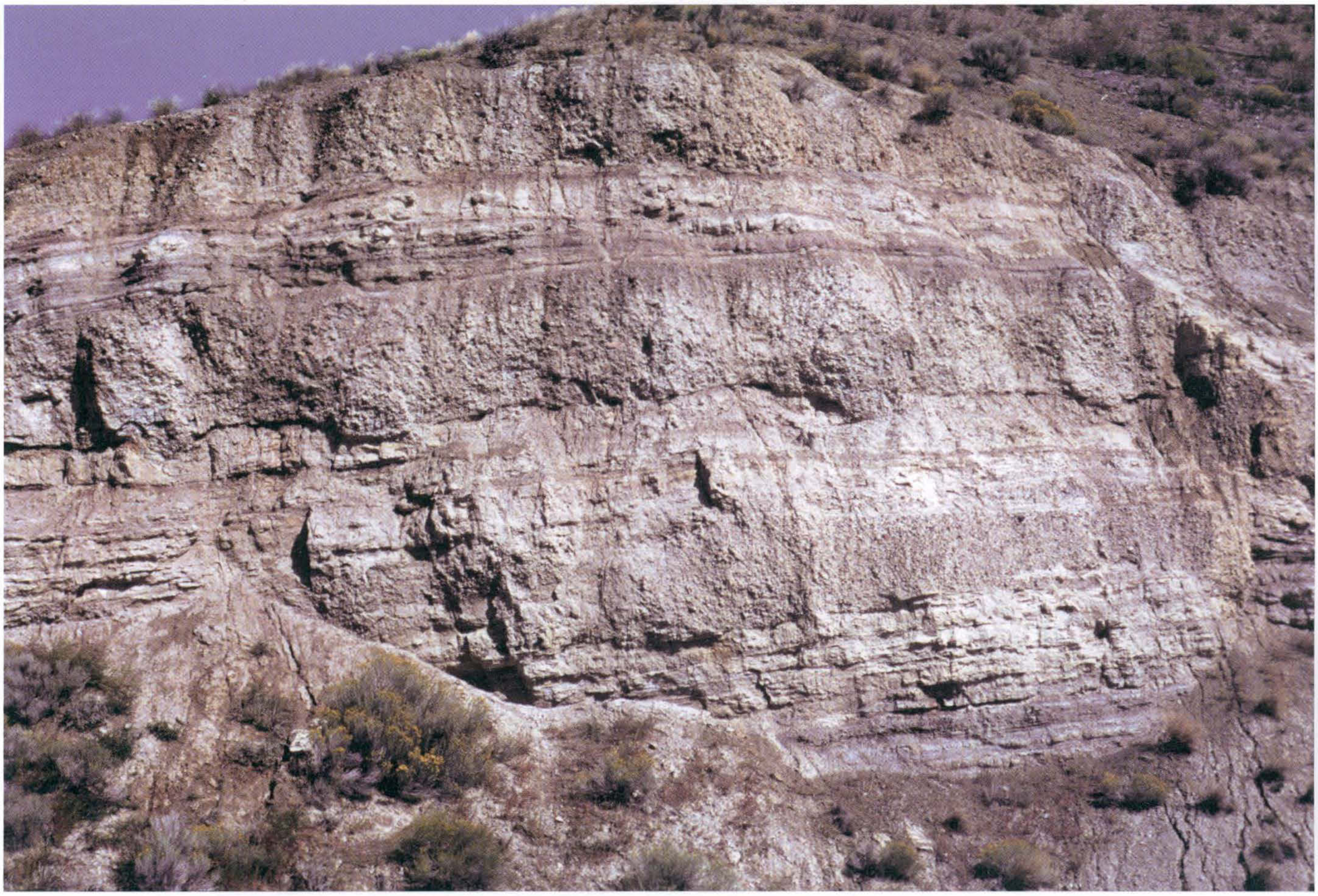


Figure 4. Cliff exposure of the more distal Anaconda Conglomerate at the "old works" in the town of Anaconda. Height of exposure about 30 ft. The 3–6 ft thick conglomerate beds have uneven, scoured bases and flat upper surfaces, and they grade up into finer grained sandstone and siltstone.

The conglomerates, comprising 40–50 percent of the beds, are poorly sorted and consolidated, and generally are grayish-buff. The coarse components, all well rounded, consist chiefly of unmetamorphosed Belt Supergroup rock fragments, such as crossbedded Missoula Group quartzites, hard, red Missoula mudstones and Newland limestones. Smaller amounts of Paleozoic and Mesozoic fragments are also present, but their abundance varies from locality to locality. The Paleozoic and Mesozoic pebbles include both thermally metamorphosed and unmetamorphosed rock fragments. The conglomerates are essentially free of volcanic rock fragments, but rare granitic pebbles occur throughout the conglomerate. A large portion of the Missoula quartzite clasts attain a diameter up to 1 or 2 feet, but many of the coarse components are less than 6 inches. The thickness of the individual conglomerate beds varies from about 2–3 feet up to 10 feet or more. These beds have the typical lenticular shapes of fluvial channel conglomerates [this report, fig. 4].

The wackes have varying degrees of sorting, i.e. amount of matrix. They can be subdivided into a somewhat sorted type and a more poorly sorted type, the latter making up the bulk of the wackes. The better sorted wackes have a relatively small amount of matrix, slightly more than 10 percent. The main constituent is subangular quartz with grain sizes belonging to the fine sand grade. The wackes are poorly cemented by limonite, which gives them a buff color. Thickness of the individual beds varies, generally between 1 and 2 feet. The poorer sorted wackes are generally medium to coarse grained, but some of them are conglomeratic. They all contain about 20–25 percent matrix. The pebbles of the conglomeratic varieties are composed of thermally unmetamorphosed Belt, Paleozoic quartzite and Mesozoic mudstone fragments [this report, fig. 5]. The sand sized grains are made up, in decreasing quantity, of quartz, sedimentary rock fragments, fresh and altered mafic minerals, a varying small amount of feldspar and muscovite. The larger the sand-sized grains are, the better rounded they are,

Figure 5. Close-up view of conglomerate at the "old works." Mainly clast supported pebbles that are poorly sorted but show faint bedding, and are interlayered with thin seams of lithic sandstone (uppermost part of photo). Hammer for scale.

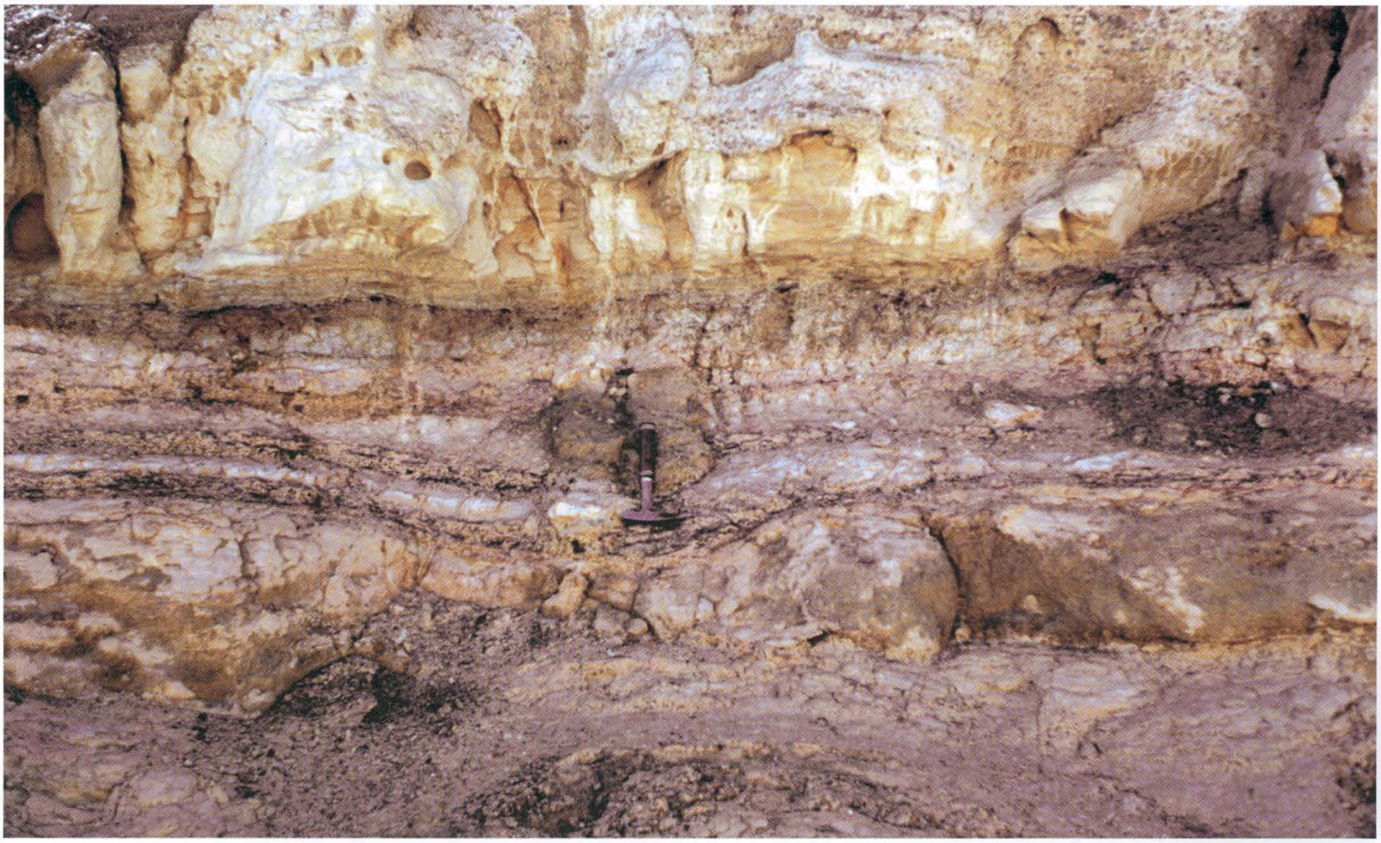


Figure 6. Close-up view of finer grained interbeds in the Anaconda Conglomerate. Horizontal stratification is well developed. Darker seams are lignite. Hammer for scale.

> although none of them are as well rounded as the pebbles. These grayish brown or buff wackes are very poorly cemented by limonite or, rarely, by calcite. The thickness of the individual beds ranges from a few inches up to about 2 feet.
>
> At several localities there are a few bentonitic layers, each about 1 foot thick, interbedded with the finer wackes.
>
> The kaolinitic siltstones usually occur, as does the lignitic material, interbedded with the wackes. The siltstones are composed mostly of quartz, much less kaolinite and mica, and very little feldspar, and possibly some chlorite. The beds are about 1 to 3 feet thick and are light gray.
>
> At few localities the lignitic layers contain authigenic pyrite crystals and, rarely secondary gypsum crystals. Minor shale beds are associated with the lignitic beds [this report, fig. 6].

Wanek and Barclay (1966, p. B15–B16) also mapped and described conglomerates exposed at the "old works" in Anaconda. These individuals described the conglomerate as having a "maximum thickness of about 400 feet and generally weathers into a boulder rubble***. The conglomerate unit consists of moderately indurated thick-bedded gray to buff conglomerate***intercalated with thick beds of tuffaceous siltstone and thin lenses of carbonaceous material and lignitic coal beds. The conglomerate rests unconformably on a volcanic breccia and red-bed unit near an andesite plug at the tramway; the relief of the erosion surface is considerable."

West Valley Chaos

Within the Warm Springs synform is a zone of immense structural complexity called the West Valley chaos (O'Neill and others, 2004). This chaos zone is bounded by normal faults (graben-like structure) in the upper plate of the Anaconda detachment and formed during Eocene extension. The detachment lies beneath the West Valley chaos at a depth of about 300–500 ft.

Within the chaos zone are several rock quarries opened and mined for silica flux, which was used in the smelting process of copper ore at the nearby Anaconda smelters. Exposed in the quarry directly west of Blue Eyed Nellie Gulch (fig. 1) is a sedimentary breccia derived from the directly adjacent and underlying upper plate detachment of the Anaconda metamorphic core complex (AMCC). The breccia in this quarry is of two types and generations. A coarse sedimentary breccia composed almost exclusively of angular pebbles and cobbles of Paleozoic quartzite is the older of the deposits. Interstices between the clasts are filled with angular sand-sized grains of quartzite as well. Horizontal bedding is not present in these rocks. This older, more resistant and lithified breccia was later rebrecciated and redeposited as boulder-sized angular to subrounded clasts in a matrix of coarse lithic sandstone with obvious subhorizontal fluvial cross-stratification (fig. 7); the lithic sand-sized grains are composed mostly of limestone, imparting a dark-gray color to the younger unit. The sedimentary-tectonic relationships exposed in this outcrop represent ongoing, simultaneous brecciation and fluvial sedimentation. At Blue Eyed Nellie Gulch, both tectonic and sedimentary breccias are well exposed. Here, the sedimentary breccia typically includes clast-supported angular pebbles and cobbles of both carbonate rocks and quartzite in a matrix of angular sand derived from the same source as the larger clasts. The sedimentary breccia in this area, which may be as much as 400 ft thick, also encloses exotic "boulders" of adjacent bedrock as much as tens of yards across (fig. 8). The sedimentary breccias were deposited in extension-related depressions of the West Valley chaos that developed synchronously with extension and cataclasis of the detached upper plate of the AMCC.

Correlative Conglomerate

Probable correlative conglomerate and gravel of the Anaconda Conglomerate were described by Csejtey (1963) from the southeast flanks of the Flint Creek Range at Hoodoo Gulch and Modesty Creek (fig. 1). Although Csejtey was not certain that the gravels from these three locations were correlative, he described them as lower Tertiary deposits and noted probable similarly aged gravels and conglomerates on Grassy Mountain at the east end of the Anaconda Range (Emmons and Calkins, 1913; Noel, 1956) and along the northeast flank of the Flint Creek Range (Mutch, 1960).

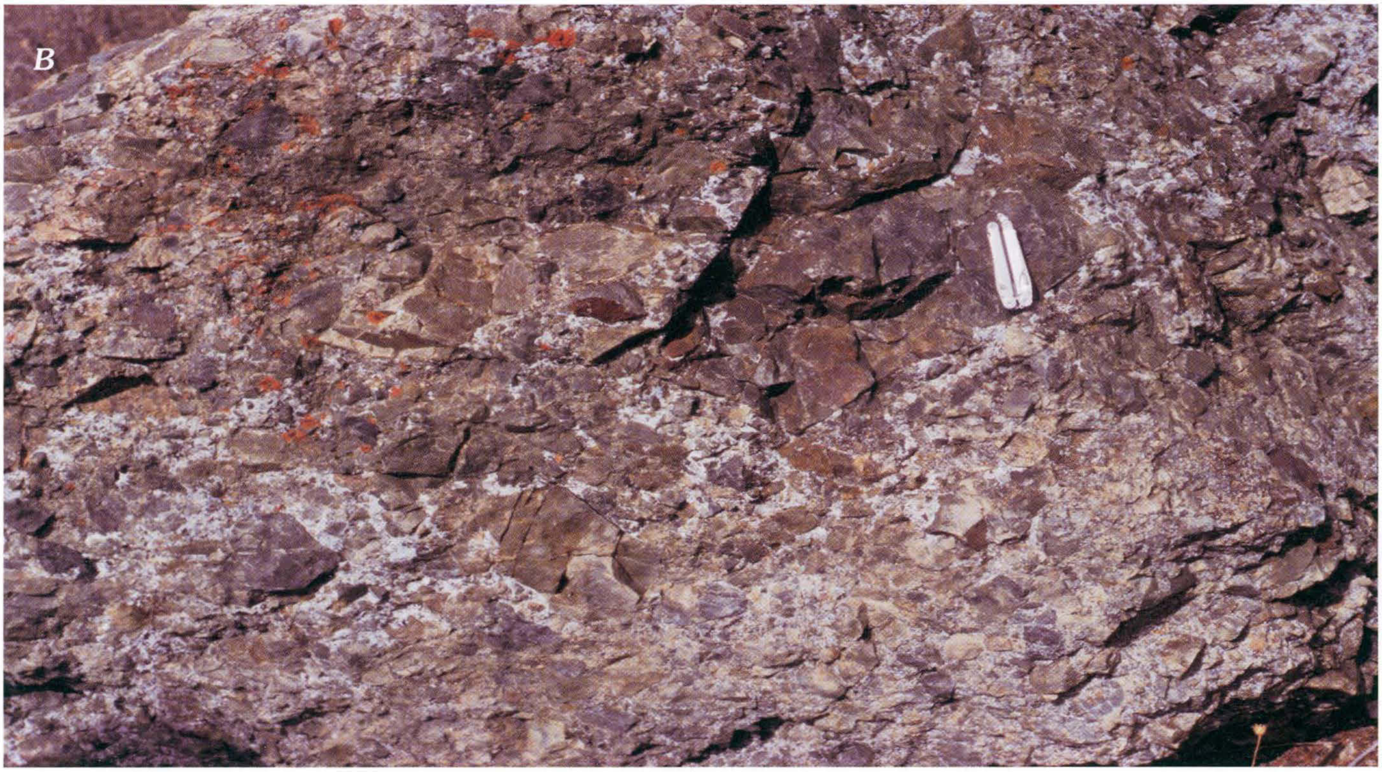
Hoodoo Gulch

At Hoodoo Gulch a distinct sequence of fluvial sedimentary rocks composed mostly of volcanic detritus is interlayered with welded tuff and tuff breccia of the Lowland Creek Volcanics. Most of these rocks are buff to brownish-gray fine-grained wackes. Minor amounts of conglomerates and conglomeratic wackes with sedimentary pebbles and volcanic matrix are also present. The pebbles are about 1 inch in diameter and are composed mostly of Cretaceous mudstones, Belt mudstones, and quartzites. The wackes consist chiefly of reworked tuffaceous material and contain abundant but unidentifiable fragmentary plant material. The Hoodoo Gulch beds are clearly interlayered with the Eocene Lowland Creek Volcanics.

Figure 7. Sedimentary breccia exposed in the West Valley chaos zone. Large boulder-sized angular clasts as much as 6 ft across in mainly grain supported sedimentary deposit. Matrix of coarse- to granule-sized lithic sand is horizontally stratified. Angular breccia clasts derived from an older, syntectonic, finer grained sedimentary breccia composed of angular to subrounded pebbles and cobbles of locally derived upper plate sedimentary rock.

A

Figure 8 (above and overleaf). Sedimentary breccia exposed at Blue Eyed Nellie Gulch. *A*, bus-sized boulder of quartzite enclosed in a much finer grained angular sedimentary breccia. *B* (overleaf), character of enclosing rock; pocket tool, 3 in. long, for scale.



Modesty Creek

At Modesty Creek lithologically distinct, reddish-brown to buff, poorly sorted fluvial conglomerates and wackes are exposed. The conglomerates are poorly sorted and generally well indurated. They consist of metamorphosed Paleozoic limestone and quartzite fragments, some metamorphosed, possibly Mesozoic mudstone pebbles, and small amounts of contact metamorphosed Belt material. Limestone fragments derived from the Mississippian Madison Group are especially abundant. Because a small patch of Madison Group underlies the beds at Modesty Creek, probably most of the Madison pebbles are locally derived. No igneous fragments are present in these beds. The coarse components of the conglomerate have diameters as much as 5–6 in. and are locally subangular.

The wackes of Modesty Creek contain abundant conglomerate beds. The coarse components are subangular, whereas the sand fraction is angular to subangular. The wackes are composed of metamorphosed Paleozoic and Belt rock fragments, quartz, and lesser amounts of mafic minerals, and some feldspar. In general, both conglomerates and wackes are firmly cemented by calcite derived from limestone fragments. Bedding in the whole sequence is poor and irregularly developed.

One mile north of Modesty Creek, at the mouth of Racetrack Creek, are patchy outcrops of red conglomerate and poorly sorted lithic sandstone and siltstone similar in composition and texture to the beds at Modesty Creek. The lowermost outcrops of these rocks consist of coarse, poorly sorted sedimentary breccia. The outcrops, mostly covered by extensive glacial drift, rest on cataclasized Cambrian Flathead Quartzite where the base is exposed.

Southeast Anaconda Range

A very large area on the southeastern flank of the Anaconda Range is underlain by gravels that Emmons and Calkins (1913) correlated with similar deposits west of Anaconda (fig. 2). To paraphrase their description of exposures on the east side of Grassy Mountain, the deposits are consolidated to a moderate degree with pebbles and boulders, some of which have diameters as much as 2 ft but most of which are considerably less than 1 ft, only fairly well rounded, and not well graded to size. The pebbles and boulders consist for the most part of lower and middle Belt sandstone and carbonate rocks, upper Belt quartzite, and unmetamorphosed Paleozoic limestones. Some exposures show the conglomerate beds to be intercalated with thinner beds of cream-colored, pink, and light-brown clay and sand, some of which is firmly cemented with lime. Emmons and Calkins also described what I would interpret as near-source angular sedimentary breccia. The clasts in the sedimentary breccia rocks are not well rounded and have diameters as much as 5 ft. Emmons and Calkins clearly entertained the thought that these breccias were subangular pieces of waste from the underlying rocks, an interpretation with which I firmly agree. They also noted that the pebbles in the old gravels in this area are largely different from those that now underlie the adjacent Anaconda Range. I would interpret these rocks as having been derived from the detached carapace of the core complex.

Noel (1956) mapped and described these gravels of Grassy Mountain as well, concurring with the general description given by Emmons and Calkins (1913). Noel did measure a section of these rocks exposed on the east slopes of Grassy Mountain and described them as follows (Noel, 1956, p. 41–42):

Figure 9. Laharic deposits of the Lowland Creek Volcanics enclosing cobbles and boulders of rounded quartzite in a tuffaceous matrix. Deposits are interlayered with Anaconda Conglomerate at the "old works." Hammer for scale.

Unit 3: Conglomerate: light gray, very coarse grained, pebbles from 0.1 inch to 2 feet, rounded, dominantly limestone and marble, also quartzite and sandstone, matrix of sand composed of limestone fragments and quartz, calcareous cement. Thickness is 75 feet.

Unit 2: Gravel: tan with reddish tint, unconsolidated, non-calcareous, pebbles to boulders, matrix of silty clay, limestone fragments much less than in unit 3, Miller Peak quartzite fragments dominant, average size of pebbles about 1 inch in diameter. Thickness is 215 feet.

Unit 1: Gravel: brownish-red, unconsolidated, noncalcareous, pebbles in silty clay, pebbles nearly all Miller Peak quartzite, 6 inches is predominant size of pebbles, size decreases toward bottom. Thickness is 350 feet.

Total thickness of gravels and conglomerate is 650 feet.

Northeast Flint Creek Range

Numerous gravel deposits of various inferred ages have been reported and mapped from the northeast Flint Creek Range. The earliest recognition of an older conglomerate in this area was made by Pardee (1951, p. C81), who described but did not map deposits of "patchy and irregularly distributed***patches of gravel [that] are the remnants of a formerly extensive sheet that formed a plain that descended from the mountains at a height of 700 to 800 feet above the present valley of Gold Creek." Pardee described the gravel as a washed and sorted boulder gravel consisting predominantly of quartzite with minor hornfelsed rock and quartz-mica schist.

Mutch (1960) reexamined the northeast flank of the Flint Creek Range and actually mapped a large deposit of older gravel, which he considered to be Oligocene, from the area just north of Csejtey's beds at Modesty Creek (fig. 2). Between Modesty Creek and Gold Creek, Mutch (1961) also recognized and mapped perched gravels similar in composition and occurrence to the Modesty Creek beds but, following Pardee, tentatively called them early glacial drift. Mutch described the early glacial drift in somewhat confusing terms: the drift is not related to any identifiable glacially carved valleys; it is characterized by a general absence of boulders of the granitic bedrock that underlies the strongly glaciated peaks of the Flint Creek Range; the deposits of drift have no morainal form; and the majority of cobbles and boulders are quartzite. He also acknowledged that his early drift may be a composite deposit—that is, the drift only has the appearance of till, and is likely underlain by his lithologically similar Oligocene gravel mapped north of Modesty Creek or the equivalent older conglomerate of Pardee.

In the vicinity of Gold Creek, Mutch also mapped an extensive sheet of intermittently exposed arkosic sandstone and conglomerate that he called Miocene gravel. Mutch's comments (1960, p. 119) show him to be concerned by the fact that whereas his Miocene sand and gravel clearly were derived from granitic rocks in the Flint Creek Range, the younger early glacial drift, which he considered to be Quaternary, was derived from the same area with the same granitic bedrock cirques, but contained no granite clasts.

My reexamination of this area reveals the following relationships:

1. Mutch's older Oligocene gravels, exposed directly north of Modesty Creek, are correlative with Csejtey's Modesty Creek beds.

2. Pardee's Cretaceous shale, sandstone, and conglomerate were mapped by Mutch as the arkosic Miocene beds.

3. Both Pardee's and Mutch's early drift deposits (with no granite boulders and neither a morainal geomorphic expression nor related to any glacial valleys) are locally overlain by Eocene and Oligocene lake beds of the Renova Formation.

4. All of Mutch's Miocene arkosic beds are overlain by Eocene and Oligocene lake beds.

5. The reworking of earlier gravels of both Pardee and Mutch during the Quaternary is extensive and complex and resulted in the mixing of the older deposits with true glacial deposits (Loen, 1986) derived from glacial cirques whose headwalls are everywhere in granitic plutonic rocks.

6. Mutch postulated that the older gravels were deposited on an older, deeply eroded surface (Pardee's pediment that descended from the mountains at a height of 700–800 ft above the present stream valleys) occurring at elevations between 8,000 and 9,200 ft in the Flint Creek Range. The older surface Mutch referred to is not an erosion surface; it is the basal detachment of the Anaconda metamorphic core complex.

7. Both Pardee's and Mutch's early gravels and almost all their early glacial drift are interpreted to be Eocene and in many cases are demonstrably older than the Renova Formation; these deposits are included in the Anaconda Conglomerate of this report.

Upper Rock Creek, Anaconda Range

As early as 1946 (C.P. Ross, unpublished mapping), conglomeratic deposits exposed in the upper Rock Creek drainage of the Anaconda Range were tentatively correlated with the early conglomerates of Emmons and Calkins (1913). These conglomerates were mapped and described in detail by Poulter (1957, p. 112–115) from exposures along Trout Creek and the East Fork of Rock Creek (fig. 1). His descriptions of these deposits (paraphrased) are as follows.

The conglomerate, best exposed above the West Fork of Rock Creek, consists of a buff- to maroon-weathering, massive and well-indurated pebble to boulder conglomerate interbedded with minor thin, lenticular sandstone. The conglomerate clasts are heterogeneous, poorly sorted, and well rounded. Belt-age quartzite composes more than 90 percent of the clast-supported deposit in a matrix composed of fine- to coarse-grained sandstone, clay, and a ferruginous siliceous rock. Minor clasts of Paleozoic Quadrant Quartzite, gray argillite, gray and black chert, and rare volcanic fragments make up the remainder of clasts. Flaggy sandstone beds exposed along Trout Creek contain poorly preserved deciduous leaves and conifer needles. Of the four plant species collected by Poulter, all are Tertiary; two are known only from the Eocene.

Age

An early Eocene age for the Anaconda Conglomerate seems compelling, especially where the conglomerate is associated with Lowland Creek Volcanics. These volcanic rocks, named from exposures along Lowland Creek 18 mi east of the AMCC, range in age from 52 to 48 Ma (Smedes and Thomas, 1965; Ispolatov and others, 1996). The volcanics are well exposed along the east side of the Anaconda Range and in the adjacent Deer Lodge Valley. At the "old works," the Anaconda Conglomerate clearly rests with angular unconformity above these volcanic rocks (Wanek and Barclay, 1966). Directly above this unconformity is a 5-m thick lens of volcanic rocks in the conglomerate that consists of three parts (fig. 9): (1) A well-indurated bed of poorly sorted laharic conglomerate that contains cobbles and boulders of volcanic rock in a coarse-grained volcanic matrix; (2) an overlying, discontinuously exposed, platy flow of andesite; and (3) an uppermost welded, laharic conglomerate in a tuff matrix in which some of the largest boulders appear to have been derived from the directly underlying flow rocks. The lower and upper volcanic clast conglomerate beds and intervening andesite flow are clearly interlayered with the Anaconda Conglomerate. This critical relationship, the interfingering of Lowland Creek Volcanics with the Anaconda beds, indicates coeval volcanism and sedimentation and constrains the age of the Anaconda Conglomerate at the "old works" to the Eocene.

The inferred correlative strata of the conglomerate discussed in this report also suggest an early Eocene age of deposition. Strata exposed in the northeast Flint Creek Range are locally overlain by the upper Eocene and Oligocene lake beds of the Renova Formation. Fossil leaves of probable Eocene age, preserved in the conglomerate of the Rock Creek area, also indicate an early Tertiary age for these coarse conglomeratic deposits. And the conglomerates at Hoodoo Gulch exposed directly north of the type locality are clearly interlayered with the Lowland Creek Volcanics.

O'Neill and others (2004), based on a $^{40}Ar/^{39}Ar$ age determination of 47 Ma for mica fish developed in mylonite during the formation of the AMCC, interpreted the core complex to be early Eocene in age. Thus, the probable early Eocene age of brittle-ductile deformation and the interlayering of the fluvial/alluvial deposits of the Anaconda Conglomerate with lower Eocene Lowland Creek Volcanics imply that (1) volcanism was generally coeval with brittle-ductile extension and the formation of the AMCC, and (2) sedimentation of the Anaconda Conglomerate is indeed syntectonic, derived from the ongoing extension and concomitant erosion of the upper plate of the Anaconda metamorphic core complex.

Conclusions

The patchy, laterally discontinuous deposits described herein for the Anaconda Conglomerate share important characteristics:

1. All sedimentary conglomerates are spatially restricted to areas within or directly adjacent to the upper, detached plate of the Anaconda metamorphic core complex.

2. All clasts within the deposit, with only very minor exceptions, were derived exclusively from unmetamorphosed upper plate rocks of the core complex.

3. The conglomerates are almost everywhere interlayered with the lower Eocene Lowland Creek Volcanics.

4. Mylonitization and brittle-ductile extension within the core complex is, within $^{40}Ar/^{39}Ar$ analytical error, coeval with Lowland Creek volcanism. Interlayering of Anaconda Conglomerate and Lowland Creek Volcanics indicates that deposition of the conglomerate is coeval with brittle-ductile extension.

5. In the Flint Creek Range foothills, the Eocene and Oligocene Renova Formation clearly overlies the conglomerate.

6. Thickness of the conglomerate is not known, and it is probably different everywhere. Exposed thickness at the type locality is about 390 ft. Maximum exposed thickness of correlative deposits on the east flank of the Anaconda Range is 700 ft.

7. None of the inferred related deposits described herein are adequately exposed to serve as a type section of the formation.

The Anaconda Conglomerate is interpreted to be a syntectonic sedimentary deposit related to the formation of the Anaconda metamorphic core complex. The formation rests unconformably on allochthonous, detached rocks of the core complex carapace. The basal part of the formation is composed principally of coarse sedimentary breccia derived from adjacent bedrock that is the cataclasized, strongly faulted upper plate detachment. The breccia appears to grade laterally and vertically into well-bedded alluvial and fluvial sandstone and conglomerate. The uppermost as well as the more distal beds consist of interlayered finer grained sandstone, siltstone, shale, and lignitic, paludal deposits. The formation is locally unconformably overlain by either the upper Eocene and Oligocene Renova Formation of the Bozeman Group or by Quaternary glacial till (fig. 10). The regional extent of the formation is not known; it may be much more widespread and laterally continuous than described herein.

Discussion

Cenozoic sedimentary deposits in southwestern Montana have been divided into three main groups (Fields and others, 1985): lower to middle Eocene pre-Renova alluvial gravels and interlayered volcanic rocks; middle Eocene to upper Miocene basin-fill deposits of the Bozeman Group; and Pliocene to Holocene alluvial deposits and a variety of deposits related to extensive glaciation. Each group of deposits is separated by a major unconformity, and each group except the glacial deposits is loosely related to a major tectonic event. The oldest alluvial deposits were inferred to be related to Laramide uplifts. The Renova Formation and the overlying Sixmile Creek Formation of the Bozeman Group were related to early basin development. The youngest deposits are in part related to basin-range faulting and, of course, Quaternary glaciation.

Lower Tertiary rocks were first recognized and mapped in southwestern Montana by Emmons and Calkins (1913). Alden (1953) summarized the known extent of these rocks as they were understood and recognized by the mid-century as occurring near Livingston, Mont. (Livingston Group), at Sphinx Mountain in the Madison Range (Sphinx Conglomerate), conglomerate of the Beaverhead Group south of Dillon, Mont., in the Gravelly Range as bouldery deposits, and near Armstead and Anaconda in extreme southwest Montana as bouldery gravel. Fields and others (1985) expanded the discussion and analysis of these earliest, pre-Renova Formation rocks in their summary of Cenozoic rocks of western Montana. To summarize the conclusions of Fields and others (1985, p. 15–16), the lower Tertiary deposits consist of two distinct sequences of deposits related to basin development in the region.

1. Paleocene to lower(?) Eocene post-thrust conglomerates that predate or are coeval with eruption of the Lowland Creek Volcanics.

2. Lower Eocene to lower Oligocene local fanglomerates and conglomerates related to earliest extension.

Fields and others (1985, p. 15–16) discussed the possible relationships between the Sphinx Conglomerate, high-level gravels in the Snowcrest, Gravelly, and Highland Ranges, and known "small patches and plasters of similar conglomerates and breccias scattered along the flanks of the basins." They concluded that, although these deposits "share lithologic similarity, their time of deposition and their depositional and structural relationships remain uncertain." Fields and others (1985, p. 16) also stated that "the ultimate explanation of these confusing conglomerates awaits further provenance studies, detailed mapping, and better age determinations.***The fact that the conglomerates are lithologically similar is no reason to associate them as one or even several related formations. They appear similar because they were deposited under similar ***circumstances."

The Anaconda Conglomerate represents a syntectonic sedimentary accumulation spatially and temporally related to early Tertiary brittle-ductile deformation in turn related to metamorphic core complex development in the northern Rocky Mountains. It may be realistic to postulate that similar deposits discussed and analyzed most recently by Fields and others (1985) are, in fact, related and spatially restricted to areas of regional, early Eocene brittle-ductile extension that now appears to have pervaded more of southwestern Montana than we had previously suspected.

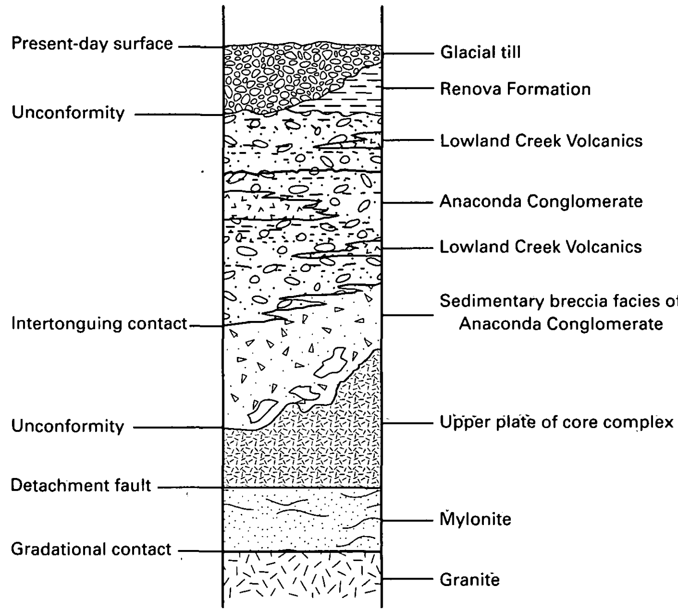


Figure 10. Composite stratigraphic section of the Anaconda Conglomerate and underlying and overlying rocks. Not to scale.

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Alluvial Facies, Paleocurrents, and Source of the Mesoproterozoic Gunsight Formation, East-Central Idaho and Southwestern Montana

By Russell G. Tysdal, David A. Lindsey, Karen I. Lund, and Gary R. Winkler

Chapter B of

Stratigraphic Studies in Southwestern Montana and Adjacent Idaho—Lower Tertiary Anaconda Conglomerate and Mesoproterozoic Gunsight Formation

Descriptions of sedimentary rocks and measurements of paleocurrent directions are used to infer a source for the fluvial strata of the Gunsight Formation in the gneiss terrane of southwestern Montana

Professional Paper 1700

U.S. Department of the Interior
U.S. Geological Survey

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Alluvial Facies, Paleocurrents, and Source of the Mesoproterozoic Gunsight Formation, East-Central Idaho and Southwestern Montana

By Russell G. Tysdal, David A. Lindsey, Karen I. Lund, and Gary R. Winkler

Abstract

The Mesoproterozoic Gunsight Formation is chiefly of fluvial origin. In general, the silt and clay content increases from the Beaverhead Mountains on the northeast into the Lemhi Range on the southwest. The fluvial rocks show a general southward decrease in grain size, scale of individual channel sandstone bodies, and scale of sedimentary structures. These regional changes are interpreted to reflect decreasing stream gradients to the southwest. Near Ayers Canyon in the Beaverhead Mountains, at the eastern margin of the study area, sandstone and conglomeratic sandstone of the Gunsight lie depositionally on Paleoproterozoic gneiss of amphibolite grade. We interpret this contact relationship to indicate deposition of Gunsight strata directly on its source rocks, and not to be a structural contact as previously interpreted.

The Gunsight Formation overlies the Mesoproterozoic Apple Creek Formation throughout the Lemhi Range and the eastern part of the Salmon River Mountains. This stratigraphic succession is used to confirm the correlation of the Gunsight from the Lemhi Range and the Salmon River Mountains northeastward into the Beaverhead Mountains. On the northeast flank of the Beaverhead Mountains, northeast of the Miner Lake–Beaverhead Divide fault zone, rocks previously assigned to the Mesoproterozoic Belt Supergroup are tentatively correlated with the Gunsight Formation.

Paleocurrent azimuths in the Gunsight Formation and tentatively correlated Gunsight strata northeast of the Miner Lake–Beaverhead Divide fault indicate overall southwesterly and northwesterly streamflow during deposition. The Belt(?) Supergroup of the Big Hole Divide area of the Beaverhead Mountains shows southwesterly paleocurrent directions. The overall pattern of paleocurrent directions toward the northwest and southwest, all measured in arkosic fluviatile strata, indicates a common source for the Gunsight Formation, its tentative correlative northeast of the Miner Lake–Beaverhead Divide fault zone, and the Belt(?) Supergroup of the Big Hole Divide area. The sediment source likely was to the east, in the region of cratonic Archean and Paleoproterozoic gneiss of southwest Montana.

Introduction

Purpose of Investigation

Previous paleogeographic interpretations of the depositional setting and source of the Mesoproterozoic Lemhi Group and inferred equivalent strata of the Yellowjacket Formation are in conflict. The previously proposed interpretations include (1) for the Yellowjacket Formation, a rift basin filled with distal turbidites derived from stream-fed submarine fans on the southwest, south, and east sides (Hughes, 1982; Lopez, 1981); (2) for the Gunsight Formation, a continental margin basin filled with onshore, near-shore, and deep-water sediments shed from fault blocks of Precambrian gneiss in southwestern Montana (McBean, 1983); and (3) for the Yellowjacket Formation and Lemhi Group, both correlated with part of the Mesoproterozoic Belt Supergroup, an intracratonic rift basin filled with playa and alluvial sediments derived principally from a continent on the west side of the basin (Winston and others, 1999). Interpretations of the Mesoproterozoic metasedimentary rocks in Idaho and Montana presented here incorporate new detailed and reconnaissance mapping, additional scattered sedimentologic observations, and updated stratigraphic correlations.

The stratigraphy of the Lemhi Group, established by Ruppel (1975), has been clarified by new mapping in the Lemhi Range (Tysdal, 1996a, 1996b; Tysdal and Moye, 1996). Correlations presented in this report concern rocks in the Lemhi Range and contiguous rocks in the Salmon River Mountains, and in the Beaverhead Mountains. Clarification of the stratigraphy of the Lemhi Group permits reconstruction of regional lithofacies patterns and reassignment of sedimentary features and paleocurrent directions to individual formations. Mesoproterozoic metasedimentary rocks of the Salmon River Mountains and Lemhi Range, previously assigned to various informal members of the Yellowjacket Formation (Connor and Evans, 1986; Lopez, 1981), are correlated with the Big Creek, Apple Creek, and Gunsight Formations of the Lemhi Group (Tysdal, 2000a, 2003). Correlation of strata in the vicinity of the principal reference

Table 1. Stratigraphic correlation chart for Gunsight Formation and selected associated formations in central Idaho and southwestern Montana.

LEMHI RANGE AND SALMON RIVER MOUNTAINS	BEAVERHEAD MTNS southwest of Bloody Dick fault (includes concealed northwest extension)	BEAVERHEAD MTNS and BIG HOLE DIVIDE northeast of Miner Lake–Beaverhead Divide fault and Bloody Dick fault (does not include concealed northwest extension)	BIG HOLE DIVIDE and adjacent northeast flank of BEAVERHEAD MOUNTAINS
Tysdal (2000a, 2000b, 2003)	This report	Ruppel and others (1993)	Coppinger (1974)
Strata eroded	Strata eroded	[Belt Supergroup (part)] Missoula Group, undivided	[Belt Supergroup (part)] Post-Bonner Quartzite unit
			Bonner Quartzite
Lawson Creek Formation (west side of Lemhi Range)			Pre-Bonner Quartzite "transitional unit"
Swauger Formation	Swauger Formation		Wallace(?) Formation
			THRUST FAULT
[Lemhi Group (part)] Gunsight Formation	[Lemhi Group (part)] Gunsight Formation	Mount Shields Formation	Yellowjacket Formation
		THRUST FAULT	
[Apple Creek Formation] Banded siltite unit	Apple Creek Formation (undivided)	No pre-Mount Shields strata exposed northeast of fault	
Coarse siltite unit			
Diamictite unit			
Fine siltite unit			
Big Creek Formation	Big Creek Formation		No pre-Yellowjacket Mesoproterozoic rocks

sections[1] of the Yellowjacket Formation and the Hoodoo Quartzite (Ross, 1934), which are on a thrust sheet separate from that of other Mesoproterozoic metasedimentary rocks of the Salmon River Mountains (Tysdal, 2000a; Tysdal and others, 2003), are not discussed herein.

The present investigation is focused on the Mesoproterozoic Gunsight Formation. Among formations of the Lemhi Group, the source of the Gunsight is perhaps most readily determined because it is mainly of fluvial origin. Thus, interpretation of paleocurrent indicators is reasonably straightforward. Although analysis of a single formation does not establish the paleogeographic and structural setting for the entire depositional basin, it provides a reference point from which to examine other formations in the Lemhi Group. Determining the source area and provenance of the Gunsight Formation, first attempted by McBean (1983), places some constraints on our interpreting the paleogeography and plate-tectonic setting of the western margin of North America during Mesoproterozoic time. The source of the Gunsight Formation is identified by considering three types of evidence: (1) regional variations in lithofacies, (2) paleocurrent directions, and (3) stratigraphic and structural relations of a proximal conglomerate lithofacies.

[1]No type sections exist for the Yellowjacket Formation and the Hoodoo Quartzite. Naming of these formations preceded the requirement to designate a type section according to the guidelines of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Sections of each formation, measured in the vicinity of the townsite of Yellowjacket (fig. 1) by Ross (1934), who named the formations, were designated the principal reference sections by Ekren (1988).

Correlation of Gunsight Formation

The general depositional setting of the Gunsight Formation is complicated by the structural setting. Some miscorrelations of Proterozoic strata in central Idaho have occurred in the past because rocks deposited in similar depositional environments were correlated with one another, but they lie on different thrust sheets and within different stratigraphic sequences. Strata of the Beaverhead Mountains, the northern part of the Lemhi Range, and the type area of the Gunsight Formation in the central part of the Lemhi Range are in four separate thrust sheets (Lund and others, 2003; Tysdal and others, 2003), spatially telescoped by Mesozoic thrust faults. Table 1 shows stratigraphic units in the study area.

The stratigraphic succession from Apple Creek Formation to overlying Gunsight Formation is used to confirm the correlation of the Gunsight from the Lemhi Range and the Salmon River Mountains into the Beaverhead Mountains, because the lithology of the Gunsight records different fluvial environments. The Gunsight Formation lies depositionally above the Mesoproterozoic Apple Creek Formation throughout the Lemhi Range and the eastern part of the Salmon River Mountains. Unpublished mapping in the central part of the Beaverhead Mountains of central Idaho and southwestern Montana (R.G. Tysdal and K.I. Lund), and unpublished mapping in the northern part of the Beaverhead Mountains (K.V. Evans and R.G. Tysdal), show that the Apple Creek Formation also lies beneath the Gunsight. Many of the correlations recognized during the course of this work have been incorporated into the geologic maps of the Salmon National Forest (Lund and others, 2003; Tysdal and others, 2003).

Apple Creek strata in the Beaverhead Mountains and the mountains northwest of North Fork previously were correlated with the Yellowjacket Formation, Gunsight Formation, and Cambrian rocks, or given a metamorphic rock name. Much of the Gunsight Formation in the central and northern part of the Beaverhead Mountains previously was mapped as Yellowjacket Formation (Staatz, 1979; Ruppel and others, 1993) or correlated with Neoproterozoic to Cambrian strata (Skipp and Link, 1992). On the northeast flank of the Beaverhead Mountains, northeast of a major northwest-striking thrust fault that trends along much of the northern part of the mountain range, rocks that we tentatively correlate with the Gunsight Formation previously were assigned to the Mount Shields Formation of the Mesoproterozoic Belt Supergroup (Ruppel and others, 1993).

Terminology

Proterozoic rocks throughout most of the region discussed here have been metamorphosed to the greenschist facies. Chlorite-grade metamorphism is typical of most of the rocks in the Lemhi Range and Beaverhead Mountains, although biotite-grade rocks are common in the northwestern parts of these mountain ranges (fig. 1). Biotite-grade metamorphism characterizes most of the rocks in the eastern parts of the Salmon River Mountains and the mountains northwest of North Fork. In this report, the following terminology is used for the clastic rocks.

Argillite. Metamorphosed claystone.

Siltite. Metamorphosed siltstone or mudstone.

Mudstone. Rock composed of a mixture of silt- and clay-size grains, and perhaps a very small percent of sand-size grains.

Metasandstone. Metamorphosed sandstone; generally applied only to rocks composed of less than 90 percent quartz grains.

Quartzite. Metamorphosed sandstone composed of at least 90 percent quartz grains.

Orthoquartzite. Metamorphosed sandstone composed of at least 95 percent quartz grains.

Acknowledgments

We thank K.V. Evans for sharing his insights, in both the field and the office.

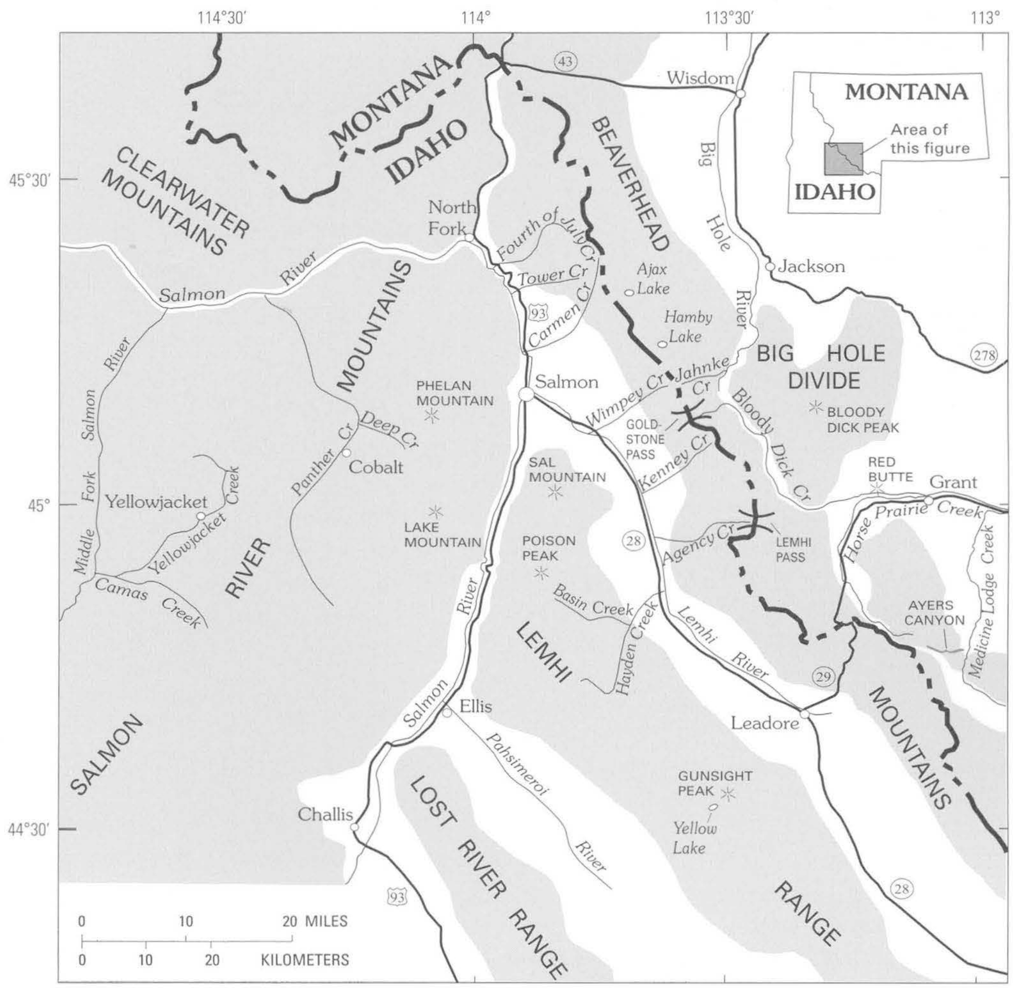


Figure 1. Index map of east-central Idaho and adjacent part of southwestern Montana, showing geographic features. Light shading shows mountains.

Gunsight Formation

The Gunsight Formation was named by Ruppel (1975) for a sequence of strata in the vicinity of Gunsight Peak in the central part of the Lemhi Range (figs. 1, 2). The type locality extends north from near Yellow Lake to Gunsight Peak (Ruppel, 1975). Fluvial strata make up most of the Gunsight where examined in the Lemhi Range, Salmon River Mountains, and Beaverhead Mountains. They show a general southwesterly decrease in grain size, scale of individual channel sandstone bodies, and scale of sedimentary structures. These changes are interpreted to reflect differing depositional settings as stream gradients decreased southwestward. A general southwestward increase in the clay and fine silt content of the rocks is represented by metamorphic chlorite and biotite, yielding a medium- to dark-gray color for the Gunsight Formation in the Lemhi Range and Salmon River Mountains. This color contrasts with the light-gray color of metamorphosed sediment of lower silt and clay content in the Beaverhead Mountains.

Lemhi Range

Gunsight Peak (Type Locality)

The Gunsight Formation at the type locality, south of Gunsight Peak, is 1,725+ m thick and consists of five informal members defined and described by McBean (1983). Member A (341 m thick) was interpreted to be gradational into the underlying Apple Creek Formation. Members B (160 m), C (818 m), and D (265 m) are interpreted as fluvial in origin. Member E (135+ m) is gradational into the overlying Swauger Formation. The Swauger may be a littoral deposit (Tysdal, 2000a).

The fluvial lithofacies (members B, C, and D) of the Gunsight Formation in the type locality is characterized by fining-upward sequences of crossbedded metasandstone, siltite, and minor argillite. Sequences are as much as 100 m thick (McBean, 1983) but are typically much thinner, about 5–15 m thick. Fining-upward sequences in member B consist

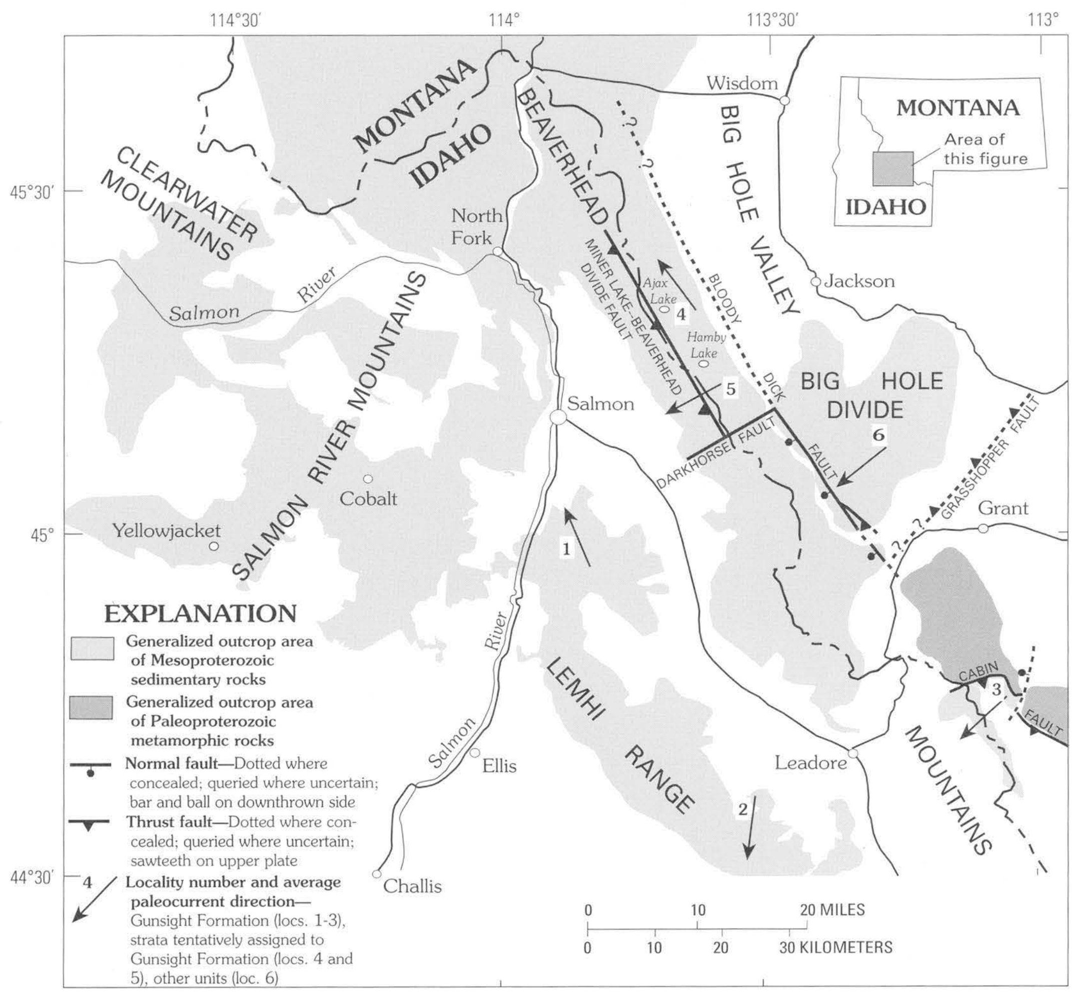
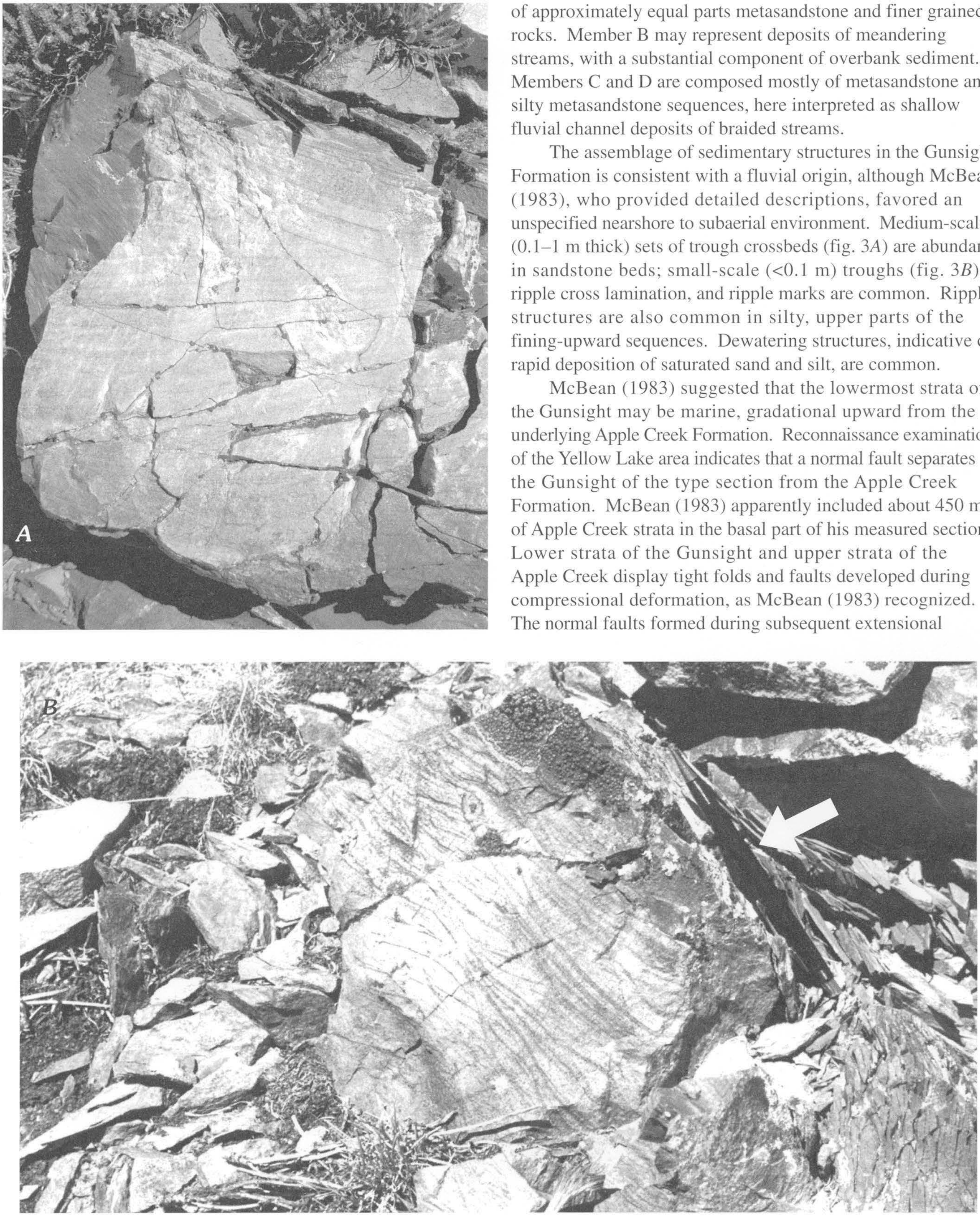


Figure 2. Generalized distribution of Mesoproterozoic sedimentary rocks (including Gunsight Formation) and paleocurrent directions at numbered localities in the Gunsight and in strata tentatively assigned to the Gunsight. Localities are: 1, Sal Mountain; 2, Gunsight Peak; 3, Ayers Canyon; 4, Ajax Lake; 5, Jahnke Creek; 6, Big Hole Divide area. Distribution of Mesoproterozoic rocks modified from compilations by Ruppel and others (1993); Lund and others (2003); Tysdal and others (2003); and unpublished mapping of K.I. Lund and R.G. Tysdal.



of approximately equal parts metasandstone and finer grained rocks. Member B may represent deposits of meandering streams, with a substantial component of overbank sediment. Members C and D are composed mostly of metasandstone and silty metasandstone sequences, here interpreted as shallow fluvial channel deposits of braided streams.

The assemblage of sedimentary structures in the Gunsight Formation is consistent with a fluvial origin, although McBean (1983), who provided detailed descriptions, favored an unspecified nearshore to subaerial environment. Medium-scale (0.1–1 m thick) sets of trough crossbeds (fig. 3*A*) are abundant in sandstone beds; small-scale (<0.1 m) troughs (fig. 3*B*), ripple cross lamination, and ripple marks are common. Ripple structures are also common in silty, upper parts of the fining-upward sequences. Dewatering structures, indicative of rapid deposition of saturated sand and silt, are common.

McBean (1983) suggested that the lowermost strata of the Gunsight may be marine, gradational upward from the underlying Apple Creek Formation. Reconnaissance examination of the Yellow Lake area indicates that a normal fault separates the Gunsight of the type section from the Apple Creek Formation. McBean (1983) apparently included about 450 m of Apple Creek strata in the basal part of his measured section. Lower strata of the Gunsight and upper strata of the Apple Creek display tight folds and faults developed during compressional deformation, as McBean (1983) recognized. The normal faults formed during subsequent extensional

Figure 3. Sedimentary features of fluvial facies of the Gunsight Formation, member B, type locality, south of Gunsight Peak. *A*, Fining-upward sequence of sandstone and siltite; sandstone has sharp base, trough crossbedding, and gradational top (about 1 m thick). *B*, Small-scale trough crossbedding in sandstone; pencil (arrow) points in general direction of current flow.

deformation. Reconnaissance mapping of the Apple Creek and overlying strata west to southwest of Yellow Lake (incorporated into the geologic map of Lund and others, 2003) indicates that strata of the lower Gunsight, gradational upward from the Apple Creek into the Gunsight, may have been omitted by the faulting.

Beaverhead Mountains

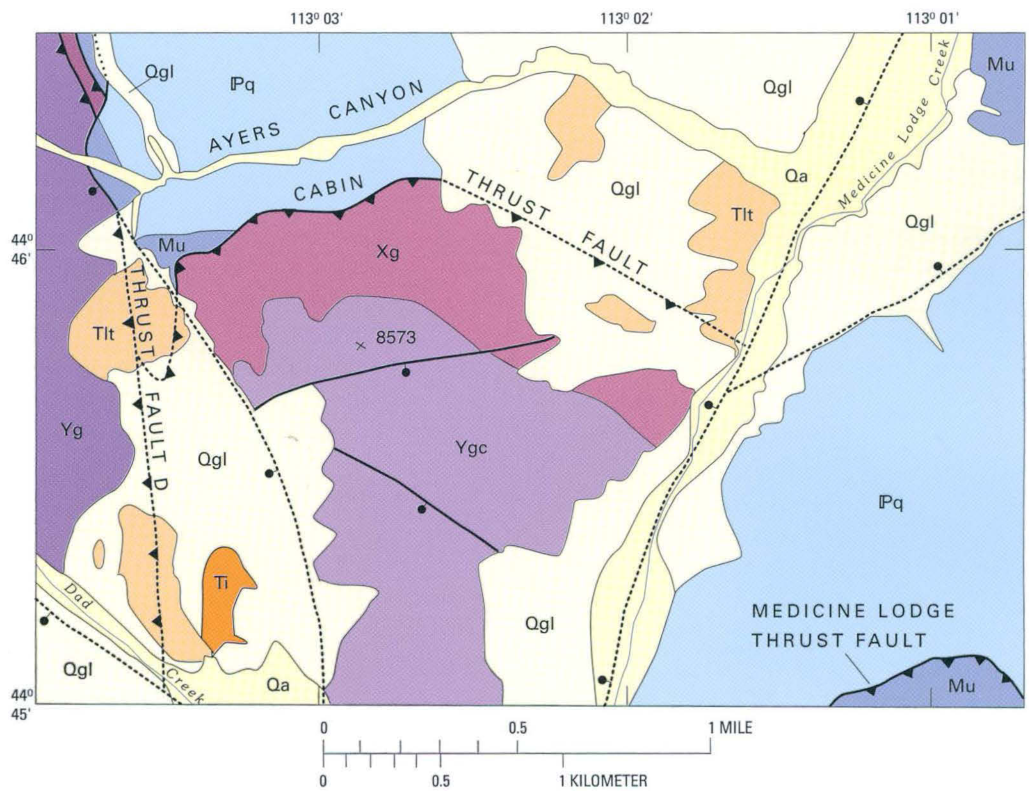
Ayers Canyon

In the Beaverhead Mountains near the east edge of the study area, south of Ayers Canyon (fig. 1), metasandstone and conglomeratic metasandstone of greenschist metamorphic grade lie directly on Paleoproterozoic gneiss of amphibolite grade. We interpret (1) the metasandstone and conglomeratic metasandstone to be part of the Mesoproterozoic Gunsight Formation, (2) the contact to be depositional, and (3) the relationship to indicate deposition of Gunsight strata directly on source rocks. McBean (1983) previously correlated the metasandstone and conglomeratic metasandstone with the Gunsight Formation, finding similarities with rocks of the type section in the Gunsight Peak area of the Lemhi Range. M'Gonigle (1993) considered the Ayers Canyon rocks to possibly correlate with the Mesoproterozoic Big Creek Formation or, following the tentative suggestion of Skipp and Link (1992), to possibly correlate with the Neoproterozoic and Cambrian Wilbert Formation. The contact of the gneiss with the overlying conglomeratic Gunsight was interpreted as a thrust fault by M'Gonigle (1993). We describe the rocks and explain our interpretations of the sedimentologic and structural relationships in this section of the report.

Gneiss

The Paleoproterozoic gneiss is reddish-orange-weathering, light-gray to brown, medium-grained porphyroblastic granite gneiss that has strong planar fabric. The medium-grained groundmass is formed of quartz and subequal amounts of plagioclase, potassium feldspar, and combined hornblende

Figure 4. Geologic map showing Gunsight Formation at Ayers Canyon, Beaverhead Mountains, Mont. (modified from M'Gonigle, 1993).



EXPLANATION

Qa	Quaternary alluvial deposits		Mesoproterozoic Gunsight Formation
Qgl	Quaternary glacial, landslide, and fan deposits	Yg	Metasandstone
Tlt	Oligocene to Eocene shale, limestone, tuffaceous sandstone	Ygc	Basal arkosic metasandstone and metaconglomerate
Ti	Tertiary basaltic to andesitic intrusive rocks	Xg	Paleoproterozoic granite gneiss
IPq	Pennsylvanian Quadrant Sandstone		Contact
Mu	Mississippian limestone and sandstone of Snowcrest Range Group and Scott Peak Formation, undivided		Normal fault—Dotted where concealed; bar and ball on downthrown side
			Thrust fault—Dotted where concealed; sawteeth on upper plate

and biotite (M'Gonigle, 1993). Porphyroblasts are deformed coarse-grained microcline that originally formed phenocrysts. Foliation and poorly formed compositional layering are defined by oriented mafic minerals, elongated porphyroblasts, and quartz and feldspar constituents of the groundmass. Some local mafic masses occur in the gneiss as do crosscutting quartz veins and pegmatite dikes. Recent U/Pb zircon analyses yielded Paleoproterozoic dates (Kellogg and others, 1999).

Gunsight Formation

The Gunsight Formation in the general area west of hill 8573 (fig. 4) is crossbedded medium-grained arkosic metasandstone and siltite. Thin-section study by M'Gonigle (1993) showed a composition of 65 percent quartz, 22 percent matrix of sericite and illite, 4 percent microcline, 4 percent plagioclase, 2 percent medium-grained muscovite, and 3 percent magnetite, ilmenite, leucoxene, and zircon. Quartz grains are subrounded to subangular.

On hill 8573 (fig. 4), stratigraphically above the granite gneiss, metasandstone and conglomerate are interbedded in the lower part of the Gunsight Formation. Outcrops are composed of one or the other or both lithologies. Beds range from about 0.1 m to more than 1 m thick. Conglomerate beds contain abundant subrounded to angular pebbles of gneiss 2–5 cm in diameter and locally contain cobbles as large as 15 cm in diameter (M'Gonigle, 1993). Also present is a subordinate amount of subrounded to angular granules and pebbles of quartz and microcline, as much as 2 cm in diameter, probably derived from pegmatite (fig. 5). Gneiss clasts resemble the subjacent Paleoproterozoic gneiss. Metasandstone beds are composed of poorly sorted coarse-grained arkose in which quartz grains are subangular to subrounded and tectonically strained prior to deposition in the sandstone. Both the conglomerate and metasandstone beds are laminated and trough crossbedded.

Contact

The contact of the gneiss with the overlying Gunsight Formation is exposed on a dip slope on the west side of hill 8573 (fig. 4). The best exposures are confined to a small area on the ridge that trends northwest from the hilltop. Our observations reveal that the conglomerate on hill 8573 is in

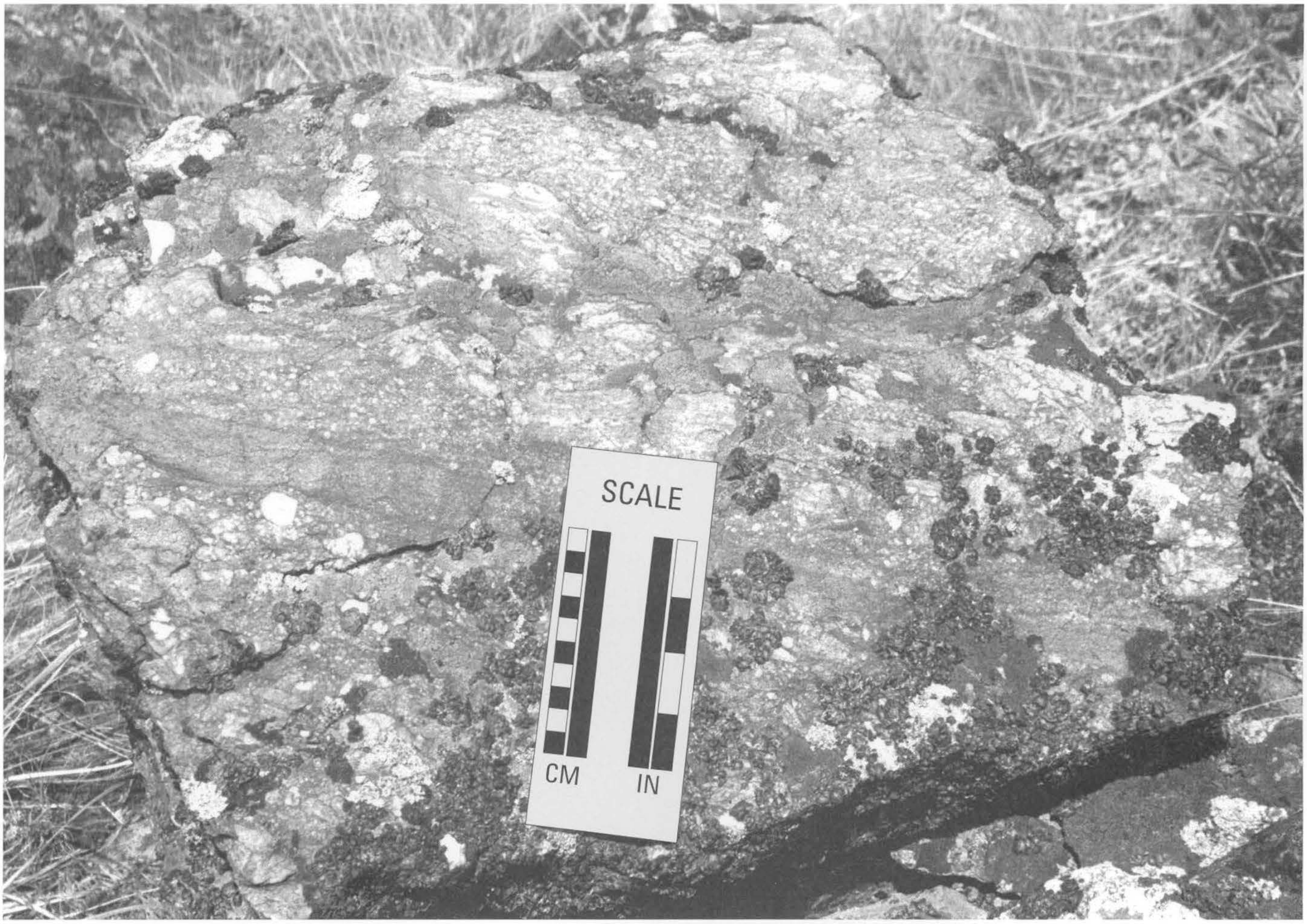


Figure 5. Conglomerate in Gunsight Formation on hill 8573, Ayers Canyon, Beaverhead Mountains, Mont. Pebbles are gneiss, quartz, and microcline feldspar.

contact with underlying Paleoproterozoic layered granite gneiss. Interpretation of the contact as depositional is supported by (1) the general lack of fault-related deformational fabric or brecciation in both layered gneiss and conglomerate, and (2) the gradational nature of the contact, resulting from the great abundance of subrounded to angular clasts of gneiss in the conglomerate near the contact.

Reinterpretation of the stratigraphy to recognize the Mesoproterozoic sedimentary rock as Gunsight Formation and remapping of the basal contact of the Gunsight Formation require a reevaluation of the structure of the hill 8573–Ayers Canyon area. Low on the north slope of hill 8573, directly south of Ayers Canyon (fig. 4), the east-west-trending Cabin thrust fault placed Paleoproterozoic gneiss northeastward over Paleozoic rocks (M'Gonigle, 1965, 1993). The gneiss at the base of the upper sheet (that is, rocks south of the Cabin thrust fault) is severely brecciated and chloritized in an approximately 100 m thick zone along the Cabin thrust fault. Southward, higher up the slope of hill 8573 (fig. 4), the contact of the Paleoproterozoic gneiss with the overlying conglomerate and metasandstone of the Gunsight Formation was first interpreted by M'Gonigle (1965) as a low-angle basin-bounding normal fault. He compared the contact with that of the faulted southern margin of the Belt basin where the arkosic conglomerate of the Mesoproterozoic LaHood Formation of the Belt Supergroup was deposited (McMannis, 1963)[2]. In contrast, M'Gonigle (1993) subsequently reported small, localized areas of breccia in gneiss below the contact high on hill 8573 and mapped the contact as a normal-fault reactivation of a thrust fault.

Our observation of the contact of the Paleoproterozoic gneiss with the Mesoproterozoic Gunsight Formation directly north of hill 8573 indicates a lack of deformation along the contact. We examined the localized outcrops of breccia reported by M'Gonigle (1993) below the contact and found the angular breccia clasts to be rotated and recemented by pseudotachylyte. These pseudotachylyte breccias are similar to those reported about 10 km southeast of Ayers Canyon (about 3 km east of map area shown in fig. 1) (Fiske and others, 1994) and are probably related to the Beaverhead impact structure (Hargraves and others, 1990; Fiske and others, 1994; Hargraves and others, 1994). The impact structure and pseudotachylyte breccias formed 850 to 900 Ma (Kellogg and others, 1999). With recognition that the breccias below the basal contact of the Gunsight Formation are unrelated to faulting, we interpret the basal contact of the Gunsight Formation as depositional, which is a modification of M'Gonigle's 1965 interpretation.

In view of the preceding discussion, the Paleoproterozoic gneiss with the depositionally overlying Mesoproterozoic Gunsight Formation lies in a thrust sheet that was displaced from the southwest. Hence, hill 8573 is not in place, and if it represents a basin margin deposit as we interpret, the margin originally was southwest of the present location of the thrust slice.

[2]In west-central Montana, about 150 km northeast of Ayers Canyon, the basin containing the Belt Supergroup forms an east-west-trending structural salient. The southern margin of the salient is delimited by an east-west-trending fault called the southwest Montana transverse zone.

Central Part of the Beaverhead Mountains

In the area between Goldstone Pass and Lemhi Pass (fig. 1), where Gunsight has not been eroded from above the Apple Creek, we are uncertain if the contact is conformable owing to very poor exposures and limited observations along the contact. Further, thrust faulting has complicated the picture in this area, as shown on the maps of Ruppel and Lopez (1984, pl. 1), Ruppel and others (1993), and Lund and others (2003), and K.I. Lund (unpub. data, 2002). Reconnaissance on the northeast flank of the Beaverhead Mountains in this area shows both shallow-water and fluvial rocks near Bloody Dick Creek. But the contact is obscure. Contact relationships are discussed further near the end of this report, in the section, "Contact of Gunsight Formation with Underlying Apple Creek Formation in the Beaverhead Mountains."

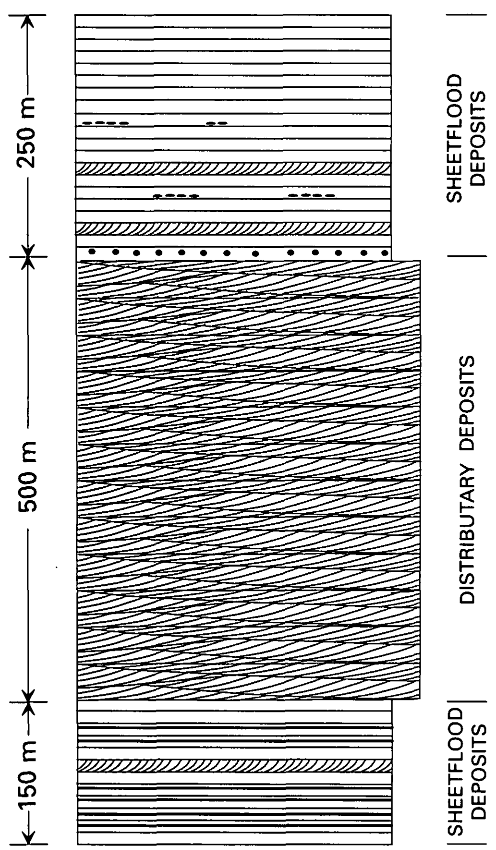
Northeast of Miner Lake–Beaverhead Divide Fault Zone

Correlation

Reconnaissance observations were made of strata along the northeast flank of the Beaverhead Mountains in the northern part of the range (fig. 1). The rocks lie northeast of the Miner Lake–Beaverhead Divide fault zone, which trends northwest along the crest of the Beaverhead Mountains from near Goldstone Pass to north of Carmen Creek, and beyond (fig. 2). The contact of these strata with the Mesoproterozoic rocks of central Idaho is entirely structural. No depositional contact with the Idaho Mesoproterozoic rocks was observed.

The rocks northeast of the Miner Lake–Beaverhead Divide fault zone, which in aggregate are more than 4,000 m thick, were assigned to the Mesoproterozoic Mount Shields Formation of the Belt Supergroup of western Montana by Ruppel and others (1993; and see this report, table 1). These workers interpreted the strata as deposits of the lower part of the Mount Shields because they differ from those of the formation elsewhere in western Montana. We, on the other hand, tentatively correlate the rocks northeast of the Miner Lake–Beaverhead Divide fault zone with the Gunsight Formation.

The lithologic similarity of the rocks on the northeast flank of the Beaverhead Mountains, northeast of the Miner Lake–Beaverhead Divide fault, to the Gunsight Formation of central Idaho suggests that these rocks belong to the Gunsight Formation. Rocks that we tentatively assign to the Gunsight northeast of the fault differ significantly from rocks that are typical of the Mount Shields Formation to the north in western Montana (J.M. O'Neill, oral commun., 2001), described by Ruppel and others (1993) and Ruppel and Lopez (1984).



EXPLANATION

- Metasandstone and coarse-grained siltite, planar to ripple cross laminated
- Siltite, fine-grained
- Subaqueous trough-crossbedded dunes, 0.2-0.5 m high
- Subaqueous trough-crossbedded dunes, 1-2 m high
- ---- Mudchips
- • • • Pebbles

Figure 6. Graphic section for part of the strata tentatively assigned to the Gunsight Formation near Ajax Lake in the Beaverhead Mountains, Mont. (location, fig. 1). See text for explanation.

Description

A reconnaissance section (fig. 6) of part of these strata was examined in the Ajax Lake area. The section starts at a lateral moraine that is well above (northeast of) the Miner Lake–Beaverhead Divide fault zone (which delimits the base of the exposed strata west of the lateral moraine). The section is composed of rocks that are within the strata that are tentatively assigned to the Gunsight Formation. Thicknesses of lithic units are estimated from dips and map patterns.

The basal unit of the section (fig. 6) was examined directly south of Ajax Lake, in isolated outcrops surrounded by ground moraine. The partially exposed basal unit is estimated to be 150 m thick. Sequences of siltite beds 2–5 cm thick are interlayered with sequences of metasandstone beds that are 20–30 cm thick. The siltite beds are planar laminated or ripple cross laminated. The metasandstone beds are planar laminated to trough crossbedded. A few beds contain tabular mudchips (siltite), as long as 2 cm, aligned along foresets of the crosslaminae. Many of the mudchips are isolated from one another. Small flame structures as much as 1 cm high occur in some beds. Beds near the top of this basal unit (fig. 6) are composed of amalgamated trough crossbed sets, all of which have erosional bases. Some crossbedded strata grade upward into rippled strata.

The middle unit of the section (fig. 6), estimated to be 500 m thick, consists of metasandstone that is medium to coarse grained and arkosic, composed chiefly of quartz and feldspar (both microcline and plagioclase); matrix ranges from 1 to 10 percent. The rocks display spectacular three-dimensional subaqueous dunes[3] as much as 2 m amplitude and 8+ m wave length (fig. 7). The metasandstone beds are stacked atop one another, forming sheets of dune sands. Locally, the subaqueous dunes clearly are erosional into underlying dunes, both in the downstream direction and normal to the flow direction. Some large-amplitude dunes commonly form a single bed. Smaller dunes are amalgamated into beds that generally are 0.5–2 m thick. No fine sediment (siltite) was observed between dune beds.

Many of the dunes display oversteepened and overturned (recumbent) crossbeds (fig. 8*A*), similar to those illustrated and discussed by Allen and Banks (1972). Overturning is consistently in the downcurrent direction, and the axial plane of overturned laminae generally is about horizontal or dips upcurrent at a low angle. Dark-gray heavy minerals are interlaminated with light-gray quartz and feldspar grains in the foresets. The dark-gray heavy-mineral laminae are concentrated in basal laminae of each crossbed set and locally are prominent in overturned crossbeds. Individual layers are thickest about the inflection area of the axial plane and thinnest away from the axial plane. In the lower part of beds, where crossbed laminae first become overturned, the laminae of light-gray minerals between the heavy-mineral laminae pinch out and only the heavy-mineral laminae remain. Some heavy-mineral laminae are so concentrated as to form sags and convolute layers within the crossbed sets (fig. 8*B*).

About 1 km along strike southeast of Ajax Lake (fig. 1), the dunes are stratigraphically overlain by several zones, a few meters thick, composed of interstratified beds of metasandstone and small dunes that contain dark-gray siltite chips (metamudstone) in the basal part. Some of the mudchip zones are lenses as thick as 1 m and extend along strike for

[3]Dune classification and description follow that recommended by Ashley (1990).

more than 10 m. In some strata, the mudchips are distributed along individual layers, separated by metasandstone from other mudchip layers.

Strata described in the preceding paragraph are succeeded by about 250 m (fig. 6) of laterally extensive fine- to medium-grained planar laminated metasandstone beds 0.3–1 m thick. Interbeds with subparallel cross laminations are distributed throughout the sequence. Climbing ripples were observed in a few beds. Heavy-mineral laminae are present in both lamina types. The tops of crossbed sets are erosionally truncated. No mudchips or dunes were observed.

About 4 km southeast of Ajax Lake, stratigraphically downsection from strata illustrated in the graphic log of figure 6, a zone 20 m thick of coarse-grained metasandstone contains well-rounded pebbles of white (vein) quartz. The associated rocks contain abundant layers of dark-gray heavy minerals, including sags. Farther southeast, about midway between Ajax and Hamby Lakes and near the crest of the Beaverhead Mountains (fig. 2), and lower still stratigraphically, pebble conglomerate layers occur at the base of some beds. The pebbles form lenses as thick as 10 cm that extend at least 50 m along strike. The pebbles commonly are rounded and generally display diameters in the 1–4 cm range, although one clast isolated at the base of a metasandstone bed was 2–3 cm thick and 15 cm long. Clast compositions include crystalline metamorphic rocks, vein quartz, granite, and metasandstone. Pebbles occur as scattered clasts within metasandstone and locally form thin lenses of clast-supported conglomerate. Some pebble layers are rippled and grade upward into cross-laminated dunes that are 20–30 cm high. Some of the dunes contain overturned crossbeds and water-escape structures, which tend to be parallel to the axial planes of overturned crosslaminae. Oblate clasts of the conglomerates are imbricated in a direction consistent with the downstream direction of transport determined for the dunes. The conglomerate beds do not fill scours and do not appear to be lag deposits.

A reconnaissance traverse along the ridge directly north of Hamby Lake (fig. 1) revealed an almost completely exposed sequence of strata about 1,500 m thick. The rocks dip steeply to the northeast. They can be subdivided into units, the lower of which generally display characteristics similar to those of strata in the Ajax Lake area. Subaqueous dunes, some with overturned crossbeds, are present, but the sequence of such beds is thinner. No pebble conglomerate zones were observed. The upper 500 m (estimated) of the

Figure 7. Large subaqueous dune in fluvial strata tentatively assigned to the Gunsight Formation near Ajax Lake, Beaverhead Mountains. Dune amplitude is about 2 m, and shows slight overturning in downstream direction, to left. Hammer handle is 22 cm long.

sequence contains beds that are 2–4 m thick and composed of amalgamated crossbeds of smaller scale than bed thickness. Dark-gray fine-grained siltite (metamudstone) was observed in the easternmost part of the sequence, in beds that are stratigraphically higher than any examined in the vicinity of Ajax Lake. The siltite forms 1–2 cm thick layers between beds of cross-laminated metasandstone. Mudcracks are prominent in the siltite and are the only such features observed during our reconnaissance examination of the stratigraphic sequence on the northeast flank of the Beaverhead Mountains.

Origin

The general sequence of sedimentary structures observed in the reconnaissance examination of strata in the Ajax Lake area is shown diagrammatically in figure 6. The aim of the illustration is to show that different sedimentary structures occur within different parts of the sequence, and to show that the size of the sedimentary structures differs within the sequence. The subaqueous dunes of trough-crossbedded metasandstone are of a much larger size (as much as 2 m amplitude) than those observed in the underlying and overlying units (less than 0.5 m and generally 0.2 m amplitude or less). Similarly, the grain size of the larger structures is medium- to coarse-grained metasandstone; that of the other units is coarse-grained siltite to fine-grained metasandstone. These differences are interpreted to reflect a contrast in the discharge magnitude of the depositing streams, with the larger scale and coarser grained structures formed in high-velocity streams that were deep enough to generate the large features.

The sequences of sedimentary structures suggest variation in hydrologic conditions and flow depths. The Gunsight of the Ajax Lake–Hamby Lake area may have been deposited in either a braided river or a meandering stream. Our limited reconnaissance work does not permit us to make a choice. Braided rivers are characterized by sheet sandstones and lenses and contain little in the way of finer sediment (Miall, 1996). Planar laminated strata, small-scale trough crossbeds, and locally climbing ripples of the units above and below the thick crossbedded unit of figure 6 may indicate deposition by unconfined sheetflood. A single zone of fine-grained siltite observed in the upper part of the reconnaissance section (fig. 6), and the fine siltite displaying mudcracks near Hamby Lake, may represent overbank deposits. The scarcity of such

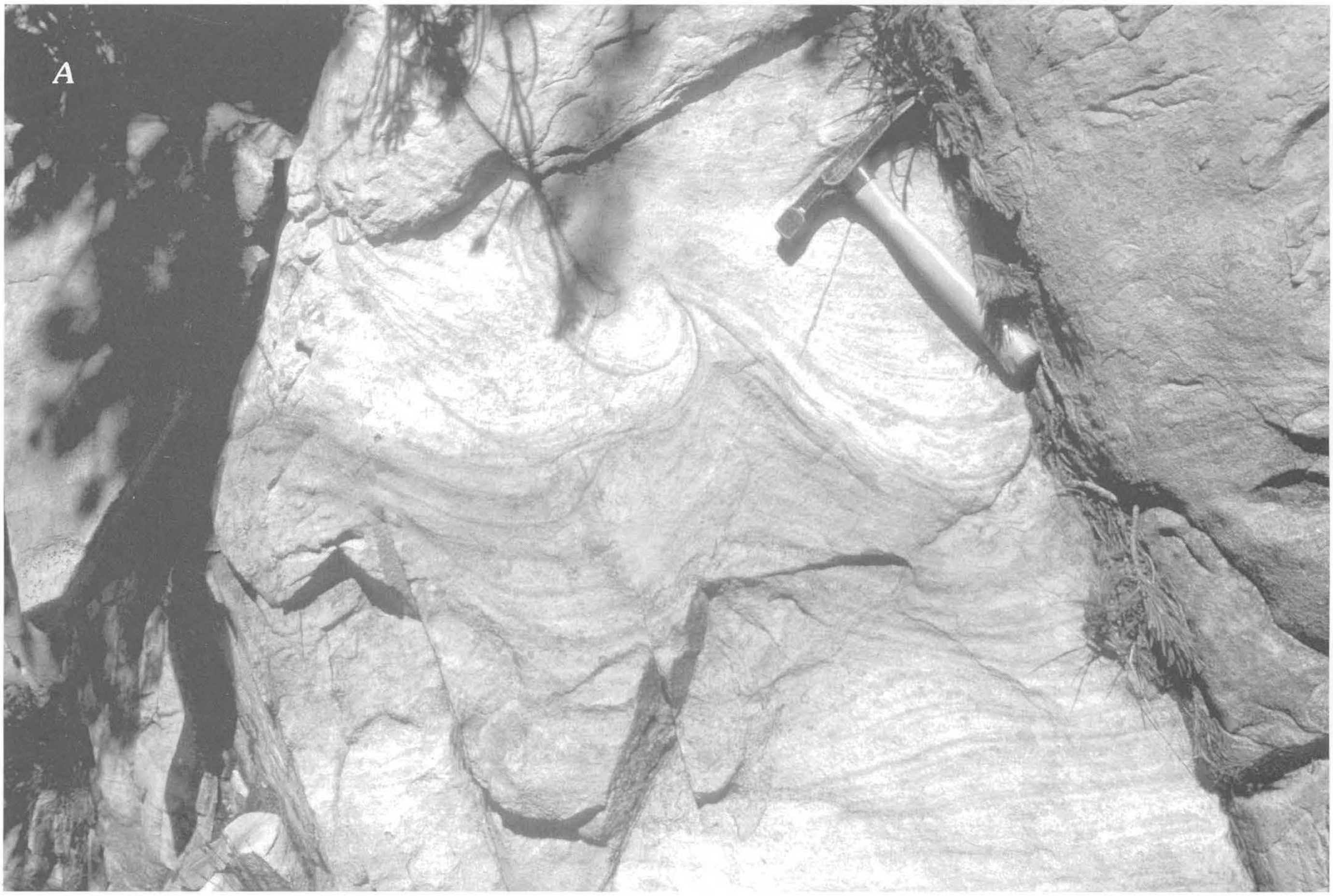


Figure 8 (above and overleaf). Overturned crossbeds in fluvial strata tentatively assigned to the Gunsight Formation near Ajax Lake, Beaverhead Mountains. *A*, Overturned crossbed with laminae of dark-gray, fine-grained heavy minerals showing inclination of layering. Transport direction is right to left. Hammer handle is 22 cm long. *B*, Overturned crossbed with dark-gray heavy-mineral sag in core area of overturned laminae. Transport direction is right to left. Hammer handle is 22 cm long.

deposits suggests that either they were not typically deposited, or such sediment was reentrained and flushed from the stream banks. The large-scale trough crossbeds illustrated in figure 6 are dune structures formed by high-energy streams. The association of steep and overturned crossbeds, some with convolutions and others with heavy-mineral sags, indicates rapid accumulation of sediment accompanied by current shear and simultaneous sediment dewatering (Allen and Banks, 1972; Hobday, 1978). Jones and Rust (1983) and Roe and Hermansen (1993) attributed similar overturned (deformed) fluvial crossbeds to liquefaction and downslope sedimentation.

Belt(?) Supergroup of Big Hole Divide Area and Correlation of Rock Units

Historical Correlation of Rock Units

Rocks of the mountainous Big Hole Divide[4] area are briefly described and discussed in this report to show their correlation, or lack thereof, with the central Idaho sequence of Mesoproterozoic rocks. The Big Hole Divide rocks lie almost entirely northeast of the Bloody Dick fault, which trends parallel to Bloody Dick Creek on its northeast side (figs. 1, 2). The Big Hole Divide area was studied by Coppinger (1974) as part of his Ph. D. dissertation; very little additional study of these rocks has taken place since. We undertook reconnaissance examination of these strata. Coppinger (1974) described and mapped several stratigraphic units, determining that the general stratigraphic sequence goes upsection northeastward from the Bloody Dick normal fault. Coppinger applied the name Bonner Quartzite to a key stratigraphic unit, which he tentatively correlated with strata of the Mesoproterozoic Belt Supergroup of western Montana (table 1). His Bonner unit in the Big Hole Divide area is directly underlain by a pre-Bonner unit, about 900 m thick, then by his lowermost unit, which he determined to have a thickness of more than 2,430 m and to crop out over a wide area.

Coppinger (1974) applied the name Wallace(?) Formation (hereafter, the "Wallace(?)" or "Wallace(?) Formation") to the lowermost unit (table 1), but he clearly recognized the tenuousness of the correlation because the lowermost unit lacks carbonate rocks typically present in the Wallace Formation; hence the query in the name. He cited the sparsity of data (at the time of his work) for the region between the Big Hole Divide area and then-known (studied) areas of Belt strata several tens to 100 or more kilometers to the north in western

[4]The name Big Hole Divide applies to the area of the Beaverhead Mountains that is bordered on the north by State highway 278, on the west by the headwaters of the Big Hole River, on the southwest and south by Bloody Dick Creek, and on the east by nonmountainous terrain (fig. 1).

Montana, and discussed the differing lithologies of Mesoproterozoic rocks of the intervening region.

Ruppel and others (1993) later assigned rocks of the Big Hole Divide area to the Missoula Group of the Belt Supergroup (table 1). The geologic map of these workers shows the Big Hole Divide rocks as continuous with the strata that lie directly east of Jackson, Mont., and to be part of the Grasshopper thrust plate (Ruppel and Lopez, 1984; Ruppel and others, 1993), which lies west of the Grasshopper thrust fault (fig. 2). In the rocks directly east of Jackson, Ruppel and Lopez (1984) tentatively identified the Garnet Range Formation and the underlying McNamara Formation. They (Ruppel and Lopez, 1984, p. 20) stated that "a very thick and largely homogeneous sequence of quartzitic rocks beneath the McNamara Formation is thought to be equivalent to the Mount Shields Formation, or to both the Mount Shields and Bonner Formations." They described the strata, then wrote that "rocks similar to those included in the Mount Shields Formation and Bonner(?) Quartzite in the southwestern part of the Pioneer Mountains [north and east of State highway 278, fig. 1 of this report] form most of the Grasshopper [thrust] plate." Stanley and Sinclair (1989) interpreted some stratabound Cu-Ag rocks directly east of Jackson as fluvial rocks of the Bonner. R.C. Pearson (oral commun., 1999) interpreted these same rocks as strata of the McNamara Formation.

The Mesoproterozoic rocks at Red Butte in the eastern part of the Big Hole Divide area (fig. 1), directly west of the Grasshopper thrust fault, were assigned to the Garnet Range Formation by Elston and others (2002). But these rocks are part of the unit that Coppinger (1974) called Bonner Quartzite. Rocks of this unit are widespread in the north half of the Big Hole Divide area (Coppinger, 1974, pl. 1) and are widespread in the area east of Jackson. The certainty of either of these formation assignments is unknown because the rocks display characteristics of both formations (R.C. Pearson, oral commun., 2002).

Relationship of Belt(?) Supergroup of Big Hole Divide Area to Rocks Tentatively Assigned to Gunsight Formation Northeast of Miner Lake–Beaverhead Divide Fault Zone

The possibility exists of stratigraphic continuity of the central Idaho Mesoproterozoic sequence with the Belt(?) Supergroup strata of the Big Hole Divide area (table 1). The most likely areas for finding a demonstrable stratigraphic relationship of rock units may be in the Beaverhead Mountains northeast of the Miner Lake–Beaverhead Divide fault zone (northwest of the cross-range Darkhorse fault) and in the nearby Big Hole Divide area. But none of the rock units of the Big Hole Divide area are like those northeast of the Miner Lake–Beaverhead Divide fault zone (figs. 1, 2). In the Big Hole Divide Mountains, the "Wallace(?) Formation" (the lowermost unit) is juxtaposed against rocks of the central Idaho sequence along the Bloody Dick fault. We describe the lowermost unit in that area northeast of the Bloody Dick fault and compare it to the strata directly northeast of the Miner Lake–Beaverhead Divide fault.

The "Wallace(?) Formation" of the Big Hole Divide area was described by Coppinger (1974) as a homogeneous sequence of light-gray ("white") medium- to coarse-grained feldspathic "quartzites," with scattered interbeds of fine-grained micaceous feldspathic "quartzites" and feldspathic graywackes. Coppinger stated that the feldspathic quartzites, which make up most of the map unit, are typically composed of 77–89 percent quartz and 5–16 percent feldspar, based on his examination of thin sections. The quartz grains range from subangular to well rounded. Our reconnaissance observations reveal that these rocks contain trough crossbeds, coarse grain size (including granule-size clasts), and dark-gray heavy minerals; they generally lack matrix fines.

The "Wallace(?) Formation" of the Big Hole Divide area contains a much higher percentage of quartz grains than do the rocks northeast of the Miner Lake–Beaverhead Divide fault zone, and the rounded to well-rounded quartz grains are atypical of the quartz grains in the strata northeast of the Miner Lake–Beaverhead Divide fault zone. Silty strata are largely absent in the basal unit of the Big Hole Divide area, and the scale of sedimentary structures, particularly subaqueous dunes, is smaller. Two possibilities are considered for the relationship of the rocks of these two areas, as explained in the following paragraphs.

1. Lowermost strata northeast of the Bloody Dick fault were deposited directly upsection of the strata northeast of the Miner Lake–Beaverhead Divide fault zone. In this possibility, the Bloody Dick fault ends where it meets the cross-range Darkhorse fault (fig. 2). However, strata northeast of the Miner Lake–Beaverhead Divide fault zone are not demonstrably contiguous with strata of the Big Hole Divide area because glacial deposits conceal bedrock in the junction area of the two faults. Strata like those northeast of the Miner Lake–Beaverhead Divide fault zone are absent directly northeast of the Bloody Dick fault, and lowermost Big Hole Divide strata are not exposed directly upsection (northeast) of those northeast of the Miner Lake–Beaverhead Divide fault zone.

Rocks directly southwest of the Bloody Dick fault (southeast of the cross-range Darkhorse fault, fig. 2) are Gunsight Formation, but they are not like the strata northeast of the Miner Lake–Beaverhead Divide fault zone; they are from the lowermost part of the Gunsight, directly upsection from Apple Creek strata that crop out on the northeast flank of the Beaverhead Mountains southwest of Bloody Dick Creek. The absence of strata like those northeast of the Miner Lake–Beaverhead Divide fault zone from directly northeast of the Bloody Dick fault could be because (a) they were cut out by normal displacement (down-on-the-southwest) on the Bloody Dick fault; and (or) (b) southeast of the cross-range Darkhorse fault, strata like those northeast of the Miner Lake–Beaverhead Divide fault zone were thrust northeastward, and later eroded; the thrust sheet subsequently was downdropped by the Bloody Dick normal fault.

2. Another possibility, favored here, is that strata like those northeast of the Miner Lake–Beaverhead Divide fault zone are separated from the Big Hole Divide area by the Bloody Dick fault—strata of the two areas are not directly correlatable. In this possibility, the Bloody Dick normal fault extends northwestward beyond the end of the cross-range Darkhorse fault (fig. 2) and lies concealed beneath the extensive glacial deposits of the area. The concealed northwest extension of the fault lies approximately along a steep gravity gradient that delimits the southwest margin of the Big Hole Valley (in which alluvial and glacial deposits conceal thick deposits of Tertiary sedimentary rocks) as shown by the Bouguer gravity anomaly map of Hanna and others (1993). These authors showed several strands of normal faults along the gravity anomaly, but the sense of displacement is down-on-the-northeast, which is opposite to that of the exposed Bloody Dick normal fault. The structural zone may have had a long history of activity, with multiple movements, and some with opposite sense of displacement along part of the fault.

Strata between the Miner Lake–Beaverhead Divide fault and the concealed, northwest extension of the Bloody Dick normal fault (fig. 2) were assigned to the Mount Shields Formation of the Belt Supergroup by Ruppel and others (1993). In our interpretation, presented previously in this report, we tentatively assign these strata to the Gunsight Formation. With this interpretation, the contact of the Gunsight Formation (and other Mesoproterozoic rocks of the central Idaho sequence) with the Big Hole Divide Mesoproterozoic Belt(?) Supergroup (however tentative the correlations of these strata with the Belt may be) is entirely structural. In the Beaverhead Mountains directly west of the Leadore-Grant road (fig. 2), the Bloody Dick normal fault and the short segment of the Bloody Dick thrust fault (near where the normal fault meets the trace of the Grasshopper thrust fault) form the present southwest limit of the Grasshopper thrust sheet. The Gunsight Formation is not part of the Grasshopper thrust sheet.

Table 2. Summary of trough-crossbedding azimuths, Gunsight Formation, strata tentatively assigned to Gunsight Formation northeast of Miner Lake–Beaverhead Divide fault zone, and Belt(?) Supergroup of Big Hole Divide area, central Idaho and southwestern Montana.

[Localities shown in figure 2]

Locality No. (fig. 2)	Locality name	Vector mean in degrees	Vector magnitude (R)[1]	Rayleigh test (P)[2]	Number of vector measurements (N)[3]
			Gunsight Formation		
1	Sal Mountain	339.4	0.708	<0.01	10
2	Gunsight Peak, members B, C[4]	187.6	0.691	<0.01	24
3	Ayers Canyon	224.7	0.709	<0.01	12
	Summary	[5]213.9	0.415	<0.01	46
		Strata tentatively assigned to Gunsight northeast of Miner Lake–Beaverhead Divide fault zone			
4	Ajax Lake	325.0	0.854	<0.01	14
5	Jahnke Creek	245.0	0.539	<0.02	15
	Summary	[5]294.2	0.536	<0.01	29
		Belt(?) Supergroup, Big Hole Divide area[6]			
6	Summary	[5]232.5	0.607	<0.01	17

[1]Vector magnitude (R) represents resultant of all vectors at a locality divided by the number of measurements (N).

[2]P=probability that vector mean represents randomly oriented vectors.

[3]Vectors are azimuths of individual trough crossbeds at each station.

[4]Informal members of McBean (1983).

[5]Confidence interval at 95th percentile: Gunsight Formation, ±26.68°; Gunsight Formation northeast of Miner Lake–Beaverhead Divide fault zone, ±25.07°; Belt(?) Supergroup, Big Hole Divide area, ±28.01°.

[6]Coppinger's (1974) pre-Bonner Quartzite transitional unit (1 measurement), Bonner Quartzite (14 measurements), and post-Bonner (2 measurements).

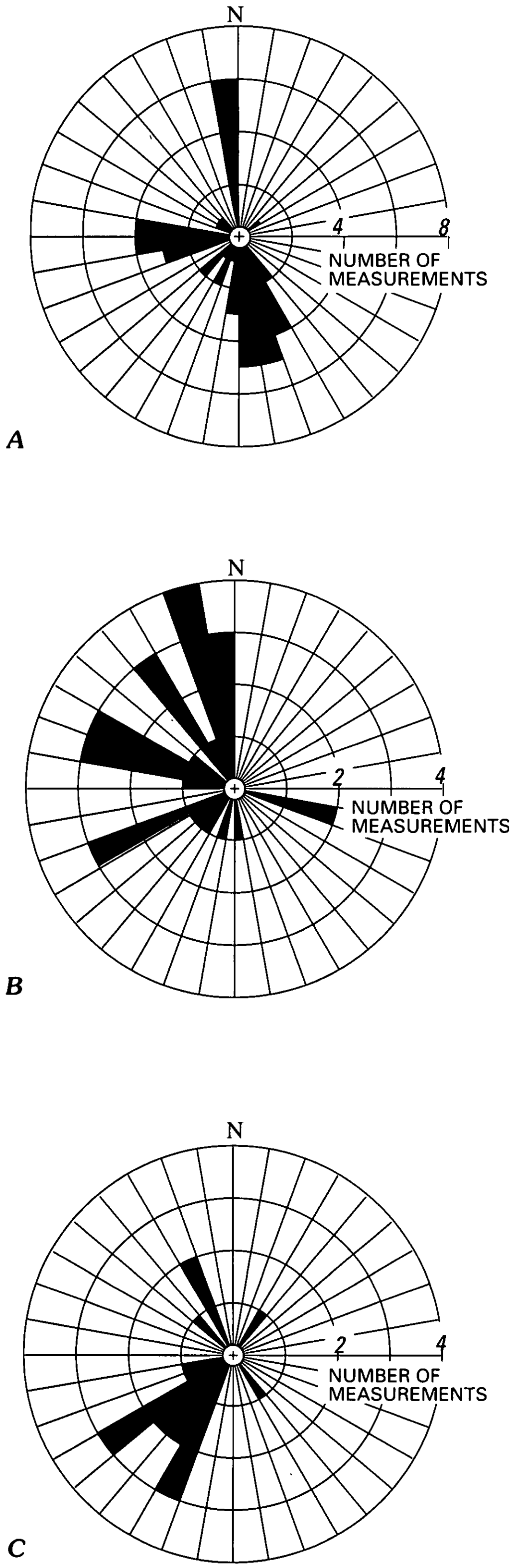


Figure 9. Summary rose diagrams of trough-crossbedding azimuths. *A*, Gunsight Formation (localities 1-3, forty-six measurements); *B*, strata tentatively assigned to the Gunsight northeast of the Miner Lake–Beaverhead Divide fault (localities 4 and 5, twenty-nine measurements); *C*, Belt(?) Supergroup of the Big Hole Divide area (locality 6, seventeen measurements).

Paleocurrents

Paleocurrent directions were determined at six localities (figs. 1, 2) in the Gunsight Formation, rocks tentatively assigned to the Gunsight Formation northeast of the Miner Lake–Beaverhead Divide fault zone, and Belt(?) Supergroup strata in the Big Hole Divide area (table 2; fig. 9). Directions were determined by measurement of trough-crossbedding (Potter and Pettijohn, 1963) axes with a Brunton compass. In the Gunsight Formation, 46 directions were obtained from Sal Mountain (locality 1), from ridges in the type Gunsight south of Gunsight Peak (locality 2), and from proximal Gunsight at Ayers Canyon (locality 3). In strata tentatively correlated with the Gunsight, located northeast of the Miner Lake–Beaverhead Divide fault zone, 29 directions were measured on mountain sides south of Ajax Lake (locality 4), and on the ridge tops on both sides of Jahnke Creek (locality 5). In the Big Hole Divide area (locality 6), crossbedding was measured in fluvial strata of the Belt(?) Supergroup on Bloody Dick Peak and mountains to the south and east.

Only trough axes whose azimuth and directional sense could be observed from foreset curvature around most of the trough were measured. Both medium- and small-scale crossbed troughs (fig. 3) were measured. In some cases, owing to conditions of exposure and precarious footing on outcrops, only general estimates of trough azimuths could be made. Such measurements were considered to be good within one quadrant (± 45°). Only one measurement per bed was recorded; multiple measurements in a single bed were combined to increase reliability and avoid overweighting from individual beds. Azimuths were rotated in the field to correct for bedding tilt. Rotation was done by aligning a field notebook parallel to bedding, aligning a pencil or compass parallel to the trough axis on the notebook, and then rotating the notebook with pencil or compass held in place by hand.

Crossbedding azimuths were summarized using vector statistics for circular normal distributions (Curray, 1956). For the three localities in the Gunsight Formation, vector means trend nearly north, west, and south (table 2; fig. 9). For the strata tentatively assigned to the Gunsight northeast of the Miner Lake–Beaverhead Divide fault zone, vector means lie in the southwestern and northwestern quadrants. The formations of the Belt(?) Supergroup of the Big Hole Divide area have a vector mean direction in the southwest quadrant, similar to that of the type Gunsight. Locality vector magnitudes range from 0.539 to 0.854, indicating consistency at the locality level, and Rayleigh tests indicate little likelihood that vector measurements were drawn from a randomly oriented population. The cause of variation among locality vector means cannot be evaluated; such variation may be caused by differences in paleocurrent directions at different stratigraphic levels, by regional differences in flow directions, or by insufficient sampling.

Summary statistics (table 2) and rose diagrams (fig. 9) of all paleocurrent azimuths in the Gunsight Formation, including the strata tentatively assigned to the Gunsight northeast of the

Miner Lake–Beaverhead Divide fault zone, indicate overall southwesterly and northwesterly streamflow during deposition. The Belt(?) Supergroup of the Big Hole Divide area shows southwesterly paleocurrent directions.

The overall pattern of paleocurrent directions toward the northwest and southwest, all measured in arkosic fluviatile strata, indicate a common source for the Gunsight Formation, including those rocks tentatively assigned to the Gunsight northeast of the Miner Lake–Beaverhead Divide fault zone, and for the Belt(?) Supergroup of the Big Hole Divide area to the east. The source must lie to the east, in the region of Archean and Paleoproterozoic gneiss in southwest Montana.

The Lemhi Group has subsequently been disrupted by Laramide thrust faulting, so that the rocks southwest of the Bloody Dick fault (including its concealed northwest extension) once were located farther southwest than the present distribution of the Lemhi Group. Similarly, the Belt(?) Supergroup strata of the Big Hole Divide were once located farther west than their present outcrop area (Ruppel and Lopez, 1984; R.G. Tysdal, K.I. Lund, and K.V. Evans, unpub. data, 2001). Fault disruption of the original depositional setting and uncertainty about the magnitude of displacement on thrust faults make precise reconstruction of the paleocurrent pattern difficult. Thus, the present distribution of locality vector means in figure 2 can only be a general picture of the original flow pattern.

Contact of Gunsight Formation with Underlying Apple Creek Formation in the Beaverhead Mountains

The Apple Creek Formation in the Beaverhead Mountains was observed mainly in reconnaissance traverses, site-specific examinations, reconnaissance mapping, and limited detailed mapping. Most of the Apple Creek strata in the Beaverhead Mountains are shown as Yellowjacket Formation on the maps of Ruppel and Lopez (1984) and Ruppel and others (1993), but their map unit includes more formations than the Apple Creek. Our changes in the formation assignments have been incorporated into the maps of the Salmon National Forest (Lund and others, 2003; Tysdal and others, 2003). Apple Creek strata in the Beaverhead Mountains have not been subdivided. In general, they resemble strata of the coarse siltite unit of the Apple Creek (Tysdal, 2000b), but beds generally are somewhat thicker and coarser grained in the Beaverhead Mountains than those present in the Lemhi Range and Salmon River Mountains (Tysdal, 2000b, 2002).

The coarsest grained unit of the Apple Creek Formation, the diamictite unit, is not known to occur in the Beaverhead Mountains. It is known only from the Lemhi Range and from a small area of the Salmon River Mountains about 15 km north of the townsite of Ellis (fig. 1). No occurrences of the diamictite were observed by the authors in the Beaverhead Mountains. K.V. Evans (oral commun., 1998) has observed strata of the banded siltite unit of the Apple Creek Formation in the drainage basin of Wagonhammer Creek (not shown in fig. 1; east of hamlet of North Fork, the stream flows about parallel to Fourth of July Creek and is about 3 km north of it).

Contact

The contact of the Apple Creek Formation with the overlying Gunsight Formation in the Beaverhead Mountains is depositional in some areas and is structural in others. The upper contact of the Apple Creek previously was interpreted as a thrust fault or system of flat thrust faults throughout central Idaho and adjacent southwestern Montana—the regionally extensive Medicine Lodge thrust fault system of Ruppel (1978) and Ruppel and Lopez (1984, 1988). At the time of their work, rocks now assigned to the Apple Creek Formation were assigned to the Mesoproterozoic Yellowjacket Formation and were interpreted as autochthonous. Overlying, younger Mesoproterozoic rocks of the Lemhi Group and post-Lemhi Group units were interpreted as allochthonous and to have been displaced northeastward above the zone of thrust faults of the Medicine Lodge thrust system.

The Medicine Lodge thrust fault was mapped originally by Kirkham (1927) southeast of the area of figure 1 and extended into the vicinity of Medicine Lodge Creek in the southeastern part of the study area (fig. 1) by Scholten and others (1955). Only a short segment of the Medicine Lodge thrust fault is shown in figure 4 because the thrust sheet delimited by the fault was subsequently overridden, and is now concealed in this area, by the more extensive Cabin thrust sheet (fig. 2). Where originally mapped the Medicine Lodge thrust placed older over younger rocks. In the vicinity of Medicine Lodge Creek, near Ayers Canyon (fig. 4), Ruppel's (1978) depiction (model) of the central Idaho–southwest Montana thrust fault system included a thrust fault that placed younger over older strata. This fault, called thrust fault D by M'Gonigle (1993; shown in fig. 4 of this report), juxtaposed Mesoproterozoic rocks over rocks as old as Paleoproterozoic rocks of the structurally lower Cabin thrust sheet.

Recent mapping (generalized map of Lund and others, 2003; K.I. Lund, unpub. mapping, 2001–2002) shows that none of the faults west of the Leadore-Grant road is continuous with, or on the same structural level as, the older-over-younger Medicine Lodge thrust fault as mapped by Scholten and others (1955) and M'Gonigle (1993) in the Beaverhead Mountains. However, in the central part of the Beaverhead Mountains, Gunsight Formation is faulted over Apple Creek strata in the arched hangingwall of the Bloody Dick thrust fault. The central part of the Beaverhead Mountains also is underlain by a structurally extended section of the Lemhi Group (not the Mesoproterozoic Yellowjacket Formation), in stratigraphic order from Apple Creek through Swauger Formations.

Observations in the central part of the Beaverhead Mountains are limited, owing to reconnaissance examination and to sparse exposures. Whether the Apple Creek–Gunsight contact is everywhere structural, or if a depositional contact occurs in some areas away from the thrust faulting, is yet to be determined. Additional field study is needed to clarify relationships.

On the west flank of the northwestern part of the Beaverhead Mountains, in the headwaters of Tower Creek (fig. 1), the geologic map of Ruppel and others (1993) showed Apple Creek strata (their Yellowjacket Formation) to be separated from overlying strata (Gunsight(?) Formation) by the Medicine Lodge thrust fault. No Apple Creek strata were observed in this area. The thrust fault shown by Ruppel and others (1993) was not found there. Further, 3 km north of the hamlet of North Fork (fig. 1) and directly east of U.S. highway 93 (in the Trail Gulch area—not shown in fig. 1), Ruppel and others (1993) again showed the Medicine Lodge thrust fault to lie between the Apple Creek (their Yellowjacket Formation) and the overlying strata. No structural contact was found in this area. Rocks exposed on the ridge crest are Apple Creek Formation; they are overlain by coarse-grained siltite to fine-grained metasandstone (Gunsight(?) Formation). The contact is interpreted to be erosional.

In the western part of the Beaverhead Mountains, the upper contact of the Apple Creek Formation also was shown as the Medicine Lodge thrust fault by Lopez (1982) and by Ruppel and others (1993), but we found no evidence of a thrust fault during reconnaissance work there.

Conclusions

The Gunsight Formation is largely composed of fluvial deposits. Fining-upward sequences of crossbedded metasandstone and siltite, abundant trough crossbedding with unidirectional paleocurrent directions, overturned crossbedding that contains heavy-mineral laminae, and a near-source facies of conglomerate all support a fluvial interpretation.

Paleocurrent directions and the regional distribution of grain size indicate that Gunsight fluvial sediment was transported northwest and southwest from the cratonic area of southwestern Montana. Silt content of Gunsight fluvial rocks increases southwestward into the Lemhi Range, and overall grain size and scale of sedimentary structures decrease southwestward. The coarsest facies, a conglomerate at Ayers Canyon in the Beaverhead Mountains, lies depositionally on Paleoproterozoic gneiss. The underlying gneiss of the craton in southwestern Montana is interpreted as source terrain for the conglomerate. The gneiss and the conglomerate of Ayers Canyon are in a thrust sheet that was displaced northeastward during Mesozoic orogeny, indicating that the basin margin originally lay southwest of the present location of these rocks. A source in quartzofeldspathic gneiss of southwestern Montana is consistent with the feldspathic composition of many Gunsight fluvial rocks (Lindsey and others, 2003).

The Apple Creek Formation, which lies beneath the Gunsight Formation throughout central Idaho and directly adjacent southwestern Montana, generally coarsens somewhat northeastward in concert with the coarsening of the Gunsight. In the western part of the Beaverhead Mountains, the contact is interpreted as erosional. In the central part of the Beaverhead Mountains, Goldstone Pass to Lemhi Pass (fig. 1), reconnaissance mapping to date (2002) has shown the contact to be structural. However, additional work is needed to determine if a nonstructural, depositional contact also exists in the area.

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