Precambrian and Lower Ordovician Rocks in East-Central Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 889

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Precambrian Y Sedimentary Rocks in East-Central Idaho
By EDWARD T. RUPPEL

Precambrian Z and Lower Ordovician Rocks in East-Central Idaho
By EDWARD T. RUPPEL, REUBEN JAMES ROSS, JR., *and* DAVID SCHLEICHER

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By EDWARD T. RUPPEL

PRECAMBRIAN AND LOWER ORDOVICIAN ROCKS IN EAST-CENTRAL IDAHO

GEOLOGICAL SURVEY PROFESSIONAL PAPER 889-A

Definition and description of newly named and revised formations deposited in the Belt miogeocline

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PRECAMBRIAN Y SEDIMENTARY ROCKS IN EAST-CENTRAL IDAHO

By EDWARD T. RUPPEL

ABSTRACT

Sedimentary rocks of Precambrian Y age in east-central Idaho crop out in a belt that reaches 150 miles (240 km) from the Snake River Plain northward to the Idaho-Montana line at Lost Trail Pass. In the northern part of this belt, the rocks are mostly fine-grained, dark-colored, micaceous, feldspathic quartzites that closely resemble and are tentatively correlated with the Yellowjacket Formation. Farther south, the Yellowjacket-like rocks are overlain by a thick sequence of lighter colored, fine-grained feldspathic quartzites and argillitic siltites of the Lemhi Group (formerly called Lemhi Quartzite) that can be separated into a number of new mappable units, and the Swauger Formation at the top. The Lemhi consists of, in ascending order, the Inyo Creek, West Fork, Big Creek, Apple Creek, and Gunsight Formations. The thickness of the Yellowjacket is not known, but probably exceeds 10,000 feet (3,050 m); the Lemhi Group is about 20,000 feet (6,100 m) thick; and the Swauger Formation is at least 10,000 feet (3,050 m) thick.

Regional considerations suggest that at least the sequence above the Yellowjacket has been moved from the original depositional area perhaps as much as 100 miles (160 km) eastward on major flat surfaces of detachment, and the entire eastern boundary of these Precambrian sedimentary rocks appears to be tectonic.

Correlation of Precambrian rocks of east-central Idaho with the better known Belt Supergroup in western Montana and northern Idaho remains tenuous because of the different characteristics of the sequences and the likelihood that they were deposited under different conditions—the Belt Supergroup in the Belt basin, and the east-central Idaho rocks in the Belt miogeocline. Therefore, the Yellowjacket, Lemhi, and Swauger are removed from the supergroup, as is the Hoodoo Quartzite of central Idaho. However, possible correlations are suggested by a few geologic events and lithologic features that seem to be represented in both sequences. The Yellowjacket and Prichard are both basal sequences that differ greatly from the overlying rocks, and are possible correlatives. The Apple Creek Formation is the only carbonate-bearing formation in east-central Idaho, and perhaps is equivalent to the middle Belt carbonate rock unit represented by the Wallace Formation and Helena Dolomite; the Inyo Creek, West Fork, and Big Creek Formations thus occupy a stratigraphic position similar to that of the Ravalli Group. The Swauger Formation differs so strikingly from the rocks of the Lemhi Group as to suggest a fundamental change in sedimentary environment, perhaps reflecting the tectonic adjustments that took place during Missoula Group deposition; the Gunsight Formation, at the top of the Lemhi Group, therefore could be equivalent to part of the Wallace Formation, and the Swauger Formation to part or all of the Missoula Group.

INTRODUCTION

The approximate distribution of slightly metamorphosed sedimentary rocks of Precambrian age in east-central Idaho and adjacent southwestern Montana has long been known, for the antiquity of at least some of these rocks was recognized in early geological studies. But the relation of these old rocks to each other and to the better known rocks of the Belt Supergroup farther north in Idaho and Montana has remained uncertain. Perhaps the most appropriate conclusion was that finally reached by C. P. Ross (1963, p. 7), that the then-known relations and correlations were tenuous, partly contradictory, and premature. To some extent, Ross' conclusions are still valid, but as a result of detailed mapping of these rocks in the central part of the Lemhi Range and reconnaissance mapping in surrounding areas, it is possible now to better define the sequence of rocks and to suggest some regional relations—even while acknowledging that my grip on some rock units is insecure and that regional correlations are still somewhat premature and will remain so until more detailed geologic mapping is available.

The Precambrian sedimentary rocks of east-central Idaho crop out in a belt that reaches about 150 miles (240 km) from the south end of the Lemhi Range at the Snake River Plain northward to the Idaho-Montana line at Lost Trail Pass—the approximate edge of the Idaho batholith. In the northern third of this belt, where it is almost 50 miles (80 km) wide, the rocks are not well known; available descriptions suggest that they are similar from one place to another and that they are mainly rather dark, fine-grained micaceous quartzites. This northern area includes the Yellowjacket mining district, one of the few northern localities where the Precambrian rocks have been divided—into the Hoodoo Quartzite and Yellowjacket Formation. Farther south, the better known Precambrian rocks in the Lemhi Range finally narrow to a strip on the west side of that range where it plunges beneath the lavas of the Snake River

Plain; the Precambrian rocks in the Lemhi Range differ considerably from those to the north. Rocks similar to some of those in the Lemhi Range also crop out north and east of Round Valley, near Challis, Idaho, in exposures that are isolated by Tertiary volcanic rocks.

Precambrian rocks extend eastward across the Beaverhead Mountains along the Idaho-Montana boundary, and reconnaissance shows that the Precambrian rocks which crop out in the Beaverhead Mountains (Ruppel, 1968) north of the village of Leadore underlie much of that range farther north (Sharp and Cavender, 1962, p. 4–8; Staatz, 1972, p. 10–15) and extend into the Big Hole Basin, which becomes a critical area indeed, for rocks more clearly identified with the Belt Supergroup in western Montana crop out at the north end of the basin. Rocks similar to those near Leadore also are known in the upper reaches of Medicine Lodge Creek and Sheep Creek along the east flank of the Beaverheads in Montana (Scholten and others, 1955, p. 353; M'Gonigle, 1965; Lucchitta, 1966). In the area west of Dillon, Mont., quartzitic rocks considered part of the Belt Supergroup are present (Myers, 1952, p. 4–6). But in the Bannack-Grayling area, Montana, 30 miles (50 km) northeast of Leadore, no sedimentary rocks of Precambrian age like those in the Beaverhead Mountains and Lemhi Range are present, and the Flathead Sandstone of Cambrian age overlies high-grade metasedimentary rocks and granite gneiss (Lowell, 1965).

Detailed geologic mapping in the Leadore, Patterson, and Gilmore quadrangles, straddling the central part of the Lemhi Range (fig. 1), has shown that the Precambrian sedimentary rocks there can be divided into six formations (four of which are new in this report) that have an aggregate thickness of more than 30,000 feet (9,150 m). These rocks are underlain by a less well known seventh unit, probably also very thick, and are overlain in places by rocks that have been described both as Cambrian and as Precambrian but are now known to be partly Early Ordovician and partly late Precambrian or Cambrian.

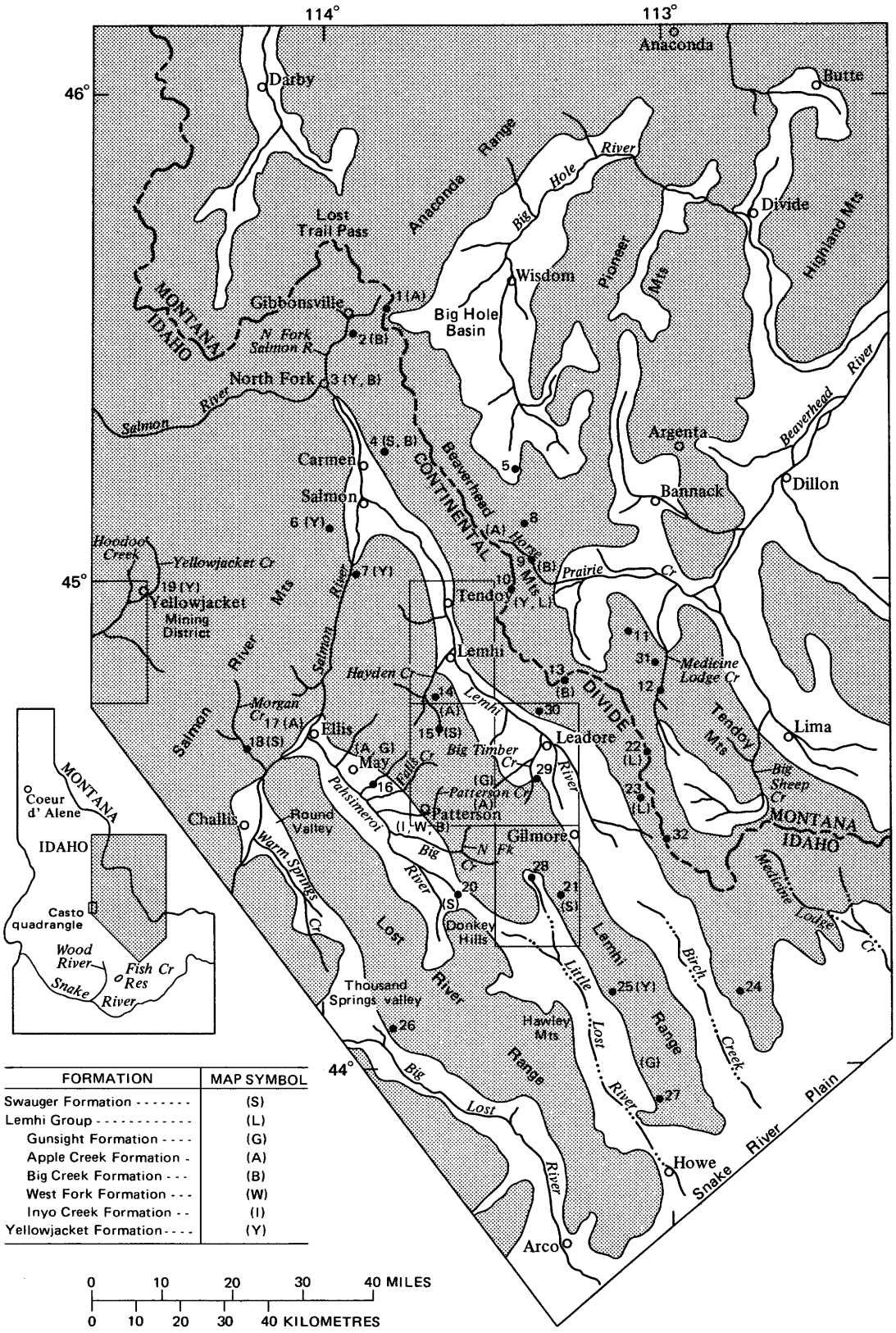
This report represents part of a more general study by the U.S. Geological Survey of the geology and mineral deposits of the central part of the Lemhi Range. In the course of my studies of the Precambrian sedimentary rocks, I have profited greatly from discussions with J. E. Harrison, M. R. Klepper, J. D. Wells, M. H. Staatz, and S. W. Hobbs, and I am indebted to them for their counsel; I am particularly indebted to J. E. Harrison for his thoughtful advice on possible correlations between the east-central Idaho rocks of Belt age but not formally part of the Belt Supergroup and those of the Belt Supergroup in western Montana.

SUMMARY OF EARLIER WORK

Sedimentary rocks of Precambrian age were first recognized in the Lemhi Range and east-central Idaho by J. B. Umpleby (1913, p. 30–32; 1917, p. 23), who assigned them to the Belt Series, and outlined their areal extent. In 1947, C. P. Ross (p. 1097–1102) named and described the Lemhi and Swauger Quartzites on the west-central flank of the Lemhi Range, formations that included part of the rocks earlier mentioned by Umpleby. A. L. Anderson (1959, p. 16–18; 1961, p. 16–21) extended these two names to include rocks in the Beaverhead and Salmon River Mountains and the northern part of the Lemhi Range. Ross (1962, p. 14) questioned these correlations, pointing out that rocks in these areas are more like the Yellowjacket Formation (Ross, 1934, p. 16–18) in the Casto quadrangle, central Idaho. Anderson (1961, p. 19–23) also named another formation in the central part of the Lemhi Range, the Apple Creek Phyllite, which he believed to be beneath the Lemhi Quartzite. Ross (1961, p. 195) extended the name Swauger from the central part of the Lemhi Range southward in a later reconnaissance study.

Thus, three formations were named to include the sedimentary rocks of Precambrian age in the central part of the Lemhi Range, in ascending order, the Apple Creek Phyllite of A. L. Anderson (1961, p. 19–23), and the Lemhi Quartzite and the Swauger Quartzite of C. P. Ross (1947, p. 1097–1102). These names were extended to Precambrian rocks in the southern Lemhi Range, in the northern part of the range, and still farther north into the Salmon River and Beaverhead Mountains; but they could not be extended far from their type areas or localities without exciting controversy. Original descriptions of these formations, and those to the west in the Casto quadrangle, are summarized in table 1.

Other rocks of Precambrian age have been described in areas near the Lemhi Range, but have not been correlated with those in the Lemhi Range. The Hyndman and East Fork Formations were described by Umpleby, Westgate, and Ross (1930, p. 9–17) in the Wood River region of central Idaho, but their relation to the less-metamorphosed rocks farther east was not discussed and remains unknown; Dover (1969, p. 24-25) considered these rocks to be most probably post-Belt in age. Scholten, Keenmon, and Kupsch (1955, p. 353) briefly described rocks in the Medicine Lodge Creek region of southwestern Montana supposed then to be equivalent to Belt rocks farther north, and pointed out that no Precambrian sedimentary rocks occur east of the Tendoy



FORMATION	MAP SYMBOL
Swauger Formation	(S)
Lemhi Group	(L)
Gunsight Formation	(G)
Apple Creek Formation	(A)
Big Creek Formation	(B)
West Fork Formation	(W)
Inyo Creek Formation	(I)
Yellowjacket Formation	(Y)

FIGURE 1.—Index map of east-central Idaho and southwest Montana, showing localities mentioned in text and outcrops of formations. Pattern indicates mountainous areas.

TABLE 1.—*Summary of previous descriptions of Precambrian sedimentary rocks of east-central Idaho*

Formation	Description
	Lemhi Range
Swauger Quartzite (Ross, 1947, p. 1097–1099; named for rocks exposed in vicinity of Swauger Ranch (fig. 1, loc. 20), Lemhi Range, Idaho, T. 11 N., R. 24 E.)	Mostly rather pure quartzite, purple to almost pure white, but with beds of green, relatively impure quartzite near base and locally higher in formation; distinctly bedded, partly cross-bedded; grain size 0.2–1.0 mm, typically <0.5 mm; feldspathic (generally <10 percent), and contains abundant fine flakes of sericite; colored by disseminated hematite dust; includes a few lenses of conglomerate and of rusty, impure dolomite; lenses of maroon, green, and brown to black argillite are most conspicuous in the lower part of the formation; thickness at least 5,000 ft (1,525 m).
Lemhi Quartzite (Ross, 1947, p. 1096–1097; named for widespread exposures in the Lemhi Range, Idaho)	Principally grayish-green impure quartzite interlayered with subordinate argillaceous beds that are darker than the quartzite; quartzite contains as much as 10 percent plagioclase, and minor amounts of sericite, chlorite, apatite, biotite, and tourmaline; grain size 0.05–0.5 mm in different beds; several thousand feet thick.
Apple Creek Phyllite (Anderson, 1961, p. 19–21; named for exposures near Apple Creek (fig. 1, loc. 14), Lemhi Range, Idaho)	Upper part is chiefly light-gray to pale-greenish-gray phyllite; lower part is dark phyllitic quartzite and interbeds of fine- to coarse-grained graywacke; thickness not given.
	Yellowjacket district
Hoodoo Quartzite (Ross, 1934, p. 18–19; named for exposures on Hoodoo Creek (fig. 1, loc. 19), Salmon River Mountains, Idaho)	Nearly white to pale-gray quartzite; bedding indistinct, but with faint laminae and small-scale crossbedding; composed of quartz (70–80 percent), and feldspar (microcline and albite), sericite, and chlorite; grain size 0.2 mm; thickness about 3,500 ft (1,070 m).
Yellowjacket Formation (Ross, 1934, p. 16–18; named for town and mining district of Yellowjacket (fig. 1, loc. 19), Idaho).	Upper quartzitic beds, about 7,000 ft (2,100 m) thick, are colored various dark shades of gray; generally argillaceous; composed of quartz (about 70 percent), biotite and chlorite (about 15 percent), and plagioclase, sericite, iron oxide, and scattered grains of epidote and zircon; average grain size about 0.1 mm. Lower beds, as much as 1,500 ft (460 m) thick (base not exposed), also dominantly quartzitic, include calcareous lenses that range from hornfelses to impure quartzites. Colors range from white, gray, and green to dark green and black; grain size of calcareous rocks 0.03–0.1 mm.

Mountains. Most other reports or geologic studies in this region describe the Precambrian sedimentary rocks only cursorily.

A sequence of sandstone, quartzite, shale, and conglomerate near the Wilbert mine (Dome mining district), in the southern part of the Lemhi Range (fig. 1, loc. 27), has been assigned to either the Precambrian or Cambrian(?) or both at different times by different writers, most recently again to the Cambrian(?) by Beutner and Scholten (1967, p. 2305–2311). The upper part of this sequence, the Summerhouse Formation, is now known to be of Early Ordovician age (Ruppel and others, chapter B, this report), and the lower part, the Wilbert Formation, probably is late Precambrian in age, perhaps equivalent to part of the Brigham Quartzite or the Windermere Group. The sequence is clearly younger than the thick group of rocks discussed in this report as equivalent to part of the Belt Supergroup; they are more fully described, and their regional relations discussed, in chapter B of this report (Ruppel and others).

PRECAMBRIAN SEDIMENTARY ROCKS IN THE LEMHI RANGE

The type localities of the Apple Creek Phyllite, Lemhi Quartzite, and Swauger Quartzite are all in the central part of the Lemhi Range (figs. 2, 3), but structural complexity in the type localities makes uncertain the identity of the formations there. Similar complexity elsewhere in the Lemhi Range has made attempts to extend these formations away from their type localities less than satisfactory. In my mapping in the central part of the Lemhi Range I have separated the Precambrian sedimentary rocks somewhat differently (table 2). I propose (1) that the Swauger Quartzite be changed to Swauger Formation to make clear its lithologic characteristics and distribution as far as known; (2) that the Lemhi

TABLE 2.—*Revised sequence of Precambrian sedimentary rocks, Lemhi Range, Idaho*

Swauger Formation:
Pale-purple to grayish-green medium-grained hematitic quartzite; maximum thickness about 10,000 ft (3,100 m)

Lemhi Group:
Gunsight Formation:
Light-brownish-gray to grayish-red-purple fine-grained feldspathic quartzite; minimum thickness about 6,000 ft (1,830 m)
Apple Creek Formation:
Grayish-green siltite containing abundant lenses of fine-grained sandstone cemented by ferrodolomite; thickness about 2,500–3,000 ft (760–900 m)
Big Creek Formation:
Greenish- to light-gray fine-grained feldspathic quartzite; thickness about 10,000 ft (3,100 m)
West Fork Formation:
Medium- to greenish-gray siltite that contains lenticular algal limestone; thickness 1,500 ft (460 m)
Inyo Creek Formation:
Medium- to light-gray fine-grained to very fine grained feldspathic quartzite, thin-bedded; thickness unknown, minimum measured thickness about 700 ft (215 m); base not exposed

Yellowjacket Formation:
Medium- to medium-dark-gray fine-grained feldspathic finely biotitic quartzite, and interbedded siltite; thickness unknown, but possibly as much as 10,000 ft (3,100 m)

Quartzite be elevated to Lemhi Group, including five formations, the Gunsight Formation, Apple Creek Formation, Big Creek Formation, West Fork Formation, and the Inyo Creek Formation, of which the Apple Creek Formation is the same as Apple Creek Phyllite of Anderson (1961) and the other formations are new; and (3) that the rocks in the lower part of the Precambrian section are part of the Yellowjacket Formation, thus extending this name from its type locality as suggested by Ross (1962, p. 14).

Taken together, the Precambrian sedimentary rocks are a sequence dominantly of feldspathic quartzites and of immense thickness. The thickness of the Yellowjacket Formation is not known with certainty but must be many thousand feet; the Lemhi Group and Swauger Formation together are more than 30,000 feet (9,150 m) thick. In general, these rocks have very little in common with the partly equivalent and much better known rocks of the Belt Supergroup farther north; the grain size of most Belt Supergroup rocks in Montana and northern Idaho is medium silt or finer (Harrison and Campbell, 1963, p. 1415), but most of the Lemhi Range rocks are composed of fine- to medium-grained feldspathic or micaceous sand. Shallow-water features—mudcracks, ripple marks, salt casts, and so on—are rare in most of the Lemhi Range rocks but fairly common farther north; many quartzite beds are laminated or cross-laminated, a few beds contain mud chips, and a few beds are ripple marked, but other sedimentary structures are rare. Stromatolites, comparatively common in Belt rocks, have been found only at two places in the Lemhi Range. Limestone and dolomite are nearly absent in the Lemhi Range section but form thick, key stratigraphic units to the north. The Precambrian sedimentary rocks of the Lemhi Range and adjacent areas in east-central Idaho and southwestern Montana thus clearly reflect a depositional environment different from that of the Belt rocks farther north.

Nevertheless, the rocks in the two regions do have features in common. Most contacts are gradational, commonly through thicknesses of many feet; and nearly identical rocks occur in different formations, and so one formation cannot always be readily and certainly distinguished from another; both groups of rocks show low-grade regional metamorphism that increases with depth in the section—biotite zone in the lower units, chlorite-sericite zone in the upper, and slight or no metamorphism at the top. Indeed, it is the occurrence of low-grade metasedimentary rocks apparently sandwiched between high-grade metamorphic rocks below and Paleozoic sedimentary rocks above, rather than lithologic similarities, that leads to the inferred correlation of the two groups of rocks.

The stratigraphic problems are further complicated in the Lemhi Range by folding that has overturned about half of the rocks, by imbricate thrust faults that shuffle upright and overturned limbs, and by other, younger faults. As a result, there are few complete sections of any of the Precambrian formations.

The principal divisions in the revised sequence of Precambrian rocks in the Lemhi Range are based on substantial and mappable differences in the character of the units. The Yellowjacket Formation, mostly quartzite, is rather dark, impure, feldspathic, and micaceous, and includes euhedral grains of magnetite. The Lemhi Group is dominantly quartzite, but generally is lighter colored and includes detrital feldspar—as much as 35 percent—and grains of black heavy minerals, mainly magnetite, but little mica and that mainly on bedding surfaces. The Swauger Formation is coarser grained than the underlying rocks, contains hematite rather than magnetite or other black heavy minerals, and contains little or no detrital feldspar and little or no mica.

YELLOWJACKET FORMATION

The rocks mapped by Ross (1947) and Anderson (1961) were studied in the central part of the Lemhi Range, and attempts to extend the formations they mapped into the northern part of the Lemhi Range were unsuccessful, and with good reason, because the rocks in the northern part of the range underlie those

exposed farther south. These underlying rocks, the lowest Precambrian sedimentary rocks exposed in east-central Idaho, are here correlated on the basis of lithologic similarity with the Yellowjacket Formation of central Idaho as defined by Ross (1934, p. 16).

The quartzite and associated rocks of the Yellowjacket Formation are the most widespread—and poorly known—of the Precambrian sedimentary rocks. The formation apparently underlies most of the northern part of the Lemhi Range, and extends farther north to the vicinity of Gibbonsville and Lost Trail Pass, where it nears the margin of the Idaho batholith. It extends westward, seemingly without a break, to the vicinity of the Yellowjacket mine, but little of this region is mapped, and the exact relations are not known. The formation also crops out in many places along the Salmon River Canyon between Salmon and Ellis (fig. 1). It apparently underlies much of the Beaverhead Mountains from Leadore northward (Sharp and Cavender, 1962, p. 5–8; Staatz, 1972) although other, younger Precambrian sedimentary rocks are present in places, too. Rocks similar to the Yellowjacket at the north end of the Lemhi Range crop out farther south in a single isolated exposure beneath a thrust fault in Squaw Creek (fig. 1, loc. 21), southwest of Gilmore, and perhaps in and near Basinger Canyon (fig. 1, loc. 25; see Umpleby, 1917, p. 23).

The thickness of the Yellowjacket is not known; the base of the formation—its lower contact with unlike sedimentary rocks or, more probably, with older Precambrian crystalline rocks—has not been found. C. P. Ross (1934, p. 16) suggested a thickness of about 9,000 feet (2,750 m) in the type locality. Anderson (1956, p. 18; 1959, p. 17; 1961, p. 23) suggested that the thickness of the rocks I include in the Yellowjacket in the Lemhi Range is at least 5,000 feet (1,500 m) and possibly as much as 10,000 feet (3,100 m). The great areal extent of these rocks suggests, too, that their thickness must be great, but any closer approximation of the actual thickness must await more complete mapping, particularly in the region west of the Lemhi Range.

The rocks above the Yellowjacket appear to differ from place to place, and the nature of the contact with overlying rocks is not well known. In the type locality, Ross (1934, p. 18–19) described the contact of the Yellowjacket with the overlying Hoodoo Quartzite as gradational. In the unmapped area southeast of Gibbonsville, Yellowjacket-like rocks are overlain by light-colored quartzite that probably is part of the Big Creek Formation named in this paper, and the contact seems to be gradational (Anderson, 1959, p. 18). Near Patterson, however, the Big Creek is underlain by more than 2,000 feet (610 m) of siltite and fine-grained quartzite; the Yellowjacket is not exposed.

The Yellowjacket Formation in the Lemhi Range is a sequence of medium-gray to medium-dark-gray, fine-grained to very fine grained, feldspathic, finely biotitic quartzite in beds commonly 0.2–2 feet (6–60 cm) thick but in places as much as 5 feet (1.5 m) thick. These rocks are partly thinly laminated, partly cross-laminated, and partly color banded in various shades of gray. The formation includes interbeds and interbedded units as much as several tens of feet thick of dark-greenish-gray to medium-dark-gray siltite and argillite in thin to medium beds, and includes beds of quartzite that are darker or lighter colored—some beds are light gray to medium light gray, and greenish-gray beds are common throughout the formation. The lighter colored rocks generally are somewhat coarser grained. The weathered rock is brownish gray and limonite stained, and generally is not well exposed but, rather, underlies smooth slopes that are littered with small rock fragments.

The micaceous quartzites of the formation are characteristically fine grained or very fine grained; the quartz grains commonly are about 0.1 mm in diameter. Studies of thin sections reported by Anderson (1959, p. 17; 1956, p. 17; 1961, p. 22) suggest that the typical rock of the formation contains 40–60 percent quartz, 20–30 percent albite, 10–20 percent biotite, 5–10 percent sericite and muscovite, and a small percentage of zircon, magnetite, tourmaline, apatite, and pyrite.

LEMHI GROUP

The Lemhi Group draws its name from the Lemhi Quartzite (Ross, 1947, p. 1096), which included impure grayish-green quartzites and lesser amounts of darker colored argillaceous rocks in the west-central part of the Lemhi Range. Although subsequent use of the name has been confused, the rocks that I include here in the Lemhi Group are essentially those originally included in the Lemhi Quartzite by Ross. The original formation is herein raised to group status and includes five formations; four are new, and the fifth, the Apple Creek Formation, is revised Apple Creek Phyllite of A. L. Anderson (1961, p. 19). The formations in the Lemhi Group are, in descending stratigraphic order:

Gunsight Formation—brownish-gray fine-grained feldspathic quartzite.

Apple Creek Formation—greenish-gray argillite, siltite, and very fine grained quartzite.

Big Creek Formation—medium- to light-gray fine-grained feldspathic quartzite.

West Fork Formation—dark-greenish-gray siltite.

Inyo Creek Formation—medium- to light-gray fine-grained to very fine grained feldspathic quartzite.

The greatest known thickness of the group is somewhat more than 20,000 feet (6,100 m) in the central part of the Lemhi Range, the only place where the Inyo Creek and West Fork Formations are known; the base of the lowest formation, the Inyo Creek, is not exposed. Farther north, along the North Fork of the Salmon River southeast of Gibbonsville, the lower two formations of the Lemhi Group are missing, and the Lemhi Group thus appears to thin to the north by nondeposition or erosion of lower units, suggesting, in turn, that the Precambrian depositional basin became deeper to the southwest.

INYO CREEK FORMATION

The lowest known formation of the Lemhi Group is the Inyo Creek Formation, a new formation here named for exposures in its type area at the head of Inyo Creek in the southern part of the Patterson quadrangle, Lemhi Range, Idaho (fig. 2). The base of the formation is cut by a fault and concealed by surficial deposits, so its relation to older rocks and its total thickness are not known. The maximum measured thickness in the type area is about 700 feet (215 m). It is overlain by the West Fork Formation; the contact is gradational through a thickness of about 100 feet (30 m), in which the Inyo Creek includes increasing numbers of thin interbeds of medium-gray to greenish-gray siltite. The contact is mapped where the siltite becomes thick bedded to massive and is the dominant rock type, but a few interbeds of quartzite similar to the Inyo Creek are present throughout the overlying West Fork Formation. The formation has been mapped only in its type area in the Patterson quadrangle and in continuous exposures for a short distance farther south along the North and West Forks of Big Creek. It has not been recognized anyplace else.

The exposed part of the Inyo Creek is mainly light-greenish-gray and medium-light-gray to medium-dark-gray, very fine grained to fine-grained, feldspathic (5–25 percent) quartzite, some beds of which are silicified and extremely hard. The formation is decidedly thin bedded; beds range from 0.5 to 5 feet (0.2–1.5 m) thick, and most are 2 feet thick or less. Some beds are finely cross-laminated, some are ripple marked, and in the lower part of the formation many beds are separated by silty partings. A few beds, also in the lower part of the formation, contain mudstone chips. Thin beds of medium-gray to greenish-gray siltite, generally only 1 or 2 feet (0.3–0.6 m) thick, are sparingly present throughout the formation and are increasingly common in the upper part where the Inyo Creek grades into the overlying West Fork. The light- and dark-colored beds of the formation, reflecting lesser or greater amounts of feldspars, sericite, and heavy minerals—principally magnetite, and in one extremely "rusty" bed, pyrite—alternate in units 10–30 feet (3–10 m) thick, and the formation gives the impression of being an alternating sequence of clean and dirty beds and groups of beds.

WEST FORK FORMATION

The West Fork Formation here is named for type exposures at the head of the West Fork of Big Creek in the southern part of the Patterson quadrangle, Lemhi Range, Idaho (fig. 2). The formation is well exposed at this locality, and the gradational nature of both its upper and lower contacts is clearly evident. Part of the formation is also exposed in a thrust plate at the junction of Patterson Creek and its East Fork—a somewhat more accessible spot about 4½ miles northwest of the type locality. It is not known at any other place. The calculated thickness of the formation is about 1,500 feet (460 m).

As described before, the contact of the West Fork Formation with the underlying Inyo Creek Formation is gradational and the basal contact of the West Fork is placed at the first thick-bedded or massive siltite, above which siltite is the dominant rock. The upper contact of the West Fork is similarly gradational into the overlying Big Creek Formation, but the gradational zone is only 25–40 feet (7–12 m) thick; the top of the West Fork is placed at the highest thick or massive bed of siltite. A few thin siltite beds occur higher, but the dominant rocks are quartzite. Below the highest massive siltite, the West Fork Formation is about 90 percent siltite and 5–10 percent very fine grained quartzite and other rocks. The upper 20 feet (6 m) or so of the formation includes thin interbeds of quartzite similar to the overlying Big Creek Formation. The siltite that makes up the bulk of the formation is medium gray to medium dark gray to dark greenish gray or blackish green, partly laminated, cross-laminated, and ripple marked. Although some beds are 0.5–3 feet (0.15–1 m) thick, particularly in the lower part of the formation, most of the formation is thick bedded to massive, and blocky fracturing. The formation includes lenticular interbeds, lenses, and well-defined heads of algal limestone—almost the only stromatolites known in the entire section of Precambrian rocks in east-central Idaho. The largest algal limestone in the type locality is 10–12 feet (3 m) thick, about 100 feet (30 m) long, and consists of yellowish-gray to light-greenish-gray, light-olive-gray-weathering, laminated sandy limestone, in beds 0.5–1 foot (0.15–0.3 m) thick, with thinner lenticular interbeds of siltite and very fine grained quartzite; some of the limestone is in characteristic rounded algal heads or domes. Although the algal lenses occur throughout

the formation, they appear to be most common in its upper part. Interbeds of light-brownish-gray to greenish-gray very fine grained to fine-grained feldspathic quartzite, typically 0.5–2 feet (0.15–0.6 m) thick, but exceptionally in units as much as 50 feet (15 m) thick, occur throughout the formation, although the thicker units apparently are mainly in the lower part. The siltite also includes some small lenses typically only a centimeter or so thick of medium sand cemented by ferrodolomite, but such lenses are unusual in the West Fork Formation, in contrast to the younger Apple Creek Formation, in which

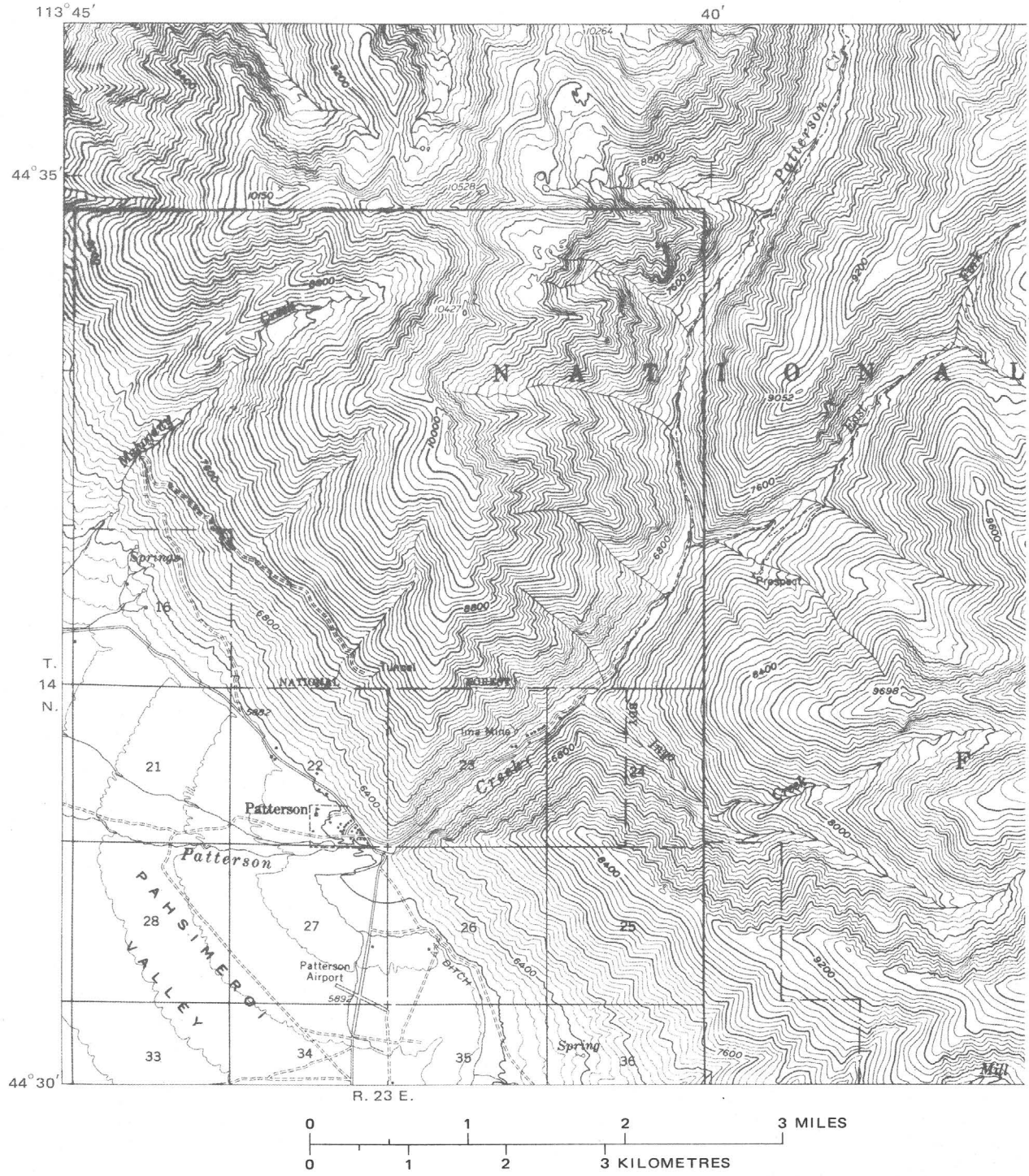
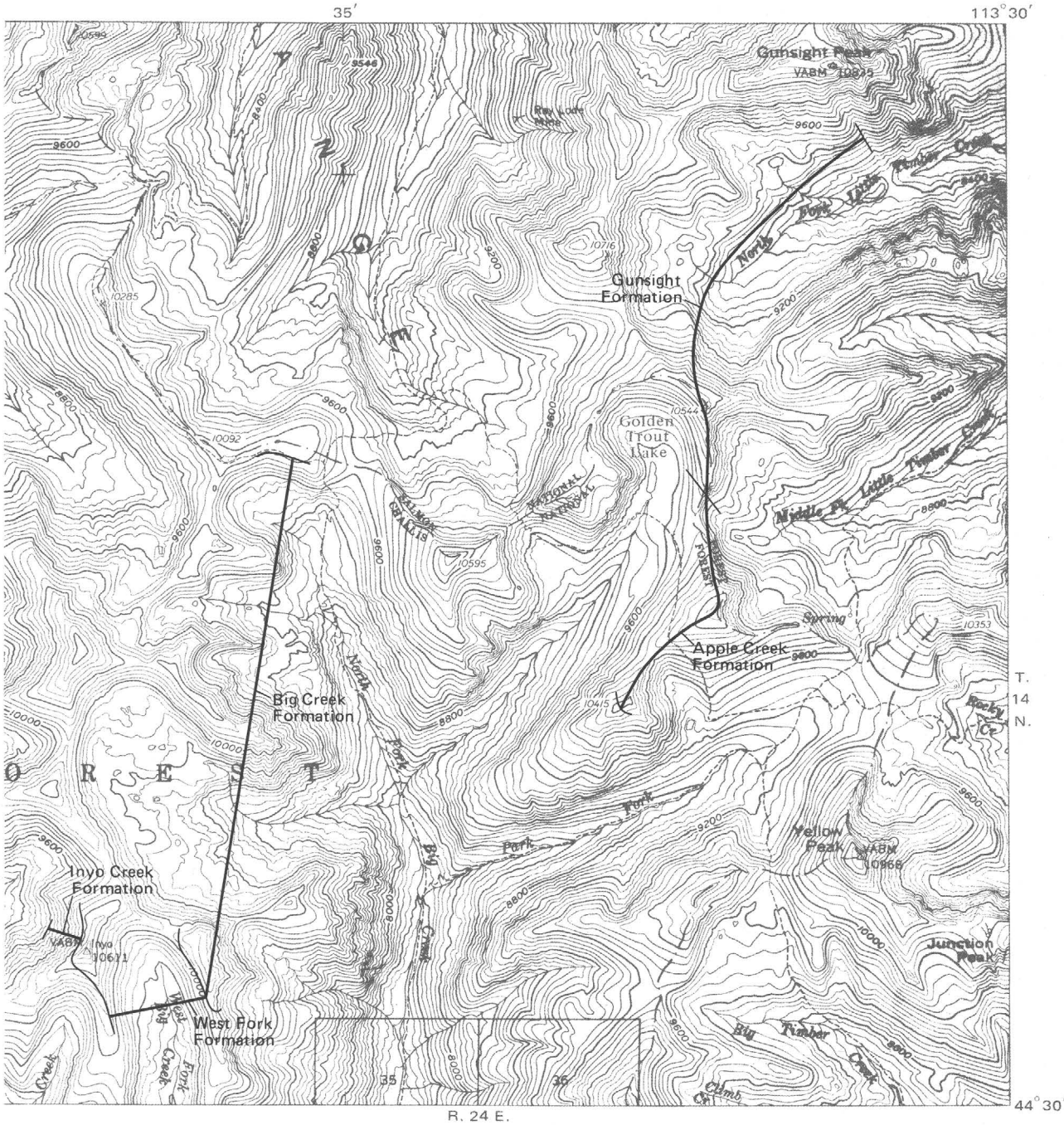


FIGURE 2.—Locations for Precambrian Inyo Creek (type area), West Fork (type locality), Big Creek (type area), Apple Creek
Survey Patterson topographic

ferrodolomite-cemented sand lenses and beds are a characteristic feature.

BIG CREEK FORMATION

The Big Creek Formation is one of the thickest and most widespread formations in the Lemhi Group. The formation is here named for outcrops in its type area along the upper reaches of Big Creek, in the south-central part of the Patterson quadrangle, Lemhi Range, Idaho (fig. 2). The formation is almost completely exposed in the ice-carved, cliffed west wall of the canyon of Big Creek and in the large, com-



(principal reference section), and Gunsight (type locality) Formations in east-central Idaho. Base from U.S. Geological quadrangle, 1956.

pound cirque above, the floor of which is mostly ice-stripped and polished bare rock, covered only by hordes of mosquitoes when they are in season. The formation crops out through the central part of the Lemhi Range from the area around and north of the mining camp at Patterson to the upper part of Sawmill canyon (fig. 1, loc. 28) at the head of the Little Lost River. It also is present in a large area in the Beaverhead Mountains, on Grizzly Hill (fig. 1, loc. 13), north of Leadore[1], and probably both north and south of there for many miles, although the Precambrian rocks of the Beaverheads have not been described for most places.

The Big Creek Formation is very thick —calculations in the type area suggest it to be about 10,000 feet (3,100 m) thick there; it is strikingly homogeneous—most of the formation is light-gray or light-brownish-gray fine-grained feldspathic quartzite. The base and top of the formation are both gradational, the base through a 25–40 foot (8–12 m) thickness from the West Fork Formation as described before, and the top through a thickness of about 150 feet (46 m) into the overlying Apple Creek formation. The upper gradational zone includes 0.1–0.2-foot (3–7 cm)-thick partings of medium-dark-gray siltite and very fine grained quartzite in its lower part; similar rocks as interbeds that progressively thicken to as much as 10 feet (3 m) are increasingly abundant in the uppermost part of the formation where it grades into the Apple Creek. The top contact is placed where the quartzite typical of the Big Creek becomes subordinate to the interbedded siltite. Most of the quartzite is pale greenish gray to light gray, weathers light brownish gray to light gray, and is fine grained (0.1–0.2 mm), moderately to strongly feldspathic (10–35 percent), and speckled with grains of iron oxide. Colors of rocks in the unit also include grayish yellow green, light olive gray, pale olive, pale red, and grayish orange pink. The rock is in beds 0.5–3 feet (0.15–1 m) thick, or massive; the upper half of the formation tends to be thicker bedded than the lower half, but thick-bedded or massive rocks are common throughout the formation. The uppermost 500 feet (150 m) is thin to medium bedded, and these uppermost beds also contain scattered chips of greenish-gray argillite and siltite, 1–2 cm in diameter. Many beds are laminated and cross-laminated; magnetite grains commonly are concentrated along the laminae, as well as being scattered through the rock.

In sharp contrast to the homogeneous feldspathic quartzite are a few layers as much as 40 feet (12 m) thick in the lower half of the formation. These layers are medium-light-gray to greenish-gray fine-grained feldspathic quartzite that contains abundant irregular lenses about 1 cm long and 5 mm thick of fine-grained quartz sandstone cemented by ferrodolomite. The sandstone weathers a striking dark yellowish brown and gives the quartzite a mottled look. The beds, 3–4 feet (1 m) thick, are strongly cross-laminated, and a few beds of pale-purple to grayish-purple quartzite are interbedded with the mottled rocks.

APPLE CREEK FORMATION

The Apple Creek Formation of this paper was originally named the Apple Creek Phyllite (Anderson, 1961, p. 19-21) for exposures in the vicinity of Apple Creek (fig. 1, loc. 14) and along Hayden Creek in the southern part of the Lemhi quadrangle, which Anderson designated as the type area. The Apple Creek Phyllite described by Anderson consisted of a lower unit of phyllitic quartzite and an upper unit entirely of phyllite; he considered these rocks to be the oldest Precambrian rocks recognized in the Lemhi Range, lying stratigraphically below the Lemhi Quartzite. However, most of the rocks that Anderson called Lemhi Quartzite are part of the Yellowjacket Formation as used in this paper, which in the Hayden Creek–Apple Creek area underlies a thrust plate of Apple Creek Phyllite; the phyllitic character of the Apple Creek is a result of shearing, and is not typical of the same formation farther south. But the formation clearly is a valid unit and is one of the most useful stratigraphic keys in the entire section of Precambrian sedimentary rocks. I propose therefore that the name be retained in modified form as the Apple Creek Formation and that the formation be revised to make clear its lithology and stratigraphic relations.

In addition to the outcrops in and near the type area in the Lemhi quadrangle, the Apple Creek Formation is widely exposed in the central part of the Lemhi Range, from the area north of Patterson southeastward into Sawmill Canyon (fig. 1, loc. 28) at the head of the Little Lost River. Some of the best partial exposures are in cliffs flanking Falls Creek and Mahogany Creek north of Patterson (figs. 1 and 2), but more accessible outcrops representative of most of the formation are at the mouth of Morse Creek where it enters the Pahsimeroi Valley (loc. 16), and along U.S. Highway 93 at Ellis, where the Pahsimeroi River joins the Salmon River (loc. 17). The entire formation is present, unfaulted, high (about 10,000 feet (3,100 m) altitude) on the ridge

[1]Precambrian rocks in the Leadore quadrangle (Ruppel, 1968) were described but not assigned to formations. The Swauger Formation of this report is unit A on the Leadore map, the Gunsight Formation is unit B, the Apple Creek Formation is unit C, and the Big Creek Formation is unit D.

between Patterson Creek and its East Fork (fig. 2), and farther east near Golden Trout Lake, where it is slightly more accessible and better exposed. The principal reference section selected here for the formation is along the crest of the ridge between Golden Trout Lake and the head of the Middle Fork of Little Timber Creek (fig. 2), in the Patterson quadrangle; it can be reached by trail from the east side of the Lemhi Range. Part of the formation is also present in thrust plates in the Mineral Hill mining area (fig. 1, loc. 30) north of Leadore (Ruppel, 1968), and reconnaissance suggests that it may be fairly widespread elsewhere in the Beaverhead Mountains.

The calculated thickness of the Apple Creek Formation in the central part of the Lemhi Range is 2,500–3,000 feet (760–900 m). The lower and upper contacts are gradational—the lower contact with the Big Creek Formation as previously described, and the upper contact into the overlying Gunsight Formation through a zone 200–300 feet (60–90 m) thick in which interbeds mostly 0.5–1 foot (0.15–0.3 m) thick of light-brownish-gray to light-gray fine-grained feldspathic, limonite-spotted and stained dirty quartzite become increasingly abundant in the siltite. The upper contact is placed at the highest bed of siltite that contains lenses of ferrodolomite-cemented sandstone, even though thin interbeds of dark-gray siltite occur higher in the overlying quartzite.

The formation includes distinctive rocks that make it the most useful and easily recognizable formation in the Lemhi Group. Siltite, the principal rock, is grayish green to grayish red purple to medium dark gray, and the darker colors commonly are tinted purple. The grayish-green siltite is typically in beds 0.2-0.5 foot (6-15 cm) thick and contains irregular streaks and lenses of light-gray, grayish-pink- to pale-brown-weathering, fine-grained sandstone that is cemented by ferrodolomite; the streaks and lenses typically are 1-2 cm thick and as much as 2 feet (0.6 m) long. A few lenses of this ankeritic sandstone are as much as 30 feet (9 m) thick and more than a hundred feet (30 m) long, but such large lenses are most exceptional. The darker gray and purplish siltite occurs mainly in the lower half of the unit, and even there is subordinate to the grayish-green rocks; it is in beds as much as 20 feet (6 m) thick, and is commonly laminated. A few beds of medium-dark-gray argillite, less than a foot thick, are in the lower part of the unit, generally associated with the gray massive siltite. All the siltite and argillite is characterized by a pencilly fracture. Quartzite is interbedded with the siltite and is itself very fine grained, in contrast to the fine- to medium-grain size in most of the other Precambrian quartzites. The rock is greenish gray to light gray, light brownish gray or pale red, feldspathic, partly cross-laminated, and is in beds 1-2 feet (0.3-0.6 m) thick. The quartzite beds are most common in the upper and lower parts of the unit, and are rare in the middle part.

Ripple marks and mudcracks are common throughout the formation; many beds are laminated or cross-laminated; and many bedding surfaces are coated by coarse detrital muscovite. The siltite locally contains sparse pyrite cubes as much as 1 mm across. Also, many of the small deposits of secondary copper minerals so common in the central part of the Lemhi Range and in the Beaverhead Mountains north of Leadore are in veins or faults that either cut the Apple Creek Formation or cut other rocks near outcrops of Apple Creek Formation; the consistent association suggests that the Apple Creek Formation may be the source of the copper.

GUNSIGHT FORMATION

The uppermost unit of the Lemhi Group, the Gunsight Formation, is named for extensive exposures in its type locality on the south and west sides of Gunsight Peak, in the central part of the Lemhi Range in the Patterson quadrangle (fig. 2); some of the best outcrops here are on the north side of the North Fork of Little Timber Creek. The formation is widely exposed from the type area westward across the Lemhi Range, and southward toward the Gilmore mining area. A well-exposed and accessible partial section that includes rocks typical of most of the formation is on the north wall of the canyon of Morse Creek (fig. 1, loc. 16), on the west side of the Lemhi Range. This section probably includes about the lower half of the formation; higher rocks are removed by faulting. The formation probably is present in places in the Beaverhead Mountains, but it has not been mapped separately there.

No complete sections of the Gunsight Formation have been found; in the Lemhi Range the rocks are everywhere cut by thrust faults, and in the eastern part of the range the formation is overlain with strong angular unconformity by the Kinnikinic Quartzite of Ordovician age. The minimum thickness of the formation estimated from the fragmented exposures is about 6,000 feet (1,830 m). The lower contact of the formation with the Apple Creek Formation is gradational through a thickness of 200-300 feet (60-90 m), as described before. In the lower 1,000 feet (300 m) of the formation the proportion of silt and argillitic beds decreases upward and the quartzite beds, 0.5-1 (15-30) cm thick, are dirty appearing, medium to light gray, fine grained, feldspathic, and limonite speckled; siltite and argillite interbeds and partings, which form almost half the basal 200-300

feet (60-90 m) of the formation, are grayish red purple to medium dark gray and platy to pencilly. The lower part of the formation includes a few massive beds 10-20 feet (3-6 m) thick, of cleaner, feldspathic quartzite like that higher in the section, and such beds contrast strikingly with the surrounding dirtier rocks.

The upper contact with overlying Precambrian rocks is also gradational; the grain size of the upper few hundred feet of Gunsight Formation coarsens upward, and so the upper rocks are medium grained, and the rocks are thick bedded to massive. The quartz grains in these upper rocks are well rounded and glassy, like those in the overlying Swauger Formation, but the rocks are feldspathic and contain abundant magnetite along laminae and cross-laminae, in contrast to the hematitic and sparsely feldspathic or nonfeldspathic rocks in the Swauger. The upper contact with the Swauger is mapped at the first beds of medium- to coarse-grained, hematitic, sparsely feldspathic or nonfeldspathic pale-red to grayish-red quartzite typical of the Swauger. A few beds of Gunsight-like quartzite are present above this contact, some in units as much as 50 feet (15 m) thick, but they clearly are subordinate. The upper contact is well exposed in the valley walls along upper reaches of Falls Creek (fig. 1), north of Patterson. Where the Swauger has been eroded away, the Gunsight is overlain by the Kinnikinic Quartzite.

Most of the Gunsight Formation is light brownish gray and medium light gray to purplish gray and grayish red purple, fine to medium grained (0.2-0.3 mm), feldspathic (5-40 percent, typically 10-20 percent), and contains abundant magnetite in rounded, detrital grains scattered through the rock and concentrated in laminae and cross-laminae. The rocks generally are thin to medium bedded (1-4 feet; 0.3-1.2 m); many beds are conspicuously laminated and cross-laminated; and many beds have been deformed by penecontemporaneous slumping. A few interbeds of grayish-yellow-green and light-olive-gray fine-grained (0.2 mm) feldspathic quartzite occur throughout the formation, which otherwise is homogeneous except for its lowermost and uppermost parts. Silty or muddy partings are also present through the formation.

The Gunsight Formation resembles the Big Creek Formation in many ways, and the two formations cannot always be distinguished with confidence. In general, though, the Gunsight is darker colored, has many beds that are tinted red or purple, is dirtier appearing, contains more magnetite and consequently is commonly limonite stained and speckled, and includes more siltite or argillite beds and partings; the Gunsight rocks tend to be dirty, the Big Creek rocks tend to be clean, but distinction between the two is not always clear.

SWAUGER FORMATION

The Swauger Formation was named for exposures in the vicinity of the Swauger Ranch (fig. 1, loc. 20) on the west side of the Lemhi Range and near the divide between the Pahsimeroi and Little Lost Rivers (Ross, 1947, p. 1096-1099), the type locality. As described by Ross, the Swauger was mainly purple to white, almost pure, medium-grained, hematitic, slightly feldspathic quartzite, a description that is appropriate for the Swauger as used here, However, the formation as originally described also included beds of impure quartzite, lenses of white quartzite, lenses of conglomerate and of rusty, impure dolomite, and beds of dark-colored argillite—rocks that mapping in the central and southern parts of the Lemhi Range indicates must belong to younger Precambrian or Lower Ordovician formations that overlie the Swauger and have been faulted into their present position in the type Swauger.

The Swauger is widely exposed in the Lemhi Range: in the type locality and in the adjacent Donkey Hills (fig. 1); farther north, in a belt that extends across the range from near Leadore (Ruppel, 1968) to east of May; along the west side of the range south of Patterson; and in a few places in the canyon of the Salmon River near Ellis (fig. 1, loc. 17). Similar rocks are exposed farther west in Morgan Creek, north of Challis (fig. 1, loc. 18) (S.W. Hobbs, 1970, oral commun.). Some of the most accessible outcrops are on Leadore Hill (fig. 1, loc. 29) near Leadore (Ruppel, 1968). Anderson (1959, p. 18-21; 1961, p. 23) suggested that the formation is also present farther north in the Lemhi Range, and in the Beaverhead Mountains. Reconnaissance studies show that the formation is indeed present in part of the northern Lemhi Range, but that the rocks Anderson called Swauger in the Beaverhead Mountains more closely resemble rocks that probably are of part of the Wilbert Formation tentatively of Precambrian Z age.

The thickness of the formation is uncertain, because no sections undisturbed by faulting are known, and because part—in places all—of the formation was eroded before deposition of the overlying rocks; it has been completely eroded in the east-central part of the Lemhi Range, and the Kinnikinic there rests on the Gunsight Formation. Ross (1947, p. 1099) stated that the exposed thickness near Swauger Ranch (loc. 20) is at least 1 mile (1.6 km); farther north, in the reference section newly designated in this report near the East Fork of Hayden Creek (loc. 15, fig. 3), the greatest thickness not cut by faults is about 10,000 feet (3,100 m) but even there the top is cut off by faulting.

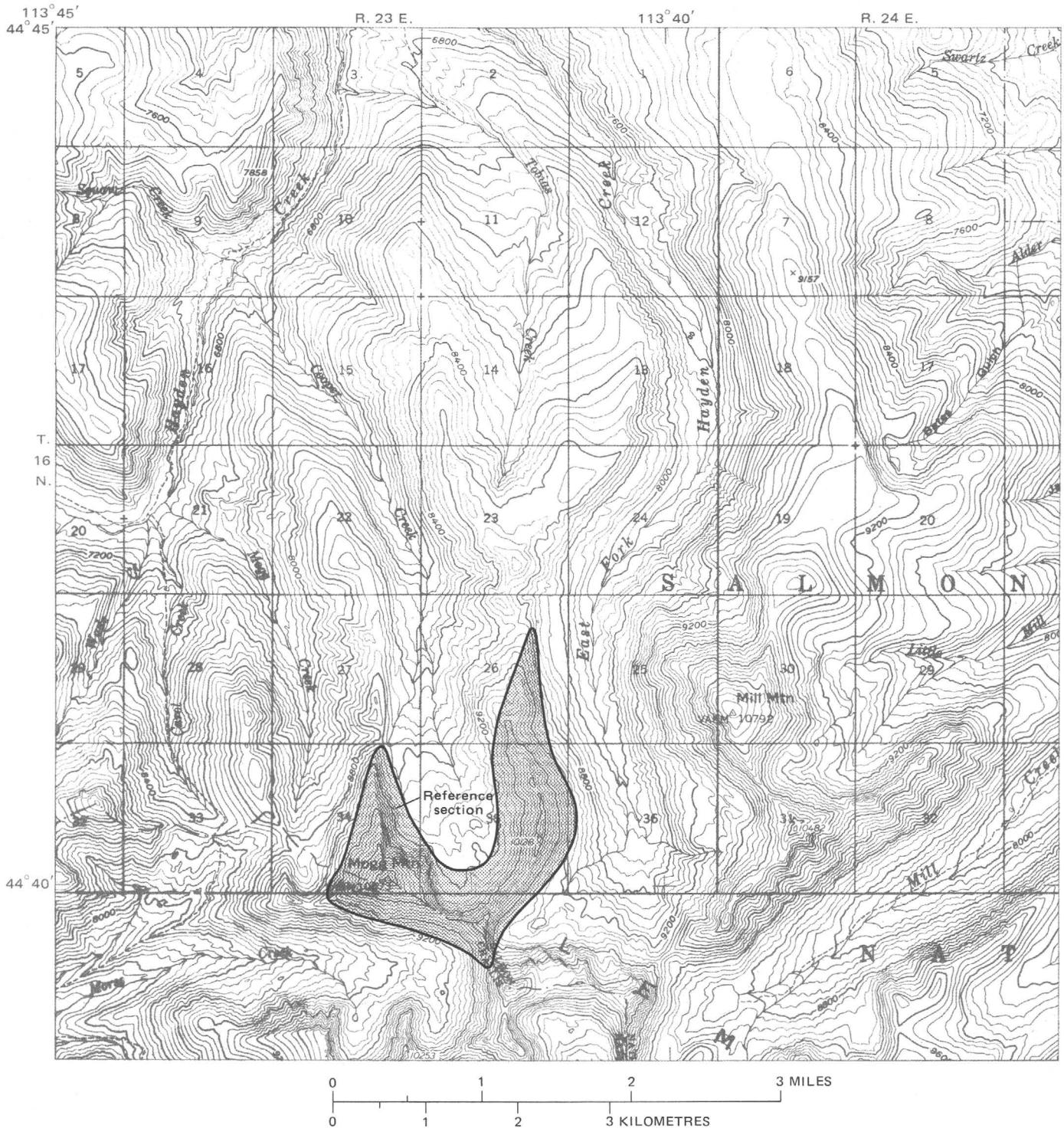


FIGURE 3.—Reference section for Precambrian Swauger Formation in east-central Idaho. Base from U.S. Geological Survey Patterson topographic quadrangel, 1956.

The lower contact of the Swauger with the Gunsight Formation is gradational through a thickness of about 150 feet (45 m), in which rocks characteristic of both formations are interbedded and, as described before, the grain size coarsens in the upper few hundred feet of the Gunsight and resembles that typical of the Swauger. The top is not known, for the Swauger is overlain with angular unconformity by the Wilbert Formation in the southern part of the Lemhi Range, by the Lower Ordovician Summer-

house Formation in the west-central part of the range and by the Middle Ordovician Kinnikinic Quartzite in the east-central part of the range. No Precambrian rocks in normal depositional contact above the Swauger are known in east-central Idaho.

The Swauger is composed of distinctive rocks that make it comparatively easy to identify, and that differ so completely from the older Precambrian quartzites as to suggest some fundamental change in depositional environment. Most of the quartzite is pale purple, grayish pink, pale red purple, or less commonly light brown to grayish green, medium to coarse grained (typically about 0.5 mm), hematitic, and only slightly feldspathic if at all. Beds are from 0.5-6 feet (0.15-1.8 m) thick, but generally are 3-6 feet (0.9–1.8 m) thick; many beds are prominently and coarsely cross-laminated, and some are ripple marked. The quartz grains are glassy, well sorted, and well rounded. Abundant hematite grains 0.5-1 mm in diameter give much of the rock a distinctive blotchy appearance as the hematite weathers and stains the surrounding quartz grains. The quartzite beds in places are separated by partings and beds 0.1-0.5 foot (3-15 cm) thick, rarely as much as 3 feet (1 m) thick, of greenish-gray to dark-grayish-green siltite or argillite; such fine-grained rocks probably are most common in the lower part of the formation, particularly in association with the interbedded Gunsight-like feldspathic quartzites near the base. The rocks of the formation thus differ from the older quartzites in their distinctive purplish color, their coarser grain size and rounded glassy quartz grains, the absence or near-absence of feldspar and black heavy minerals, and their purplish hematitic speckling and blotching.

Ross (1947, p. 1098) described the microscopic characteristics of "purple and lavender" quartzites from the type Swauger. He stated that the rocks consist mainly of quartz grains, 0.2-1.0 mm in diameter, but generally less than 0.5 mm in diameter, that are enlarged by optically oriented overgrowths. Nearly all the quartz grains show strain shadows in random orientation. Feldspar if present is generally sodic plagioclase and some microcline, and in some beds constitutes 10 percent of the rock. Scattered grains of quartzite are generally present. The matrix consists of quartz grains rarely more than 0.002 mm in diameter, and abundant fine flakes of sericite, generally not closely parallel. The color is caused by disseminated hematite dust.

My study of thin sections of Swauger from elsewhere in the Lemhi Range indicates similar petrographic features. Quartz is in grains 0.1-1 mm in diameter (typically 0.3-0.5 mm in diameter), forms 65-97 percent of the rock, is strained, and commonly is in well-rounded grains, some of which have sutured boundaries. Many quartz grains are overgrown by clear quartz in optical orientation, and some grains are crushed; grains of fine-grained quartzite are sparse (1-2 percent), but are present in most rocks. The grains generally are moderately to well sorted, but a few beds are poorly sorted, and some otherwise well sorted quartzites are bimodal in that they have distinct 0.1-mm and 0.5-mm fractions. Feldspar grains, generally completely saussuritized, are rare to absent, suggesting that the 10 percent feldspar observed by Ross may be from rocks not properly part of the Swauger. The matrix of the quartzite—a few to 30 percent—is sericite, chlorite, saussurite, and very fine grained quartz, and is squeezed around the coarser grains. Rounded detrital grains of zircon, sphene, tourmaline, and magnetite form as much as 3 percent of the rock. Hematite occurs in localized concentrations where it stains matrix and coats sand grains.

THE UNDERLYING ROCKS

Crystalline metamorphic rocks of Precambrian age, beneath the Precambrian sedimentary rocks, are not known in east-central Idaho, but such rocks do crop out in southwestern Montana, a short distance east of the Montana-Idaho line (fig. 1). The crystalline rocks have been described by Klepper (1950, p. 57–59), Scholten and others (1955, p. 350–352), Lowell (1965), Heinrich (1953, p. 1432), and M'Gonigle (1965, p. 8–15). Most of the crystalline rocks near the contact with Precambrian sedimentary rocks are granitic gneiss considered part of the Dillon Granite Gneiss of Heinrich (1953, p. 1432) and are described by M'Gonigle (1965, p. 11) as coarse-grained, light-gray to red-brown gneisses that consist of microcline (38 percent); quartz (25 percent); orthoclase (12 percent); plagioclase that is mainly oligoclase (11 percent); hornblende, pyroxene, and biotite (12 percent), and apatite, zircon, ilmenite, and leucoxene (2 percent). Scholten and others (1955, p. 351–352) stated that the most conspicuous features in almost all the rocks are cataclastic structures in quartz and feldspar, commonly accompanied by strain shadows in the quartz; perthitic, myrmekitic, and micropegmatitic intergrowths; and reaction rims around potassium feldspar and plagioclase where these are in contact.

The complex of granitic rocks, pegmatites, aplites, and quartz veins that make up the Dillon Granite Gneiss intrudes older schists and related rocks. Lowell (1965) and Scholten, Keenman, and Kupsch (1955) described these older Precambrian rocks as an interlayered sequence of schist, gneiss, marble, and metaquartzite. The schist and gneiss layers include

garnet, biotite, chlorite, and sillimanite varieties; the marble is coarsely crystalline and includes both fairly pure calcite marbles, perhaps with epidote, and impure marbles that contain abundant chrysotile and antigorite, accessory diopside, and more rarely augite, tremolite, and phlogopite.

The present contacts between Precambrian sedimentary rocks and the older crystalline rocks are faults in most places, and the location and nature of the original contact are not known. M'Gonigle (1965, p. 18-20) described Precambrian sedimentary rocks overlying Dillon Granite Gneiss in the area southeast of Maiden Peak (loc. 11); there several thin beds of arkose and arkose-conglomerate interfinger with fine-grained quartzite to the south. Angular fragments of gneiss in the conglomerate are 6-10 inches (15-25 cm) in diameter, which suggested to M'Gonigle that the source area was nearby and was of relatively great relief. McMannis (1965, p. 1803) suggested that these rocks are equivalent to the LaHood Formation (see McMannis, 1963, p. 407-436), and so are basal rocks of the Belt Supergroup. These coarse, poorly sorted rocks reflect a depositional environment, however, and not necessarily a time of deposition; correlating them with the LaHood seems premature, particularly as the Precambrian sedimentary rocks between Medicine Lodge Creek and the rocks at LaHood are poorly known, mostly not mapped, and mostly apparently different from the rocks elsewhere in east-central Idaho and southwestern Montana.

Farther south in Medicine Lodge Creek (loc. 12) the contact is concealed; it probably is a fault (Scholten and others, 1955, pl. 1). No Precambrian sedimentary rocks have been mapped in the Tendoy Mountains, east of Medicine Lodge Creek.

Sedimentary and crystalline Precambrian rocks are in contact across a fault near the mouth of Bloody Dick Creek (loc. 9). The crystalline rocks are widely exposed farther east in the Bannack-Grayling area (Lowell, 1965), but there also the relation to the Precambrian sedimentary rocks is confused by faulting. In the Argenta area, north of Bannack, Precambrian sedimentary rocks are present, but the crystalline rocks are concealed (Myers, 1952, p. 3-4). In the Highland Mountains near Butte, the basal Precambrian sedimentary rocks are conglomerate and arkose, about 5,000 feet (1,500 m) thick, considered to be part of the LaHood Formation (Sahinen, 1939, p. 13; McMannis, 1963, p. 424). Sahinen considered the contact an unconformity, but mapping by McMannis and by M. R. Klepper and H. W. Smedes (oral commun., 1971) indicates that it is a low-angle fault. A thick section of Belt rocks is preserved above the LaHood Formation.

REGIONAL TECTONIC IMPLICATIONS

The sweeping curve that outlines the Precambrian crystalline rocks of southwestern Montana and the present eastern limit of Precambrian sedimentary rocks is here interpreted as being largely or entirely tectonic in origin. In the Lemhi Range and Beaverhead Mountains, the texture, composition, and thickness of the Precambrian sedimentary rock units remain unchanged as the crystalline rocks are approached. This uniformity suggests either (1) that the Precambrian shoreline must have been farther east and that an appreciable thickness of sedimentary rocks must have been eroded before deposition of the Paleozoic sediments that now blanket the crystalline rocks, or (2) that the Precambrian sedimentary rocks were originally deposited farther to the west and have been carried eastward in thrust plates to overlap thin sedimentary deposits along the Precambrian shelf. The shelf deposits perhaps are represented by the "maroon quartzite" (Scholten and others, 1955, p. 353) in Medicine Lodge Creek and by similar rocks farther north near Bloody Dick Peak (fig. 1, east of loc. 9)—rocks that are unlike those in the Lemhi Range and the western and central parts of the Beaverhead Mountains.

The probability of significant eastward transport of Precambrian rocks is suggested by three factors that seem to be regionally significant.

1. The present eastern margin of Precambrian sedimentary rocks coincides with major zones of thrust faults, among them the Medicine Lodge thrust and related thrusts (Scholten and others, 1955, p. 381-382; Scholten, 1967, p. 9-11); thrust faults in the Bannack-Argenta area involving anomalous Precambrian rocks derived from a western source area rather than adjacent crystalline rocks (Myers, 1952, p. 4-5. 21-24); and the thrust fault recognized by Klepper and Smedes (oral commun., 1971) between the LaHood and younger Belt rocks in the Highland Mountains farther north.

2. In the central part of the Lemhi Range a major thrust fault, or detachment surface, lies beneath the complex zone of overturned folds and imbricate thrust faults that characterizes this mountain range. The detachment surface is exposed in only a few places. In these places the micaceous rocks of the Yellowjacket Formation are beneath the surface, and the adjacent rocks in the upper plate are part of the Lemhi Group, the Swauger Formation, or the Kinnikinic Quartzite and are intensely sheared and brecciated through thicknesses of hundreds of feet above the surface. Where the Kinnikinic overlies the Yellowjacket, in Squaw Creek (fig. 1, loc. 21) southwest of Gilmore, the zone of gouge and breccia is more than 400 feet (120 m) thick, and the Kinnikinic above

is shattered into a myriad of small fragments. The present mapping, only part of which is published (Ruppel, 1968), indicates that the overturned folds and imbricate thrusts are comparatively minor structural features, formed in an upper plate above a surface of detachment and major transport; the amount of displacement, from the west or southwest, is as yet unknown but may be as much as 100 miles (160 km), judged from tentative reconstructions of the edge of the Cordilleran miogeocline in Precambrian Y time[2] (fig. 4; Harrison, and others, 1974).

3. A major thurst fault has been identified by B. A. Skipp near Fish Creek Reservoir in south-central Idaho (U.S. Geol. Survey, 1972, p. A33), where rocks of differing sedimentary facies are tectonically overlapped in a manner that suggests at least several miles of displacement.

These bits of evidence from widely separated localities, combined with other studies that demonstrate widespread overturning and thrust-faulting in east-central Idaho, suggest that regional surfaces of detachment are present here, and that the Precambrian rocks, as well as younger rocks, have been carried eastward on them. The possible distance of transport, perhaps about 100 miles (160 km), is uncertain in this region of still poorly known geology, but increasingly the accumulating evidence suggests that many of the Precambrian and younger sedimentary rocks of east-central Idaho were deposited farther west, and were tectonically transported eastward in Late Cretaceous-early Tertiary time. (Regional overthrusting attributed to gravitational gliding is discussed by Scholten (1968, 1973), and Ryder and Scholten (1973).)

The extreme deformation of the Precambrian rocks and the probability of major tectonic transport obscure the nature of the depositional region. The presence of the Inyo Creek and West Fork Formations near Patterson, but not elsewhere, suggests that at least the Lemhi Group thickens to the west or southwest; and the abrupt change to Belt Supergroup rocks in western Montana in and north of the Big Hole Basin indicates that a high area separated the Belt basin from the region of sedimentation in east-central Idaho. Regional distribution patterns of Precambrian sedimentary rocks (see Harrison, 1972, figs. 1 and 2) suggest that the east-central Idaho rocks were deposited in a setting more like that of southern Canada than that of the Belt basin, that is, in the main Precambrian miogeocline rather than in an epicratonic reentrant like the Belt basin. This idea is reinforced by the presence in south-central Idaho of rocks equivalent to the Windermere System of Canada (Crittenden and others, 1971, p. 598) and the presence of rocks thought to be Precambrian Z age in the southern part of the Lemhi Range (Ruppel and others, chapter B, this report). The distribution of Precambrian Y and Precambrian Z rocks is similar in Canada and in east-central Idaho, and unlike that of rocks in the Belt basin.

[2]This term refers to an interim time scale adopted for use by the U.S. Geological Survey. Precambrian Y time is the interval between 1,600 and 800 m.y. ago and corresponds approximately to the time of deposition of the Belt Supergroup and equivalent strata in western North America. Precambrian Z time is 800–570 m.y. ago and corresponds approximately to the time of deposition of the Windermere Group and equivalent strata.

THE OVERLYING ROCKS

The Precambrian sedimentary rocks are overlain with angular unconformity by a variety of lower Paleozoic rocks. In the central parts of the Lemhi Range and Beaverhead Mountains the overlying rock is the white vitreous Kinnikinic Quartzite of Middle Ordovician age (Hobbs and others, 1968, p. J10-J12). In the south-central parts of these ranges, in the Donkey Hills and Hawley Mountains (W. J. Mapel, oral commun., 1973), and near the Elkhorn Ranch (fig. 1, loc. 26) on the west side of the Lost River Range (Baldwin, 1951, p. 887; Ross, 1947, p. 1099–1102), the mixed dolomite, sandstone, and quartzite of the Summerhouse Formation of Early Ordovician age (Ruppel and others, chapter B, this report) lies with slight angular unconformity beneath the Kinnikinic and more pronounced angular unconformity above the Precambrian rocks. And still farther south in the Lemhi Range quartz sandstone, grit, and conglomerate of the Wilbert Formation, tentatively of Precambrian Z age, lie with angular unconformity above the Precambrian Y rocks and with slight angular unconformity beneath the Summerhouse Formation; similar rocks are overlain by Devonian carbonate rocks in the southern part of the Beaverhead Mountains, but the Precambrian Y rocks are not exposed there. The regional relations of most of these rocks are discussed at length in earlier cited reports.

In southwestern Montana, east and north of the Beaverhead Mountains, the Precambrian sedimentary and crystalline rocks are unconformably overlain by rocks of Middle Cambrian age, the Flathead Quartzite or, less commonly, the Wolsey Shale (see Klepper, 1950, p. 60). Myers (1952, p. 6–7) found that the Flathead is absent, apparently by nondeposition, in much of the region southwest of Dillon, but that near Argenta it is present and abnormally thick; the Wolsey Shale apparently was deposited over most or all of the region, but was locally removed by erosion resulting from later Middle Cambrian uplift and block faulting, and development of a Middle and Upper Cambrian positive area near Bannack. A disturbance of generally similar age, called the Skull Canyon disturbance by Scholten

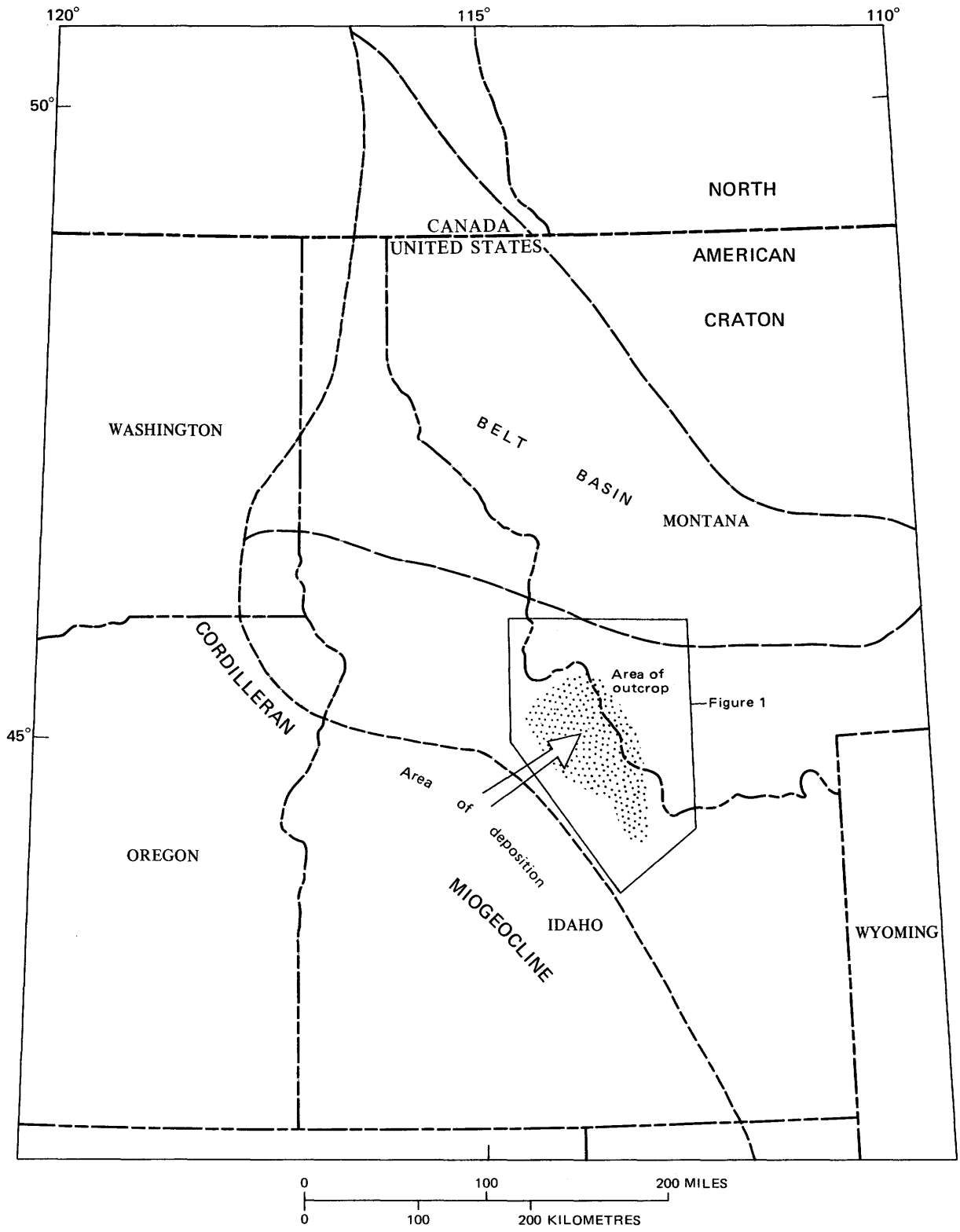


FIGURE 4.—Principal elements of the Belt basin reentrant and miogeocline, showing area of deposition of east-central Idaho Precambrian sedimentary rocks (modified from Harrison, Griggs, and Wells, 1974). Arrow shows direction of tectonic transport.

(1957, p. 165-166), is reflected by the angular unconformity between Precambrian sedimentary rocks and the Kinnikinic Quartzite in the Beaverhead Mountains. Cambrian high areas also have been described as causes of nondeposition or erosion by Sloss (1950, p. 433-434) and Sloss and Moritz (1951, p. 2139-2140).

REGIONAL CORRELATION

Correlation of the Precambrian sedimentary rocks of east-central Idaho with the rocks of the better known Belt Supergroup in west-central Montana is not possible with any certainty, and probably will remain so until geologic mapping is completed in the upper Big Hole region—a job that has only barely begun. Umpleby (1913, 1917) assigned the Idaho rocks to the Belt Series, an assignment that has been followed by later workers even though there is no real evidence, other than that the rocks look somewhat like Belt rocks and are low-grade metasedimentary rocks. But the assignment probably is correct, at least to the extent that the rocks probably are of Precambrian Y age, and the real question is what part of the Belt Supergroup, which was deposited in the Belt basin, is represented by the rocks in east-central Idaho, which were deposited in the main Cordilleran miogeocline (fig. 4).

Umpleby (1913, p. 32) suggested as a working hypothesis a broad correlation of these rocks with the Prichard Slate, Revett Quartzite and Wallace Formation as described then in the Coeur d'Alene region by Ransome and Calkins (1908, p. 25, 27), a correlation that Ross (1934, p. 19-20) later rejected. A. L. Anderson, who wrote numerous reports on areas in and near the Lemhi Range, concluded (1956, p. 18) that "direct correlation with any particular part of the Belt series is impractical, if not impossible." Ross (1962, p. 20) ultimately agreed and stated that "correlations between components of the Belt Series in south-central Idaho and * * * in northern Idaho and western Montana * * * seem premature." I can only agree with my predecessors, but would speculate, in an Umpleby-like working hypothesis, that the Yellowjacket may eventually prove to be equivalent to the Prichard, the lower part of the Lemhi Group to the Ravalli Group, the Apple Creek and Gunsight to the Helena and Wallace, and the Swauger perhaps to some part or all of the Missoula Group. These speculative correlations are based not on similar lithologies or lateral tracing, but rather on comparison of a few significant events that could have affected both the Belt Supergroup rocks in western Montana (Harrison, 1972) and the Precambrian Y sedimentary rocks in east-central Idaho. The Prichard-Yellowjacket correlation is suggested by broadly similar lithologies; by the basal position of both formations; and by lithologic changes in the overlying rocks that suggest a change in source area or environment of erosion and sedimentation, or both, and so suggest similar regional changes in depositional environment. The Apple Creek Formation is the only Precambrian formation in east-central Idaho that contains a significant amount of carbonate rock, a circumstance that suggests its possible equivalence to the middle Belt carbonate rock unit represented by the Wallace Formation and Helena Dolomite; the Inyo Creek, West Fork, and Big Creek Formations, sandwiched between the Yellowjacket and Apple Creek, thus occupy a stratigraphic position similar to that of the Ravalli Group between the Prichard and Wallace Formations. The break from fine-grained feldspathic quartzite of the Gunsight Formation to medium-grained, hematitic, nonfeldspathic quartzite of the Swauger Formation clearly reflects a major change in sedimentation and perhaps reflects the major tectonic adjustments of early Missoula time (Harrison, 1972, p. 1227); the Gunsight therefore would be equivalent to part of the Wallace Formation and possibly part of the Missoula Group, and the Swauger to part or all of the Missoula Group.

TABLE 3.—*Tentative regional correlations of Precambrian sedimentary rocks*

East-central Idaho Precambrian miogeocline		Northern Idaho-western Montana Belt basin	
Swauger Formation		Belt Supergroup	Missoula Group
Lemhi Group	Gunsight Formation		Helena and Wallace Formations
	Apple Creek Formation		
	Big Creek Formation		Ravalli Group
	West Fork Formation		
	Inyo Creek Formation		
Yellowjacket Formation			Prichard Formation

LOCAL DESCRIPTIONS AND CORRELATION NEAR THE LEMHI RANGE

As is evident from the preceding descriptions, Precambrian sedimentary rocks similar to those in the Lemhi Range are widespread in east-central Idaho and southwestern Montana. Although these rocks have been briefly described at many localities, they have been subdivided at only a few, mainly in the Beaverhead Mountains where A. L. Anderson extended the old divisions from the central Lemhi

Range, and in the Yellowjacket mining district where Ross named the Hoodoo Quartzite and Yellowjacket Formation. Only local correlations have been attempted, and most of these foundered because the rocks were so poorly known. The only generally accepted regional correlation has been that the rocks are equivalent to some unknown part of the Belt Supergroup.

The rocks at the best known of these localities are briefly described on the following pages; each locality is keyed by number to figure 1, and the principal references to earlier work, if any, are given. I have examined at least the accessible outcrops at each locality, and suggest probable correlative formations in the Lemhi Range section, but the correlations are reasonably sound only in areas adjacent to the Lemhi Range; for more distant localities, there is too much unmapped or, in terms of the Precambrian rocks, inadequately mapped intervening country, and too great a likelihood of facies changes, tectonic transport, or interfingering with other formations.

ELKHORN RANCH-SAWMILL GULCH-WEST SIDE OF LOST RIVER RANGE (loc. 26)

[Ross, 1947, p. 1099-1102; Baldwin, 1951, p. 887-889]

Hematite-flecked, pebble-bearing, light-pink to white quartzite underlying and interbedded with dark-greenish-gray to purplish laminated slate, both overlain by purple and lavender quartzite that includes thick lenses of rusty dolomite and is locally pebbly; the section includes some lenses of white, vitreous quartzite, and is about 2,000 feet (600 m) thick. These rocks unconformably underlie the Kinnikinic Quartzite.

Correlatives.—Clearly parts of the Wilbert and Summerhouse Formations, although the *Scolithid* beds in the upper part of the Summerhouse Formation apparently were removed by pre-Kinnikinic erosion.

MORGAN CREEK (loc. 18)

[S. W. Hobbs, oral commun., 1969]

Pale-red to pale-purple, medium-grained, hematitic, thick-bedded to massive, partly cross-laminated quartzite. Isolated area of outcrop surrounded by Shallis Volcanics.

Correlative.—Swauger Formation.

ELLIS, IDAHO (loc. 17)

[Ross, 1963, p. 63-68, map no. 5 (road log)]

Grayish-green mud-cracked siltite of the Apple Creek Formation, in an isolated exposure. About 1 mile (1.6 km) to the north, where the Salmon River enters a narrow canyon, the Swauger Formation is exposed in the canyon walls.

TWELVEMILE CREEK (loc. 7) AND PERREAU CREEK (loc. 6)

Medium-gray to medium-dark-gray fine-grained to very fine grained biotitic, feldspathic quartzite, and subordinate interbeds of dark-greenish-gray siltite.

Correlative.—Yellowjacket Formation.

YELLOWJACKET MINING DISTRICT (loc. 19)

[Ross. 1934. p. 15-20]

See page 4 (this report) for description of Yellowjacket Formation and Hoodoo Quartzite. The Hoodoo Quartzite is lithologically similar to the Big Creek Formation.

CARMEN CREEK (loc. 4)

[MacKenzie, 1949, p. 9-15]

MacKenzie divided the Precambrian rocks of the Carmen Creek area into quartzitic phyllite and overlying gray quartzite; the contact between the two groups of rocks is apparently gradational. The quartzitic phyllite is medium dark gray or green and fine grained (0.1-0.5 mm); it is composed of 25-60 percent quartz, 5-25 percent orthoclase, 5-25 percent sericite, 5-10 percent chlorite, 2-10 percent magnetite or ilmenite, 2-5 percent albite, and minor quantities of biotite, muscovite, leucoxene, zircon, and limonite. Most quartz grains are strained and have sutured boundaries.

The overlying gray quartzite consists of cream to gray coarse-grained quartzite that generally is prominently cross-laminated and thick bedded to massive. The grains typically are as much as 5 mm in diameter, and the rock in places is a coarse grit or conglomeratic. The rock is 50-70 percent quartz, 5-10 percent orthoclase, 5-15 percent microcline, 10-15 percent sericite, and 2-5 percent magnetite. All minerals except sericite are in rounded grains. The lower part of the unit includes lenses and interbeds of quartzitic phyllite.

Correlatives.—The quartzitic phyllite is lithologically similar to the Yellowjacket Formation. The overlying gray quartzite probably includes part of the Big Creek Formation in its lower part, and higher in the section includes parts of the Swauger Formation and of the Wilbert Formation, rocks below the Summerhouse Formation in the Lemhi Range. The description given by MacKenzie strongly suggests that the gray quartzite must include several formations.

NORTH FORK, IDAHO, AND VICINITY (loc. 3)

[Anderson, 1956, p. 16-18; 1959, p. 16-21]

As described by Anderson, the Precambrian rocks in the North Fork region are separable into two major units, a lower unit of impure dark-gray quartzite that is overlain by an upper unit of comparatively pure light-gray quartzite—a division like that made by MacKenzie in nearby Carmen Creek. The lower unit is largely rather dark-gray, fine-grained (typically about 0.1 mm), finely micaceous rusty-weathering quartzite, with some interbeds of lighter and darker colored quartzite; the rocks typically are in well-defined beds 0.1-2 feet (3-60 cm) thick, and excep-

tionally as much as 5 feet (1.5 m) thick. Some beds are laminated. Anderson describes the rocks as containing about 50 percent quartz, 30 percent albite, 12 percent biotite, 8 percent sericite and muscovite, and scattered grains of zircon, magnetite, and tourmaline.

This biotitic quartzite is gradationally overlain by lighter colored, coarser grained generally nonbiotitic quartzite through an abrupt transition zone in which both kinds of rock are interbedded; the transition zone is exposed along U.S. Highway 93 near Gibbonsville (loc. 2). The upper unit is light to medium gray and greenish gray except in its lower part, where it may be tinted red or purple, and is fine to medium grained (typically about 0.2 mm), in beds 0.5–3.0 feet (0.15–0.9 m) thick, cross-laminated and locally ripple marked and feldspathic. Anderson (1956, p. 19) gave the following composition of a rock he considered to be typical: quartz about 75 percent, albite and microcline about 15 percent, muscovite 10 percent, and accessory zircon, magnetite, and zoisite; the rocks contain virtually no biotite or chlorite. The reddish rocks in the lower part of the unit contain 50–65 percent quartz, 25–45 percent feldspar (mostly plagioclase and less abundant microcline), 3–15 percent sericite and muscovite, as much as 5 percent magnetite and hematite, and scattered grains of zircon, tourmaline, and biotite.

Correlatives.—The lower impure dark-gray quartzite is lithologically like, and clearly part of, the Yellowjacket Formation; outcrops of this formation are almost continuous from the northern part of the Lemhi Range to the vicinity of Salmon, Idaho, and from there northward along the Salmon River to the communities of North Fork and Gibbonsville.

The overlying light-gray, nonbiotitic quartzite closely resembles the Big Creek Formation, and the light-gray quartzite is overlain in Big Hole Pass (loc. 1) by rocks identical to those in the Apple Creek Formation, which overlies the Big Creek Formation in its type area. The lithologic similarity, together with the general similarity of stratigraphic sequence, supports the correlation with the Big Creek. The thickness of the light-gray quartzite probably exceeds 10,000 feet (3,100 m); Anderson (1959, p. 21) suggested more than 15,000 feet (4,600 m). The lower two formations in the Lemhi Group, the Inyo Creek and the West Fork, are not recognizable here, and apparently were not deposited.

BIG HOLE PASS (loc. 1)

Grayish-green siltite that contains irregular streaks and lenses of rusty-weathering ferrodolomite-cemented sandstone.

Correlative.—Lithologically identical to Apple Creek Formation.

HEAD OF BIG HOLE RIVER (loc. 5) AND BIG HOLE DIVIDE (loc. 8)

At the head of the Big Hole River, the rock is pale-red medium-grained feldspathic quartzite made up largely of well-rounded grains of glassy quartz. Boulders of siltite similar to the Apple Creek are common in the river gravel.

Quartzite similar to that along the upper Big Hole is widespread along the Big Hole Divide; these rocks are pale-red and grayish-red-purple to light-brownish-gray fine-grained (0.1 mm) feldspathic (15–20 percent) quartzite.

Correlatives.—In general, the rocks in the upper Big Hole are unlike any of the Precambrian sedimentary rocks farther southwest in the Lemhi Range. One possible interpretation is that these reddish feldspathic quartzites are part of the post-Belt Precambrian Z sequence represented in the Lemhi Range by the Wilbert Formation. Other interpretations are: (1) these rocks are a southern facies of the Bonner Quartzite, in the Missoula Group, or (2) they are a Precambrian Y shelf facies overridden by thrust plates containing rocks deposited in the miogeocline to the west—the most likely interpretation.

BLOODY DICK CREEK (loc. 9)

The rocks along Bloody Dick Creek and its tributary, Selway Creek, are homogeneous light-gray to light-brownish-gray, fine- to medium-grained (0.2-0.3 mm, as coarse as 0.5 mm in a few beds) feldspathic quartzite in beds 3 feet thick to massive. Quartz constitutes 60–80 percent of the rock and is in glassy, well-sorted, subrounded grains; feldspar forms 20–40 percent of the rock, and black heavy-mineral grains are present scattered through the rock and concentrated in a few laminae. The quartzite is in fault contact with Precambrian granite gneiss in the lower reaches of Bloody Dick Creek canyon. In the upper part of the canyon, near Bloody Creek Reservoir, boulders of greenish-gray siltite and brown quartzite derived from the mountains to the west are abundant in till and alluvial gravels.

Correlatives.—The composition and homogeneity of the quartzite in Bloody Dick Creek strongly suggest that it is Big Creek Formation, a correlation supported somewhat by the presence in the upper valley of the creek of boulders that closely resemble the Apple Creek Formation and Gunsight Formation, both derived from the main part of the Beaverhead Mountains to the west. The relation of these rocks in Bloody Dick Creek to the reddish and pur-

plish rocks along the Big Hole Divide a short distance to the north and east is not known.

LEMHI PASS (loc. 10)

[Staatz, 1972, p. 10–15; Sharp, and Cavender, 1962, p. 5–8; A. L. Anderson, written commun., 1965]

The Precambrian sedimentary rocks on Lemhi Pass and its approaches are mainly medium- to medium-dark-gray, fine-grained, biotitic, feldspathic quartzite and siltite; in a few places medium-light-gray rocks are present, but the predominant rocks are darker. These rocks are unlike the rocks of the central part of the Lemhi Range, but Staatz has mapped siltite and quartzite elsewhere in the Lemhi quadrangle that closely resemble formations of the Lemhi Group.

Correlatives.—The dark-colored, biotitic rocks of Lemhi Pass are much like those of the Yellowjacket Formation in the northern part of the Lemhi Range, and are virtually coextensive with them across the Lemhi Valley.

GRIZZLY HILL (loc. 13)

The Precambrian quartzite that forms the crest of Grizzly Hill, north of Leadore, is strikingly homogeneous, yellowish gray or grayish yellow green to greenish gray (with a few pale-red to grayish-red-purple interbeds) fine to medium grained (0.2–0.3 mm), feldspathic (10–20 percent est.), and partly speckled with a few percent heavy-mineral grains or their limonitic weathered residue. The quartz grains are well rounded, clear, partly glassy and partly rose colored; the feldspar is in opaque, creamy grains that typically are about 0.1 mm in diameter. Similar rocks crop out along the front of Grizzly Hill (Ruppel, 1968), where they are overlain by greenish-gray siltite that contains small lenses of ankerite-cemented sandstone.

Correlatives.—The rocks along the front of Grizzly Hill have been correlated (Ruppel, 1968) with the Big Creek Formation and Apple Creek Formation (see footnote, p. 10 this report). The rocks on top of Grizzly Hill are lithologically like the Big Creek Formation, and clearly are best correlated with that formation.

THE BEAVERHEAD MOUNTAINS SOUTH OF GRIZZLY HILL

[Lucchitta, 1966; Smith, 1961; Scholten, and Ramspott, 1968]

Precambrian sedimentary rocks are widely exposed along the crest and west side of the Beaverhead Mountains from the vicinity of Grizzly Hill (loc. 13) to their southernmost exposures in Long Canyon (loc. 24). In the Hawley Creek area (loc. 22), Lucchitta described these rocks as being mainly light-gray to pale-red, very fine to medium-grained sandstones that commonly contain oriented flakes of light-colored mica. Purplish-brown medium-grained quartzites are especially common in the upper reaches of Hawley Creek, and examination of stream boulders indicates that browninsh-gray fine-grained quartzite and greenish-gray siltite also are present. Poorly sorted medium- to very coarse grained feldspathic sandstone crops out along Meadow Creek, a tributary to Hawley Creek; the rock contains about 59 percent quartz, chert, and fragments of quartzite, 17 percent potash feldspar, 4 percent plagioclase, 7 percent fragments of schistose rocks, and 13 percent matrix, which is mainly sericite-illite. Finer grained rocks of similar composition are present along the Continental Divide nearby, and farther east in the upper part of Erickson Creek valley (loc. 31). Lucchitta described the rocks in the vicinity of Erickson Creek as being in fault contact with the Dillon Granite Gneiss, and, she noted their similarity to rocks described as basal Belt rocks by M'Gonigle a short distance to the north in Medicine Lodge Creek.

In the vicinity of Clear Creek (loc. 23) Smith described red, gray, brown and buff fine- to coarse-grained quartzose graywackes and subordinate beds of green sandstone and maroon micaceous siltstone; his descriptions suggest that the rocks closely resemble those in the Hawley Creek area (loc. 22). Farther south, in the vicinity of Eighteenmile Peak (loc. 32), Ramspott mapped purplish, reddish- or brownish- gray fine-grained feldspathic quartzitic sandstone and subordinate micaceous slaty interbeds as part of the Belt. Again, the descriptions suggest rocks much like those in Hawley Creek.

The rocks in Long Canyon (loc. 24) are medium-bedded to massive light-gray, medium-light-gray and pale-red, medium-grained (0.4–0.5 mm) feldspathic, hematitic, quartzitic sandstones that are glauconitic in the upper part of the section. The lower part of the exposed section includes thin interbeds and partings of deep maroon mudstone. The sand grains typically are glassy, well rounded to subrounded, include some rose-colored quartz, and are not well sorted; some rocks are bimodal, containing fairly well rounded larger (0.5 mm) quartz grains and less-well-rounded finer (0.2–0.4 mm) grains. Many of the rocks are gritty, and small pebbles of quartzite and shale are in some beds. Feldspar is most common in the lower part of the exposed section, where it comprises as much as 35 percent of some rocks. Heavy minerals, in rounded detrital grains, are locally abundant, particularly on cross-laminations. The rocks are in beds 1–5 feet (0.3–1.5 m) thick and are conspicuously cross-laminated and laminated. The base of the Long Canyon section is cut by a fault, and the top is an angular unconformity overlain by Ordovician and Devonian

rocks (see Scholten, 1957); the exposed section is more than 1,000 feet (300 m) thick.

Correlatives.—The variety of rocks described as Precambrian in the southern part of the Beaverhead Mountains suggests that most of the formations distinguished in the Lemhi Range are also present in the Beaverhead Mountains. Feldspathic quartzite similar to the Big Creek Formation is present along the Continental Divide northeast of Hawley Creek (loc. 22), and rocks similar to the Apple Creek Formation, Gunsight Formation, and Swauger Formation crop out in the upper reaches of Hawley Creek. The poorly sorted rocks along Meadow Creek (tributary to Hawley Creek) probably are equivalent to the Wilbert Formation, although they could instead be tongues of coarser grained rocks derived from the crystalline basement rocks to the east and interlayered in the Precambrian Y sedimentary rocks; present knowledge of the relations and distribution of the rocks does not permit any more certain understanding. The rocks in Long Canyon (loc. 24) are part of the Wilbert Formation.

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Precambrian Z and Lower Ordovician Rocks in East-Central Idaho

By EDWARD T. RUPPEL, REUBEN JAMES ROSS, JR.,
and DAVID SCHLEICHER

PRECAMBRIAN AND LOWER ORDOVICIAN ROCKS IN EAST-CENTRAL IDAHO

GEOLOGICAL SURVEY PROFESSIONAL PAPER 889-B

Definition and description of two newly recognized formations of Early Ordovician and Precambrian Z age

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PRECAMBRIAN Z AND LOWER ORDOVICIAN ROCKS IN EAST-CENTRAL IDAHO

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ABSTRACT

The sequence of calcareous sandstones, shales, and quartzitic rocks between the Middle Ordovician Kinnikinic Quartzite and Precambrian Y quartzites in east-central Idaho and southwestern Montana has been the subject of controversy since the rocks were first recognized by J. B. Umpleby. The discovery of Lower Ordovician fossils in the upper part of the sequence, coupled with recognition of angular unconformities at the base, middle, and top of the sequence, has allowed definition of two new formations—the Summerhouse Formation of Early Ordovician age, and the Wilbert Formation, tentatively of Precambrian Z age.

The Wilbert Formation is mainly brownish-gray to pale-red quartzite, grit, and conglomerate, and is 0 to about 1,000 feet (0–310 m) thick. It crops out in the southern third of the Lemhi Range and at a few places in the Lost River Range and Beaverhead Mountains, and overlies Precambrian Y quartzites with pronounced angular unconformity. Regional considerations suggest that its age is most probably Precambrian Z, equivalent to part of the Windermere System of Canada or Windermere Group of Idaho and Washington and to part of the Mutual Formation of the Brigham Group of southeastern Idaho and northeastern Utah.

The Summerhouse Formation, nearly 0 to 1,000 feet (0–310) thick, is mainly brownish- to reddish-gray, glauconitic, *Scolithus*-bearing calcareous or dolomitic sandstone, but locally includes red to gray shale and light-colored quartzite. It is present in the southern half of the Lemhi Range, and locally in the Lost River Range and Beaverhead Mountains. Both its lower contact, with Precambrian Z rocks, and its upper contact, with the Kinnikinic, are slight angular unconformities. We have found fossils of Early Ordovician age in the lower part of the formation.

INTRODUCTION

The sequence of varied rocks beneath the Kinnikinic Quartzite of Middle Ordovician age (Hobbs and others, 1968, p. J11) and above the rocks of Precambrian Y age in east-central Idaho has long been the subject of confusion and controversy. Umpleby (1917, p. 23) first described the sequence near the Wilbert mine (fig. 1, loc. 11) in the southern part of the Lemhi Range, where it consists of quartzite, shale, and conglomerate; he assigned these unnamed rocks to the Cambrian(?) and the underlying quartzitic rocks to the Precambrian. Kirkham (1927, p. 16–18) also considered the sequence at the Wilbert mine to be Cambrian(?), although he noted that parts of it were similar to rocks farther north that Umpleby had considered Precambrian (1917, p. 23). C. P. Ross (1933, p. 3–5) showed that the nearly white quartzite at the top of the sequence underlies dolomite that contains Upper Ordovician fossils, and thus he correlated the quartzite with the Kinnikinic Quartzite; he also recognized (1961, p. 199–201) that the base of the Kinnikinic in the southern Lemhi Range is an unconformity locally marked by truncation of a dolomite member at the top of the underlying beds or by slight angular discordance. Anderson (1948, p. 6–8) assigned a basal "Metamorphic series" to the Precambrian on the basis of its similarity to Precambrian rocks in the central Lemhi Range; he assigned the rocks between the metamorphic series and the Kinnikinic to the lower Paleozoic. In 1961, C. P. Ross (p. 200) reassigned all the rocks below the Kinnikinic to the Precambrian and correlated them with the Swauger Quartzite of the central Lemhi Range.

Most recently, Beutner and Scholten (1967, p. 2305–2311) reasserted the Cambrian(?) age earlier accepted by Umpleby and Kirkham for essentially the same rocks that Anderson had called lower Paleozoic. They also summarized the results of mapping by Kirkham (1927, p. 16–18), Hait (1965), and M'Gonigle (1965) to show that these rocks thin northward in the Lemhi Range to their northernmost exposures at Warm Creek (this report, fig. 1, loc. 5), and that they are present in the Beaverhead Mountains near Maiden Peak (loc. 3) and Skull Canyon (loc. 14). C. P. Ross (1947, p. 1099–1102) correlated a diverse group of somewhat similar rocks at Elkhorn Ranch on the west side of the Lost River Range (loc. 13) with those at the Wilbert mine (loc. 11), and his descriptions of rocks in the type localities of the Swauger and Lemhi Quartzites in the central Lemhi Range suggest that similar rocks occur there, too. Baldwin (1951, p. 887–889) also described the rocks on the west side of the Lost River Range but

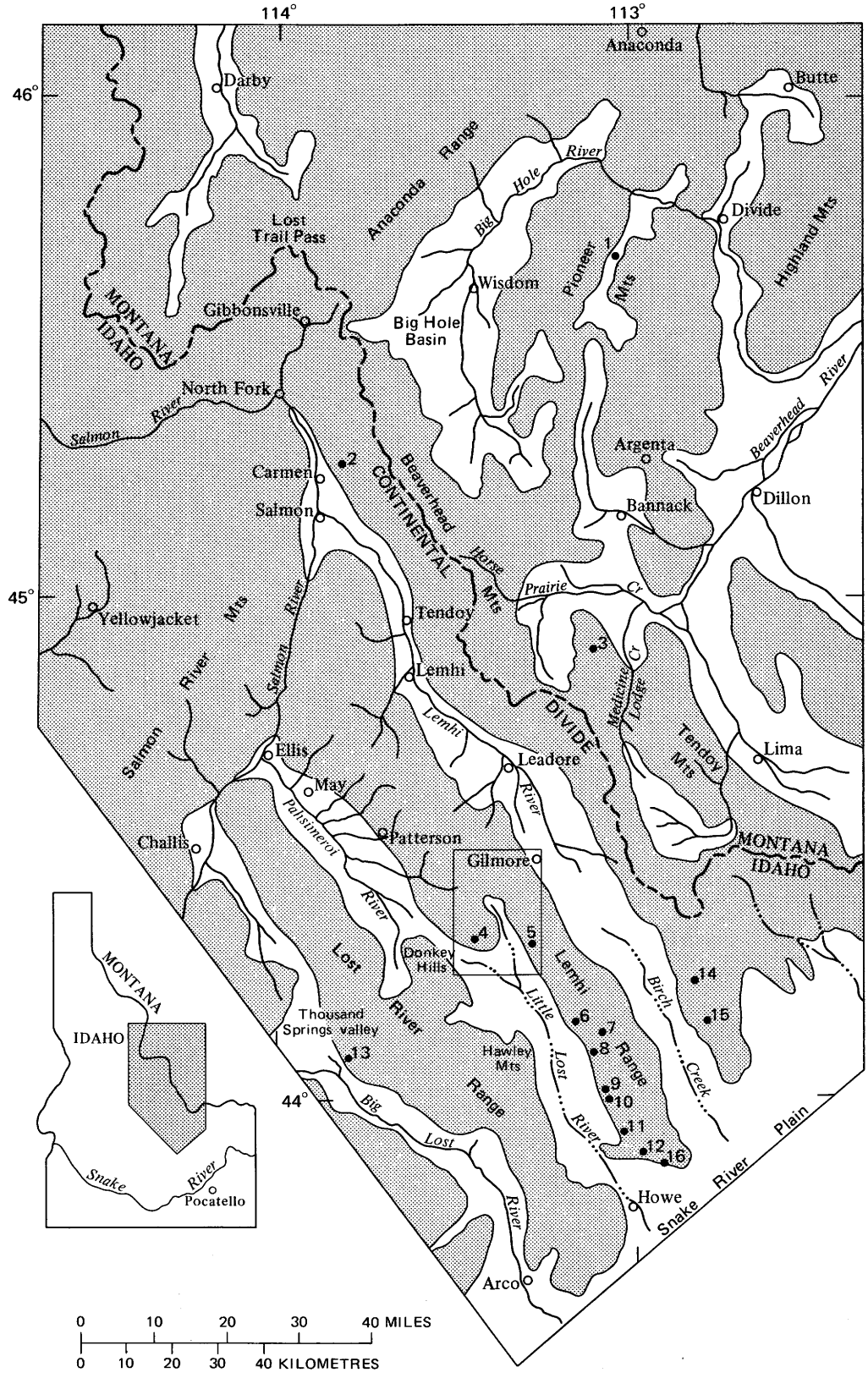

FIGURE 1.—Index map of east-central Idaho and southwest Montana showing localities mentioned in text. Pattern indicates mountainous areas.

concluded that they are probably Cambrian rather than the Precambrian age suggested by Ross. Landis (1963) described similar rocks in the Tendoy Mountains, east of the Beaverhead Mountains in Montana.

These controversial rocks extend into the central part of the Lemhi Range, where we have found Lower Ordovician fossils in the upper part of the section. As a result of this first positive indication of age and of our detailed studies in the central part of the Lemhi Range and reconnaissance studies in surrounding areas, we propose that the sequence of rocks between the Kinnikinic Quartzite and sedimentary rocks of Precambrian Y age (Ruppel, chapter A, this report) be divided into two new formations, the Summerhouse Formation of Early Ordovician age and the Wilbert Formation of probable Precambrian Z age.

WILBERT FORMATION

The Wilbert Formation is named for exposures near the Wilbert mine (loc. 11) in the southern part of the Lemhi Range. Here and in nearby South Creek (loc. 12), the type section, at least 950 feet (300 m) of dominantly gray and red quartzite, grit, and conglomerate crop out beneath the angular unconformity that separates the Wilbert Formation from the overlying Summerhouse Formation; the base of the Wilbert is cut off by a fault in South Creek, but it is well exposed near Mormon Gulch (loc. 10), where the Wilbert overlies the Precambrian Gunsight Formation (Ruppel, chapter A, this report) with angular unconformity (see Anderson, 1948, p. 8; Beutner and Scholten, 1967, p. 2307, section I).

DISTRIBUTION

Although the basal part of the Wilbert Formation in South Creek (loc. 12) is cut off by a thrust fault, and another fault cuts the sequence of rocks, this cliffed section is one of the thickest and most accessible, and it is thus designated the type section. It can be reached by a dirt road that extends eastward from the Little Lost River Highway north of Howe (fig. 1). The formation crops out farther south along the west-facing slope of the Lemhi Range almost to Black Canyon (loc. 16) (Ross, 1961, pl. 8A) and also crops out at the west end of the bedrock spur that reaches westward between South Creek (loc. 12) and North Creek (loc. 11) to the highway. To the north in the Lemhi Range, the Wilbert thins abruptly (fig. 2), but it is present at North Creek (loc. 11) (Beutner and Scholten, 1967, p. 2307, section I, unit 1), on the south slope of the valley of Uncle Ike Creek (loc. 9), and at Foss Mountain (loc. 8) (Beutner and Scholten, p. 2307, section II, unit 1). It is absent in Basinger Canyon (loc. 6) and farther north in the Lemhi Range. Similar rocks are present at Elkhorn Ranch-Sawmill Gulch (loc. 13) on the west side of the Lost River Range, where Ross (1947, p. 1099–1102) and Baldwin (1951, p. 887–889) described a hematitic, conglomeratic quartzite beneath rocks similar to those of the Summerhouse Formation. In the Beaverhead Mountains, east of the Lemhi Range, rocks like those of the Wilbert crop out in Long Canyon (loc. 15), in Skull Canyon (loc. 14) where Beutner and Scholten (1967, p. 2307) considered them part of the Belt Supergroup, and much farther north at the head of Carmen Creek (loc. 2) (MacKenzie, 1949, p. 13).

CHARACTER

The Wilbert Formation at its type section in the southern part of the Lemhi Range is about 950 feet (300 m) thick and consists mainly of brownish-gray to pale-red quartzitic fine to coarse sand, grit, or conglomerate, which commonly are poorly sorted, partly laminated and cross-laminated, and are hematitic, partly glauconitic, and partly calcareous. The upper part of the formation includes a few beds of sandy limestone and dolomite and a few of siltstone, shale, and very fine grained quartzite. A measured section of the formation at its type section at South Creek (loc. 12) is given at the end of this report. Beutner and Scholten (1967, p. 2307, section I unit 1) described the rocks at North Creek (loc. 11) as being 640 feet (200 m) thick, including a lower 250 feet (75 m) of predominantly white quartzite, overlain by 250 feet (75 m) of predominantly purple quartzite and 140 feet (45 m) of alternating purple and white quartzite; these rocks are locally gritty to conglomeratic, with white quartz pebbles as much as 1 cm in diameter. At Mormon Gulch (loc. 10), the Wilbert is about 400 feet (120 m) thick and similar to the North Creek section. At Uncle Ike Creek (loc. 9), it is about 350 feet (110 m) thick, and forms the massive ledges of crossbedded, yellowish-white and purple, rusty-weathering quartzite mentioned by Ross (1961, p. 198–199). At Foss Mountain (loc. 8), near its northern limit in the Lemhi Range, the Wilbert is about 60 feet (18 m) of mainly white quartzite with purplish lower and uppermost parts and with some grit and fine conglomerate.

The rocks at Elkhorn Ranch (loc. 13) in the Lost River Range are similar to those near the Wilbert mine (loc. 11) (Ross, 1961, p. 198), but their thickness is not known with any certainty.

At Long Canyon (loc. 15), in the southern Beaverhead Mountains, the rocks probably equivalent to the Wilbert Formation are deep-maroon and grayish-red to yellowish-gray medium- to coarse-grained poorly sorted quartzitic sandstone and grit that contain sparse pebbles, are glauconitic, prominently cross-

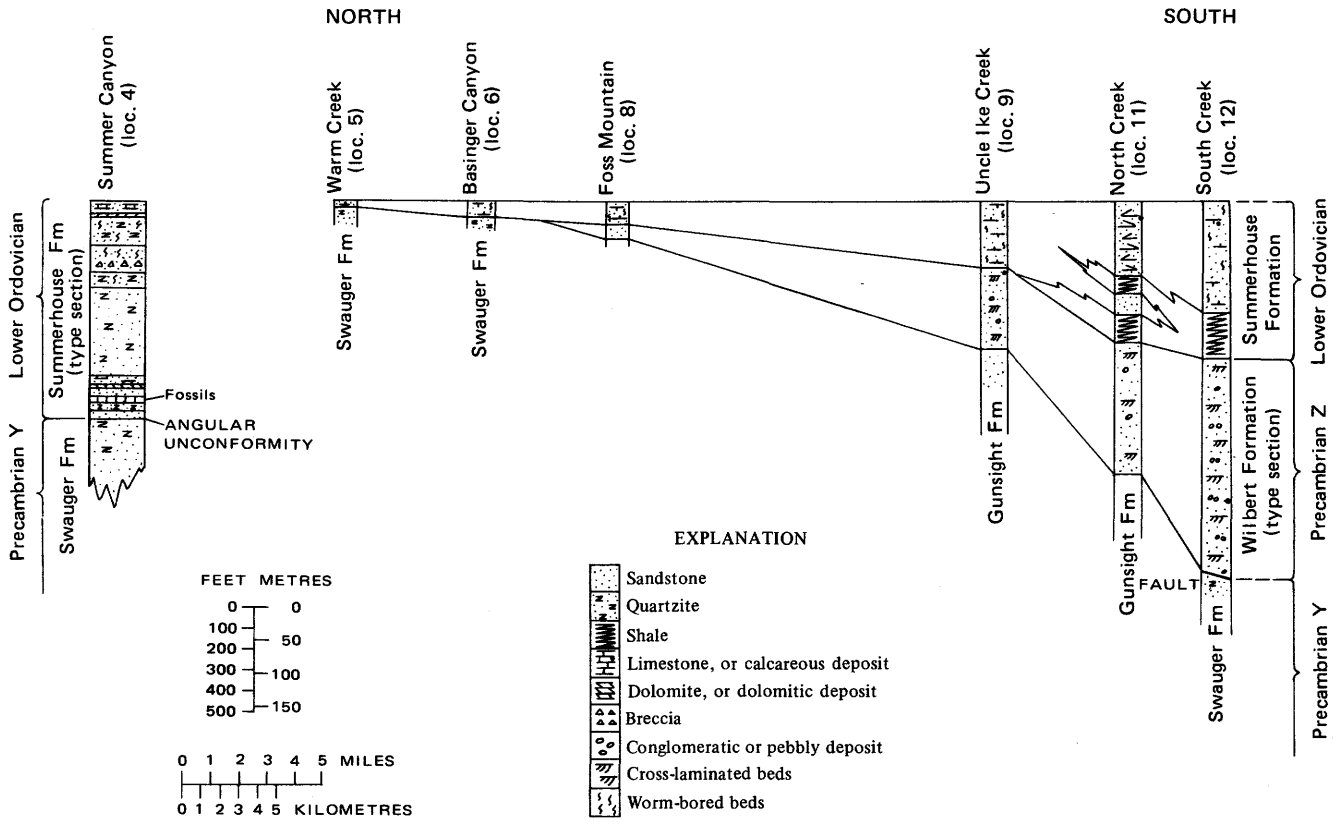

FIGURE 2.—Sketch showing northward thinning of Wilbert and Summerhouse Formations, Lemhi Range. Localities shown in figure 1.

laminated, and in beds 1-5 feet (0.3-2 m) thick; the exposed section is at least 1,000 feet (310 m) thick. The lower part of this section includes thin beds and partings of deep-maroon mudstone (Ruppel, chapter A, this report). Beutner and Scholten (1967, p. 2307) described similar rocks in the Middle Fork of Skull Canyon (loc. 14), a short distance father north; the rocks that they considered Precambrian there are most probably part of the Wilbert Formation. The Cambrian(?) rocks in their Skull Canyon section are unlike the rocks of the Summerhouse Formation that elsewhere overlie the Wilbert Formation; they appear to be a basal facies of the Kinnikinic Quartzite.

Conglomeratic and gritty rocks found at the head of Carmen Creek (loc. 2) and similar to those in the Lemhi Range were described by MacKenzie (1949, p. 13) as cream to gray quartzite that is prominently crossbedded and massive, with feldspar grains and numerous pebbles of quartz or granite (up to 4 cm in diameter) along bedding surfaces. Similar rocks near Argenta, Mont., have been assigned to the Belt Supergroup (Myers, 1952, p. 5). Conglomeratic quartzite, perhaps equivalent to the Wilbert, seems to be relatively widespread in the Wise River area (loc. 1) and elsewhere in the Pioneer Mountains of southwestern Montana.

AGE AND CORRELATION

The age of the Wilbert Formation remains somewhat in doubt, for the rocks have not yielded any fossils. The Wilbert overlies sedimentary rocks of the Gunsight Formation of Precambrian Y age (Ruppel, chapter A, this report) with strong angular unconformity in the Lemhi Range; it is overlain with slight angular unconformity by the Summerhouse Formation of Early Ordovician age, except in Skull Canyon (loc. 14) in the Beaverhead Mountains, where overlying quartzitic rocks probably are part of the Middle Ordovician Kinnikinic Quartzite; its age is thus most probably Precambrian Z and/or Cambrian. The slight angular unconformity at the top of the formation probably reflects Middle Cambrian deformation (Myers, 1952, p. 20); the much more pronounced angular unconformity at the base clearly reflects major deformation and erosion of the Precambrian Y sedimentary rocks. This unconformity represents a period of regional uplift, folding, and some faulting that ended sedimentation in the Precambrian Y miogeocline, and probably is closely related to that of the East Kootenay Orogeny in Canada about 800 m.y. ago (Gabrielse, 1972, p. 528).

The rocks of the Wilbert Formation thus seem to occupy a stratigraphic interval somewhat similar to

that of the Windermere Group (Gabrielse, 1972, p. 529) and part of the Brigham Group in southeastern Idaho and Utah (Kirkham, 1927, p. 18; Crittenden and others, 1971, p. 590; Oriel and Armstrong, 1971, p. 15–20), and the rocks lithologically most similar are those of the Mutual Formation near Pocatello, Idaho (Crittenden and others, 1971, p. 586), which farther south is included in the Brigham Group and is considered to be wholly of late Precambrian age. The Wilbert, however, is comparatively thin and lacks the assemblages of volcanic rocks[1] and the diamictites that characterize both the Windermere Group and, locally, the Mutual Formation.

We thus tentatively consider the Wilbert Formation to be entirely of Precambrian Z age, equivalent to part of the Windermere System of Canada, and part of the Mutual Formation of the Pocatello region and of the Brigham Group of northeastern Utah. The composition, generally poor sorting, abrupt and alternating changes in grain size and other textural characteristics, and lateral variability of the rocks suggest that they were deposited in a near-shore environment; the northward thinning in the Lemhi Range almost certainly reflects both onlap and Late Cambrian erosion. Regional tectonic considerations (Ruppel, chapter A, this report) suggest, however, that the shoreline must have been much farther west, and that these rocks have been carried eastward as part of large thrust plates.

SUMMERHOUSE FORMATION

The Summerhouse Formation is named here for good exposures in Summerhouse Canyon (loc. 4) in the central Lemhi Range. This is the thickest known section of the formation, and it has yielded most of the diagnostic fossils. The type section is on the east wall of Summerhouse Canyon (Gilmore quadrangle, SE¼SE¼ sec. 35, T. 12 N., R. 25 E.), and can be reached from the improved gravel highway through the Little Lost River–Pahsimeroi Valleys across Donkey Hills summit.

DISTRIBUTION

The Summerhouse Formation is widely exposed beneath the Kinnikinic Quartzite along the western slope of the Lemhi Range from Summerhouse Canyon (loc. 4) to the southern part of the range near Howe. It includes the dolomitic rocks between Summerhouse Canyon and Patterson that Ross (1947, p. 1097) included in the Swauger Quartzite. It has not been found north of Patterson in the Lemhi Range. To the west, the formation occurs around Donkey Hills summit and in the nearby Donkey Hills where it is mostly concealed by heavy float from the higher ledges of Kinnikinic Quartzite. Mapel and Shropshire (1973) mapped rocks like those of the Summerhouse beneath the Kinnikinic on the west side of the Hawley Mountains, south of the Donkey Hills. The Summerhouse also occurs in the faulted complex of rocks at Elkhorn Ranch (loc. 13) on the west side of the Lost River Range (Ross, 1947, p. 1099–1102; Baldwin, 1951, p. 887–889). Similar rocks were mapped by M'Gonigle (1965, p. 23) on Maiden Peak (loc. 3) in the central part of the Beaverhead Mountains, but are not known elsewhere in that range. Landis (1963) reported similar rocks in the northern part of the Tendoy Mountains, east of Maiden Peak.

CHARACTER

The Summerhouse Formation differs widely in thickness and lithology from place to place, mainly because it appears to represent a near-shore—perhaps lagoonal—environment and so each section reflects a different micro-environment. The resulting heterogeneity helps explain why the published descriptions of these rocks differ so widely (Anderson, 1948, p. 6–9; Ross, 1961, p. 197–199; Beutner and Scholten, 1967, p. 2307). At the risk of confusing things even more, two additional measured sections—the type section (loc. 4) and another section at South Creek (loc. 12) near the south end of the Lemhi Range—are included at the end of this report. These and other published sections show that the Summerhouse Formation does have certain characteristic features, despite its heterogeneity. The formation is below the Kinnikinic Quartzite, of Middle Ordovician age; the contact is a slight angular unconformity, as was noted by Ross (1961, p. 200). The formation overlies the Wilbert Formation with slight angular unconformity from the south end of the Lemhi Range to the point of disappearance of the Wilbert between Foss Mountain (loc. 8) and Basinger Canyon (loc. 6). Northward from there to its own point of disappearance in the central Lemhi Range, the Summerhouse rests on the Swauger Formation of Precambrian Y age with strong angular unconformity, as it does in the Donkey Hills and Hawley Mountains. In the sole known exposures in the Beaverhead Mountains, on Maiden Peak (loc. 3), the Summerhouse overlies older Precambrian Dillon Granite Gneiss of Heinrich (1953) (M'Gonigle, 1965, p. 24). Throughout this area, the Summerhouse is characterized by distinctive brownish to reddish quartzitic sandstones that are worm-bored or *Scolithus*-bearing, glauconitic, and

[1]No igneous rocks have been recognized in surface exposures of the Wilbert Formation, but C. P. Ross (1933, p. 5) described "dike rocks" in the Wilbert mine that at least partly parallel bedding, and that could be broadly interpreted as being rhyolitic tuff and basalt. Crittenden and others (1971, p. 592) stated that rhyolitic tuff and basalt occur locally in the Mutual Formation northwest of Huntsville, Utah.

calcareous or dolomitic, in places so much so that they are better described as sandy limestones and dolomites.

At the type section in Summerhouse Canyon, the Summerhouse Formation is about 1,000 feet (310 m) thick, including a lower quartzite about 60 feet (18 m) thick successively overlain by about 80 feet (25 m) of sandy, locally pebbly limestone, about 500 feet (150 m) of pink to nearly white sandstone and quartzite, about 170 feet (50 m) of yellowish-brown *Scolithus*-bearing sandstone, and about 200 feet (60 m) of pale-red to nearly white *Scolithus*-bearing sandstone. A measured section for the type section is given at the end of this report.

At South Creek, near the south end of the Lemhi Range, the Summerhouse Formation is about 700 feet (210 m) thick, and includes some rocks generally similar to those in the type section and some that are different. The lower part of the formation here, about 200 feet (60 m) thick, is mainly greenish-gray to light-gray fissile to pencilly glauconitic shale. The upper part, about 500 feet (150 m) thick, is mainly brownish, reddish, or gray dolomitic or calcareous glauconitic quartzite and well-cemented sandstone that is fine to medium grained; some beds are strongly cross-laminated, and many beds contain abundant worm tracks and *Scolithus* tubes.

The formation thins rapidly north of South Creek, to (a) 650–700 feet (200 m) at North Creek (loc. 11), where the sequence is generally similar to that at South Creek (Beutner and Scholten, 1967, p. 2307; section modified in present study), and has yielded conodonts from the lower and middle parts; (b) 250–300 feet (estimated) (75–90 m) at Uncle Ike Creek (loc. 9), where the formation is concealed; (c) about 100 feet (30 m) at Foss Mountain (loc. 8) (Beutner and Scholten, 1967, p. 2307), where the formation is wholly dolomite that is light to medium gray and pinkish gray, saccharoidal, and locally sandy; (d) 50–70 feet (15–20 m) of dolomitic sandstone in Basinger Canyon (loc. 6); and (e) 30 feet (9 m) of yellowish-brown dolomitic sandstone and sandy dolomite in Warm Creek (loc. 5). Farther north, the Kinnikinic Quartzite directly overlies Precambrian rocks, and the Summerhouse is absent. The 1,000 ft (310 m) thickness at Summerhouse Canyon, only 7 miles (11 km) west of Warm Creek, does not reflect a true stratigraphic relation, for the intervening area is one of complex normal and strike-slip faulting and of tectonic shortening on thrust faults.

The thickness of the Summerhouse Formation in the Donkey Hills is not known, for it is almost completely covered and has not been mapped. The formation at Elkhorn Ranch (loc. 13) probably is complicated by faulting, but possibly is about 600 feet (180 m) thick (Ross, 1947, p. 1099–1102; Baldwin, 1951, p. 887–889).

In the Beaverhead Mountains, the Summerhouse is about 250 feet (75 m) thick and consists mainly of medium- to coarse-grained, locally pebbly and feldspathic sandstone with many large *Scolithus*-like tubes (M'Gonigle, 1965, p. 23). The sandstone is overlain with slight angular unconformity by as much as 30 feet (10 m) of dolomite, sandy dolomite, and dolomitic limestone (Beutner and Scholten, 1967, p. 2308), beneath the Kinnikinic Quartzite.

AGE

The Summerhouse Formation has yielded distinctive fossils from the lower dolomite of the type section and from the lower and middle parts of the formation in North Creek (loc. 11).

J. W. Huddle has identified Early Ordovician conodonts from two collections made near North Creek (loc. 11) by W. H. Hays; Huddle (written commun., 1973) believes that the assemblages represent "an undescribed fauna, probably Early Ordovician in age," and that they are comparable to conodonts from the Fillmore Formation (of Hintze, 1951, 1952) of west-central Utah and the Goodwin Limestone of Nevada. These two collections are:

USGS Colln. D7504 CO. Sandy dolomite 50 ft (15 m) above base of unit, which is overlain by Kinnikinic Quartzite and underlain by white quartzite. Near middle of sec. 32, T. 8 N., R. 29 E., Idaho Falls 1:250,000 quadrangle, Idaho.

	Number of specimens
Acontiodus sp	3
Drepanodus sp	1
sp	1
sp	3
Distacodus cf. *D. stola* Lindstrom	2
Oistodus sp	2
sp	1
sp	1
Paltodus sp	1
Scandodus sp	3
sp	1
Scolopodus cf. *S. rex* Lindstrom	5
sp	2

USGS Colln. D7505 CO. Light-gray sandy dolomite about middle of the unit below the Kinnikinic Quartzite. On ridge crest near middle of sec. 32, T. 8 N., R. 29 E., Idaho Falls 1:250,000 quadrangle, Idaho.

	Number of specimens
Acontiodus sp	4
Distacodus cf. *D. stola* Lindstrom	2
Drepanodus sp	1
Drepanodus suberectus (Branson and Mehl)	1
sp	9
sp	3
Oistodus sp	4
sp	8
Scandodus sp	4
sp	2
Scolopodus cf. *S. rex* Lindstrom	24
sp	1
Ulrichodina sp.	2

Two other collections made by Hays from the same general area yielded conodonts which were identified by L. A. Wilson and are of Early Ordovician age. These collections are:

USGS Colln. D2369 CO. Light-gray dolomite, 10 ft (3 m) below base of Kinnikinic Quartzite. Near center, sec. 33, T. 8 N., R. 29 E., Idaho Falls 1:250,000 quadrangle, Idaho.
Scolopodus sp.
Oistodus lingustus Lindstrom
Drepanodus sp.
Acodus sp.

USSGS D2370 CO. Light-gray dolomite from 6 ft (2 m) below base of Kinnikinic Quartzite, on slope north of North Creek and north of newer galvanized buildings of the Wilbert mine. Near center, sec. 32, T. 8 N., R. 29 E., Idaho Falls 1:250,000 quadrangle, Idaho.
Drepanodus suberectus Branson and Mehl
Oistodus longiramis Lindstrom
lanceolatus Pander
Acontiodus sp.
Scandodus pipa Lindstrom
Oepikodus sp.
Multioistodus? sp.

A collection made by the authors and L. A. Wilson in the same vicinity yielded conodonts which Wilson identified as Early Ordovician, as follows:

USGS Colln. D2458 CO. Second brown-weathering calcareous sandstone, about 75 ft (22 m) below base of Kinnikinic Quartzite. North side of North Creek above mill buildings and sheds of Wilbert mine, near center of sec. 33, T. 8 N., R. 29 E., Idaho Falls 1:250,000 quadrangle, Idaho.
Acodus deltatus Lindstrom
Oistodus longiramis Lindstrom
sp.
Drepanodus sp.
Scolopodus rex Lindstrom
sp.

Three collections (D2305 CO, D2306 CO, D2457 CO) from Summerhouse Canyon produced a more varied assemblage that includes trilobites, brachiopods, and conodonts.

USGS Colln. D2305 CO. Summerhouse Formation, NE¼SE¼NE¼ sec. 26, T. 11 N., R. 25 E.; Idaho coordinates, central zone: E. 647,150 ft, N. 977,000 ft, Gilmore quadrangle.
Trilobite:
Asaphellus sp.
Brachiopod:
Small orthids, possibly *Nanorthis*.

USGS Colln. D2306 CO. Summerhouse Formation, SW¼NE¼ sec. 9, T. 11 N., R. 25 E.; Idaho coordinates, central zone: E. 634,900 ft, N. 960,600 ft, Gilmore quadrangle.
Trilobite:
Menoparia sp. (based on a single cranidium).

These two collections suggest an age equivalent to R. J. Ross' (1951) zone G of the Garden City Formation. The third collection (D2457 CO) seems to be somewhat younger.

USGS Colln. D2457 CO. Summerhouse Formation, about 75 ft (22 m) above pale-red quartzite of the Swauger Formation. On south side of Summerhouse Canyon, altitude 8,560 ft. SE. corner sec. 35, T. 12 N., R. 25 E. Idaho coordinates, central zone: E. 647,000 ft; N. 967,350 ft, Gilmore quadrangle.
Brachiopods:
Hesperonomia sp.
Archaeorthis? sp.
Trilobites:
Ptyocephalus sp.
Lachnostoma sp.
Proparian similar to a species identified by Hintze (1952) as *Pseudomera* cf. *P. insolita.*
Conodonts (identified by L. A. Wilson):
Scandodus pipa Lindstrom
Drepanodus homocurvatus Lindstrom
sp.
Oistodus inaequalis Pander
Paltodus sp.

The trilobites and brachiopods indicate an age approximately equal to zone J of R. J. Ross (1951) and the conodonts do not contradict this indication.

CORRELATION

The Summerhouse Formation is of Early Ordovician age. It is the first stratigraphic unit (other than graptolitic shales of the lower part of the Phi Kappa Formation) of Early Ordovician age reported in east-central Idaho.

Its nearest correlative is part of the Garden City Formation, south of the Snake River Plain in southern Idaho and northern Utah.

MEASURED SECTIONS

Type section of Summerhouse Formation, Summerhouse Canyon (fig. 1, loc. 4), Lemhi Range, Gilmore quadrangle, Idaho

[SE¼SE¼ sec. 35, T. 12 N., R. 25 E., and SW¼SW¼ sec. 36, T. 12 N., R. 25 E]

	Thickness (feet)
Kinnikinic Quartzite (Middle Ordovician):	
Light-gray to white vitreous quartzite	Not measured
Angular unconformity.	
Summerhouse Formation (Lower Ordovician):	
13. Partly concealed; light-gray and pale-red, fine-grained dolomitic sandstone that contains abundant *Scolithus* tubes in some beds	66
12. Partly concealed; medium-gray fine crystalline dolomite	11
11. Partly concealed; very light gray, fine-grained to very fine grained quartzite, beds about 0.5 ft thick, includes a few thin beds of pale-red quartzite; *Scolithus* tubes abundant in some beds	117
10. Sandstone, yellowish-brown, fine-grained, slightly calcareous, glauconitic, with sparse 1-ft-thick interbeds of pale-red to grayish-red fine- to medium-grained quartzite; *Scolithus* tubes abundant in some beds; breccia zone 1 ft thick 35 ft above base of unit	124

Summerhouse Formation—Continued	Thickness (feet)
9. Quartzite, light-gray, fine-grained	5
8. Sandstone, similar to unit 10 above	7
7. Interbedded sandstone and quartzite in gradational zone from quartzites below to sandstones above; yellowish-brown fine-grained slightly calcareous sandstone becomes dominant rock in upper part of unit; light-gray, fine- to medium-grained blocky-fracturing quartzite is dominant in lower part of unit; beds 1 to 2 ft thick; *Scolithus* tubes in some beds	36
6. Quartzite, very light gray, and irregularly interbedded pale red to grayish pink; fine to medium grained; beds 1 to 3 ft thick, blocky fracturing; sand grains well sorted, well rounded; includes sparse lenses 1 to 2 ft thick and as much as 5 ft long of limonite-cemented fine-grained sandstone	407
5. Partly concealed; interbedded yellowish-orange dolomite and siliceous dolomite, and light-gray fine-grained quartzite; gradational into overlying quartzite unit	49
4. Dolomite, medium-light-gray, fine crystalline; beds 0.5 to 1 ft thick	12
3. Sandstone, light-brownish-gray to pale-red, fine-grained, calcareous; sand grains well sorted, well rounded, quartz; hematitic cement, mottles, and laminae; beds 1 ft thick; blocky fracturing; includes white sandstone lenses to 0.4 ft thick	30
2. Limestone and dolomite, light-olive-gray to medium-gray, weathers yellowish gray to yellowish brown with siliceous laminae in relief; reddish brown at base; silty, becoming sandy or calcareous sandstone in upper part of unit, with fine well-rounded quartz grains; locally pebbly; beds 1–2 ft thick; contains interbeds up to 0.5 ft thick of light-gray to grayish-red fine-grained quartzite; upper 10–15 ft contains lenses of white chert to 2 cm thick, 10 cm long; fossiliferous	78
1. Quartzite, light gray to yellowish gray, fine to very fine grained, vitreous, blocky-fracturing, lenticular, poorly exposed; grains well sorted, well rounded; sparse grains of hematite; beds 3–10 ft thick; limonite stained; includes a few thin beds of grayish-red, fine-grained quartzite; lowermost beds have limonite and hematite-rich laminations a few mm thick; uppermost beds strongly hematitic	61
Thickness of Summerhouse Formation	1003

Angular unconformity.

Swauger Formation (Precambrian):	
Quartzite, pale-red to grayish-red, medium-grained; quartz grains well rounded, glassy	Not measured

Composite measured section of Summerhouse and Wilbert (type section) Formations, South Creek (fig. 1, loc. 12), southern Lemhi Range, Idaho

	Thickness (feet)
Kinnikinic Quartzite (Middle Ordovician):	
Quartzite, light-gray, vitreous	Not measured
Angular unconformity.	
Summerhouse Formation (Lower Ordovician):	
32. Sandstone, grayish-orange-pink to pale-yellowish-brown, weathers same color, fine to medium grained (0.2–0.4 mm); grains subround to subangular; strongly calcareous; glauconitic; many beds contain worm tubes; partly cross-laminated. Very similar to units 25–28 below	125
31. Quartzite, light-gray, weathers same color, medium to fine grained (0.2–0.4 mm), feldspathic; beds 2–3 ft thick	25
30. Quartzite, dark-grayish-red, weathers same color, fine-grained (0.1), massive thinly laminated (0.1 mm) calcareous, hematitic, glauconitic	30
29. Sandstone, medium-brown to grayish-red, weathers same colors, very fine grained (0.1 mm), grains subrounded to subangular, well sorted; limonitic, moderately to strongly calcareous. Strong suggestion of algal layering	2
28. Quartzite, greenish-gray to dark-greenish-gray to grayish-red to dusky-purple, weathers same, very fine grained (0.1 mm), well sorted, subrounded to subangular grains of glassy quartz; irregularly laminated and cross-laminated; massive	4
27. Quartzite, pale-yellowish-brown, weathers dark yellowish brown, very fine grained (0.1 mm); grains are subrounded, well sorted; limonite speckled (after glauconite?), and with moderately abundant very fine (less than 0.1 mm) grains of magnetite scattered through rock and concentrated in laminations; beds 0.5 to 2.0 ft thick, laminated	15
26. Quartzite, grayish-red to reddish-purple, weathers same colors, very fine grained (0.05 mm), grains well sorted; dolomitic; beds 0.5 to 5.0 ft thick; lower 3 ft of unit contains prominent worm borings	25
25. Dolomite, pale-yellowish-brown, weathers same color, sandy, with very fine grains (0.05–0.1 mm), in beds 0.5 to 2.0 ft thick	7
24. Mudstone, grayish-red-purple, weathers grayish red, very sandy, slightly calcareous, contains abundant mud chips and sand laminae; gypsiferous	4
23. Quartzite, medium-light-gray, weathers pale yellowish brown, fine grained; limonite speckled, and contains heavy-mineral grains concentrated in irregular laminations, slightly dolomitic	5

Note: Rocks equivalent to units 23–29 in most other exposures in the Lemhi Range are strongly cross-laminated, contain worm tubes throughout, and are slightly calcareous.

Summerhouse Formation—Continued	Thickness (feet)
22. Quartzite, pale-grayish-brown, grayish red, and greenish gray, weathers same colors, very fine grained (0.05 mm); partly glauconitic; limonite speckled; calcareous; micaceous, thin bedded to platy	12
21. Quartzite, pale-yellowish-orange, very fine grained (0.05 mm), limonite speckled (after glauconite?), sparse grains (0.1 mm) of specular hematite; calcareous beds 1–2 ft thick	8
20. Siltite, dusky-yellowish-green to greenish-gray, pencilly fracture	7
19. Quartzite, greenish-gray, weathers same but limonite stained and speckled, medium to fine grained (0.1–0.5 mm); quartz grains subangular to subrounded, contains abundant glauconite, and worm tubes and tracks; calcareous	13
18. Quartzite, similar to unit 19, but pale yellowish brown, weathers moderate yellowish brown; contains abundant worm tubes and limonite specks; glauconitic; unit includes a few thin beds of grayish-green siltite	28
17. Quartzite, similar to unit 19, but contains fewer worm tubes, is laminated and medium grained	7
16. Quartzite, similar to unit 18	15
15. Quartzite, similar to unit 19, with abundant worm tubes	3
14. Quartzite, similar to unit 18	3
13. Quartzite, similar to unit 18 but beds tend to be more platy; partly micaceous; upper 6 ft of unit includes several interbeds of grayish-green very fissile shale from 0.4 to 1.0 ft thick	11
12. Quartzite, similar to unit 18; beds 0.1 to 0.2 ft thick	50
11. Quartzite, very light gray to grayish-orange-pink, fine- to medium-grained (0.1–0.4 mm) clean, vitreous beds 1.0 to 5.0 ft thick, commonly cross-laminated	75
10. Quartzite, similar to unit 18	50
9. Shale, greenish-gray to light-gray, weathers same color, fissile to pensilly fracture; glauconitic; contains interbeds, typically 3 to 5 ft thick, of pale-yellowish-brown to light-gray fine-grained quartzite, forming about 10 percent of unit	200
Thickness, Summerhouse Formation	724

Angular unconformity.

Wilbert Formation (type section) (Precambrian Z):	
8. Quartzite, moderate-red-brown to dark-red-brown, weathers same, fine grained (0.1–0.3 mm); calcareous, partly strongly so; and sandy limestone and dolomite; rocks of unit contain abundant earthy hematite; unit includes two 10-ft-thick beds of light-gray, fine-grained, clean quartzite	100

Wilbert Formation—Continued	Thickness (feet)
7. Quartzite, greenish-gray to yellowish-gray, weathers same colors, very fine grained (0.05–0.1 mm), flaggy, glauconitic, micaceous	25
6. Quartzite, light-gray, weathers yellowish brown to reddish brown, fine to coarse grained (0.1 to 1.0 mm); poorly sorted grains subangular to subrounded, clear, glassy quartz; beds 3–5 ft thick	25
5. Conglomerate, grayish-red to dusky-red, weathers same; contains subangular to subrounded pebbles of white quartz to 1 cm diameter in a poorly sorted sand and grit matrix. Upper 10 ft of unit gradational into overlying unit	35
4. Quartzite, similar to unit 6, pale-red to grayish-red, weathers same color but limonite-stained, quartz grains clear, glassy, poorly sorted (0.1–3 mm), subangular to subrounded; contains abundant hematite disseminated in 0.05- to 0.1-mm grains, and filming quartz grains; beds 0.8 to 3.0 ft thick, well bedded. Middle of unit includes zone 5 ft thick of interbedded pale-olive to moderate-yellow micaceous siltstone, shale, and very fine grained quartzite	53
3. Quartzite, grayish-pink to light-gray, weathers same color with rusty, limonite staining, fine to medium grained (0.2–0.5 mm, some grains to 1 mm diameter); subrounded to rounded; beds 1 to 6 ft thick, partly cross-laminated	188
2. Quartzite, light-gray to pale-pink, weathers same colors, vitreous, fine grained (0.2 mm, range from 0.1 to 0.3 mm in different beds); quartz grains well sorted, well rounded. Unit includes some 0.5- to 2-ft-thick beds of grayish-red quartzite speckled with hematite, similar to unit 4; beds 3 to 5 ft thick	137
1. Quartzite, light-brownish-gray to pale-red, rarely greenish-gray; dominant color grayish red, weathers same colors; fine to medium grained (0.2–0.5 mm) contains about 10 percent feldspar in a few beds, and abundant grains of magnetite and hematite disseminated through the rock and in lower 100 ft of unit concentrated in laminae 0.1 to 4 mm thick; mudstone chips abundant in a few beds in lower third of unit and rocks sheared, sericitic; beds 1 to 3 ft thick, rarely massive, prominent cross-lamination; matrix sericitic in some beds. Grains subrounded to subangular. Upper 50–75 ft of unit weathers dusky red. Lens of light-gray to white fine-grained (0.2 mm) vitreous quartzite 100 ft long and up to 15 ft thick occurs 10 ft below top of unit. Base of unit concealed	390
Total exposed thickness, Wilbert Formation	953

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