Stratigraphic and Structural Relations of the Hoodoo Quartzite and Yellowjacket Formation of Middle Proterozoic Age from Hoodoo Creek Eastward to Mount Taylor, Central Idaho

U.S. GEOLOGICAL SURVEY BULLETIN 1570

Stratigraphic and Structural Relations of the Hoodoo Quartzite and Yellowjacket Formation of Middle Proterozoic Age from Hoodoo Creek Eastward to Mount Taylor, Central Idaho

With a GEOLOGIC MAP OF THE REGION BETWEEN THE MIDDLE FORK OF THE SALMON RIVER AND THE SALMON RIVER

By E. B. EKREN

The Yellowjacket Formation of the Yellowjacket district and Hoodoo Quartzite of Hoodoo Creek revisited, and correlation of the Hoodoo eastward to Mount Taylor. Both formations have been severely wrench faulted throughout this region.

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Stratigraphic and Structural Relations of the Hoodoo Quartzite and Yellowjacket Formation of Middle Proterozoic Age from Hoodoo Creek Eastward to Mount Taylor, Central Idaho

By E. B. Ekren

Abstract

The Hoodoo Quartzite of Middle Proterozoic age in and adjacent to Hoodoo Creek in the Casto quadrangle, central Idaho, is mostly in high-angle strike-slip fault contact with rocks of the underlying thin-bedded Yellowjacket Formation. Locally, however, both the basal and upper contacts of the Hoodoo Quartzite are exposed. Both are transitional. Both contain quartzite. The beds below the Hoodoo compose the Yellowjacket Formation; the unnamed beds above are also of Yellowjacket affinity, a circumstance that suggests a return to Yellowjacket-type sedimentation following the deposition of the Hoodoo Quartzite. A well-exposed section of Hoodoo Quartzite and Yellowjacket Formation along Shovel and Yellowjacket Creeks that was measured by C. P. Ross is designated herein as the principal reference section of both formations.

The Yellowjacket Formation, which is about 2,740 m thick in the Yellowjacket district, consists of alternating thin beds of gray, very fine grained argillaceous quartzite, siltite, and dark-gray argillite. The bedding is even and apparently rhythmic, but good grading is rare. Polygonal, well-defined mud cracks were found in siltite at three localities. The mud cracks, together with a general paucity of well-graded beds, rule out an origin as a deep-marine turbidite for the part of the Yellowjacket Formation exposed in the district and eastward to Mount Taylor.

The Hoodoo Quartzite is about 1,100 m thick on Shovel Creek, a tributary of Yellowjacket Creek, where it consists of white to off-white vitreous quartzite with mostly obscure bedding. It contains about 85 percent quartz (0.2–1.5 mm), 10 percent fresh feldspar, and 5 percent muscovite, biotite, chlorite, and iron oxide. The unnamed overlying quartzite has a preserved thickness of 500 to 1,000 m and consists of thin-bedded gray argillaceous quartzite interbedded with gray siltite and argillite. This sequence appears to be generally more siliceous than the Yellowjacket Formation beneath the Hoodoo Quartzite but cannot be distinguished from the Yellowjacket solely on the basis of lithology.

Bedding attitudes in the Yellowjacket Formation, Hoodoo Quartzite, and overlying argillaceous quartzite (pl. 1) define a large northwest-striking anticline and syncline in and adjacent to Hoodoo Creek and the Yellowjacket area (fig. 1, pl. 1). A few kilometers east of these areas, the syncline is faulted down and is deeply buried in the northeast-trending Panther Creek graben. The syncline reappears again on Mount Taylor (fig. 1, pl. 2), and there the Hoodoo (minus the overlying argillaceous quartzite) displays the same high quartz content as at Hoodoo Creek.

The area from Middle Fork Peak on the west (including Hoodoo Creek and Yellowjacket area) to Iron Creek on the east (fig. 1, pls. 1 and 2) has been cut by several northwest-trending high-angle right-slip faults and by several northeast-trending high-angle left-slip faults. The northeast-trending Panther Creek graben, although primarily of dip-slip origin, shows considerable left-slip displacement.

INTRODUCTION

Clyde P. Ross (1934, p. 15–22) named and described the Yellowjacket Formation and Hoodoo Quartzite of "Algonkian" age from exposures in the Yellowjacket mining district and at Hoodoo Creek, central Idaho. Although Ross named the Hoodoo for exposures at Hoodoo Creek, the base and top of the Hoodoo are both exposed only in the vicinity of Ross' measured section (p. 16) (designated herein as the principal reference localities for both Hoodoo Quartzite and Yellowjacket Formation) near the Yellowjacket mining district, Lemhi County, Idaho, along Yellowjacket and Shovel Creeks in T. 19 N., R. 17 E. (unsurveyed) about 2 mi (3.2 km) northeast of the mine and mill (pl. 1). Ross, (1934, p. 15–16) concluded that, in the vicinity of his measured section, the base of the Hoodoo was transitional with the underlying Yellowjacket Formation whose base was not exposed. Ross determined that the Hoodoo along Shovel and Yellowjacket Creeks is about 3,600 ft (1,100 m) thick and the incompletely exposed Yellowjacket is about 9,000 ft (2,740 m) thick.

Although Ross (1934, p. 15–16) determined that the contact between the Hoodoo and the Yellowjacket Formation along Yellowjacket Creek was transitional, he also concluded that the Hoodoo in the vicinity of Hoodoo Creek west of the Yellowjacket mine and mill was thrust over the Yellowjacket. This latter conclusion has led many subsequent workers to map the Hoodoo as being thrust over the underlying Yellowjacket in nearly every exposure of the two units in the belt of outcrops extending from Hoodoo Creek on the west to Taylor Mountain on the east (pl. 2).

The purpose of this paper is to present data showing that the Hoodoo throughout this belt of outcrops is either in transitional contact with the Yellowjacket or in high-angle strike-slip fault contact with the Yellowjacket. The transitional nature of the contact at both the base and the top of the Hoodoo in the vicinity of Yellowjacket Creek indicates that the Hoodoo is autochthonous with respect to the Yellowjacket Formation and overlying quartzites. If thrusting of Hoodoo over Yellowjacket has occurred anywhere along the belt of outcrops, it is of minor regional significance, and future workers should examine the Hoodoo-Yellowjacket relationships elsewhere in central Idaho very carefully before concluding that the Hoodoo Quartzite is thrust over the Yellowjacket Formation.

The data presented here were acquired during the U.S. Geological Survey's mapping of the Challis 1°×2° quadrangle. This work is part of the Survey's CUSMAP program (Conterminous United States Mineral Assessment Program).

STRATIGRAPHY

Yellowjacket Formation

The Yellowjacket Formation was named by Ross (1934, p. 16) for the town and mining district of Yellowjacket, Lemhi County, Idaho. According to Ross (1934, p. 16–17), the lower part of the Yellowjacket Formation at this locality (pl. 1) consists of 1,700 ft (520 m) of "banded and variegated gray, white, and green, more or less calcareous rocks, cut by numerous dikes." These calcareous rocks are overlain by 7,080 ft (2,158 m) of dark-gray argillaceous quartzite that weathers readily. A recent study by Carter (1981) has shown that the calcareous rocks described by Ross occur as discrete lenses in the argillaceous Yellowjacket and define the core of an anticline. The stratigraphic section measured by Ross possibly is further complicated by additional folds, and as noted by Ross, the Yellowjacket Formation along the line of his measured section is locally overturned. The Yellowjacket Formation lying to the east and stratigraphically above the lower calcareous rocks is composed of thin beds of argillaceous very fine grained to fine-grained quartzite that alternate with thin beds of siltite and argillite. The beds average less than 30 cm in thickness, although a few beds occur that are several meters thick. The quartzite beds are composed of 55 to 70 percent quartz grains with an average diameter of about 0.1 mm, about 30 percent biotite, chlorite, and sericite formed from original argillaceous material, and magnetite. Some beds are sufficiently rich in magnetite that they easily attract a pencil magnet. No rocks other than the argillaceous quartzite beds were examined in thin section, but hand lens examination suggests that the finer grained siltite and argillite beds differ only in that they contain fewer and smaller grains of quartz and more mafic minerals. Oscillatory and current ripples are fairly common in the Yellowjacket sequence, and unequivocal mud cracks were found in three localities: (1) about 1 km east of Yellowjacket Creek near Beagle Creek (fig. 1), (2) in exposures farther west along Hoodoo Creek Canyon, and (3) along Musgrove Creek about 1 km above its junction with Panther Creek (S. W. Hobbs, oral commun., 1981). The mud cracks in all three localities are definitely polygonal. The mud cracks west of Hoodoo Creek are larger than those on figure 2, are nearly symmetrical, and seem clearly to be mud cracks and not shrinkage cracks caused by compaction of wet sediments.

In places, the thin quartzite beds of the Yellowjacket display fine-scale crosslaminated layers that average little more than 1 cm in thickness. Load casts and zones of fine-scale convolute bedding occur locally. Very few of the quartzite beds in the Yellowjacket Creek and Yellowjacket mining district display good grading. Good top-direction data during this study were found in only a few localities, and these were derived principally from fine-scale crosslaminations and oscillatory ripple marks. Ross (1934), Anderson (1953), and Carter (1981) concluded that the Yellowjacket Formation in the vicinity of the creek and mining district was deposited in a shallow-marine environment; I concur, despite the local occurrences of fine-scale convolute bedding and a few large-scale slump features that were noted by Lopez (1982, p. 64–70). Lopez suggested that the Yellowjacket farther east is a deep-marine turbidite.

In addition to the study of Yellowjacket Formation by Lopez (1982), detailed studies of the Yellowjacket Formation in the vicinity of the Blackbird mining district (fig. 1) have been made by Hughes (1983), Sobel (1982), and Hahn and Hughes (1984), who have endorsed Lopez' conclusions that the Yellowjacket Formation is a turbidite sequence. They describe fan environments, graded beds, tuff beds, and Bouma sequences (Bouma, 1962). If the

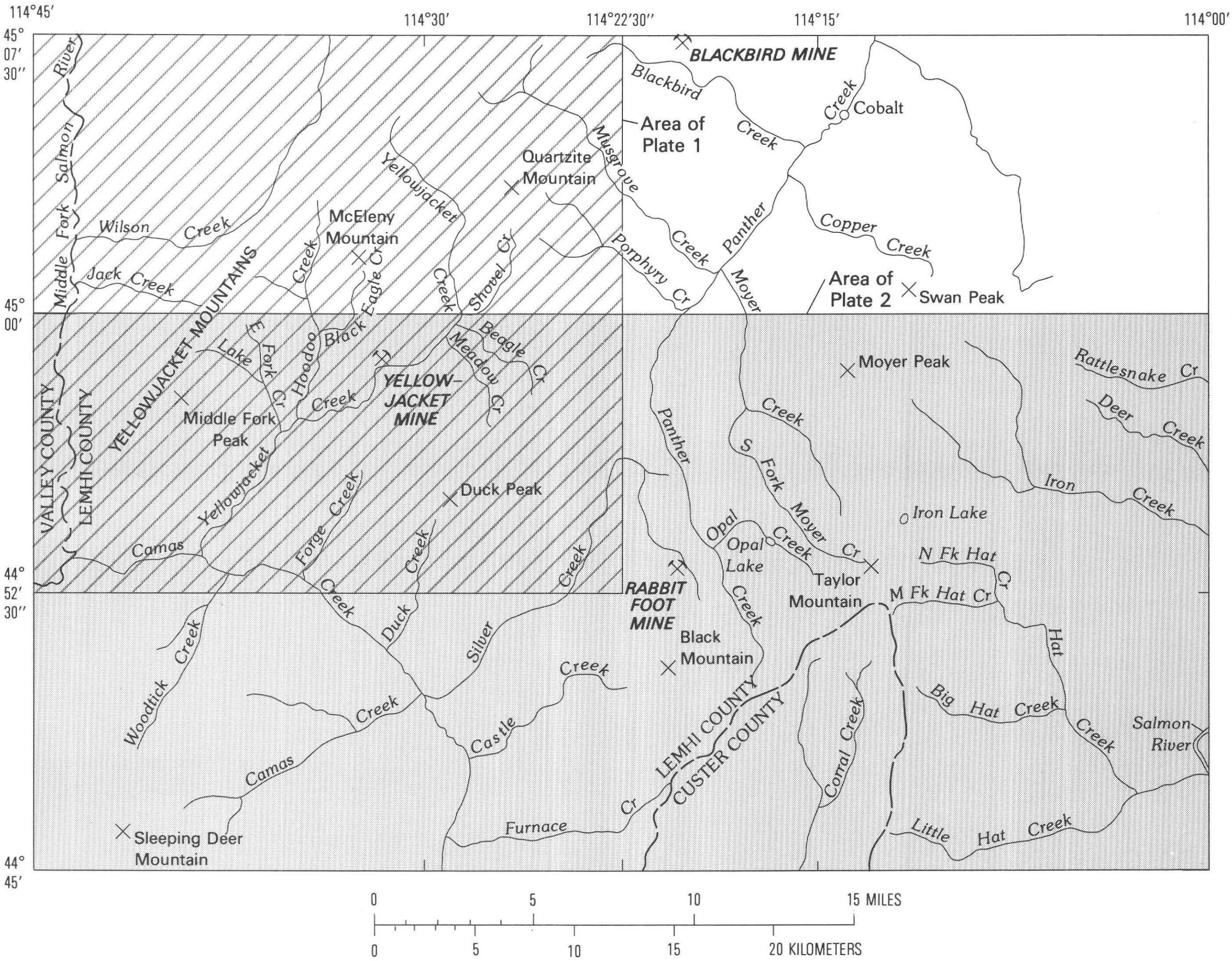


Figure 1. Index map of the region between the Middle Fork of the Salmon River and the Salmon River, Idaho.

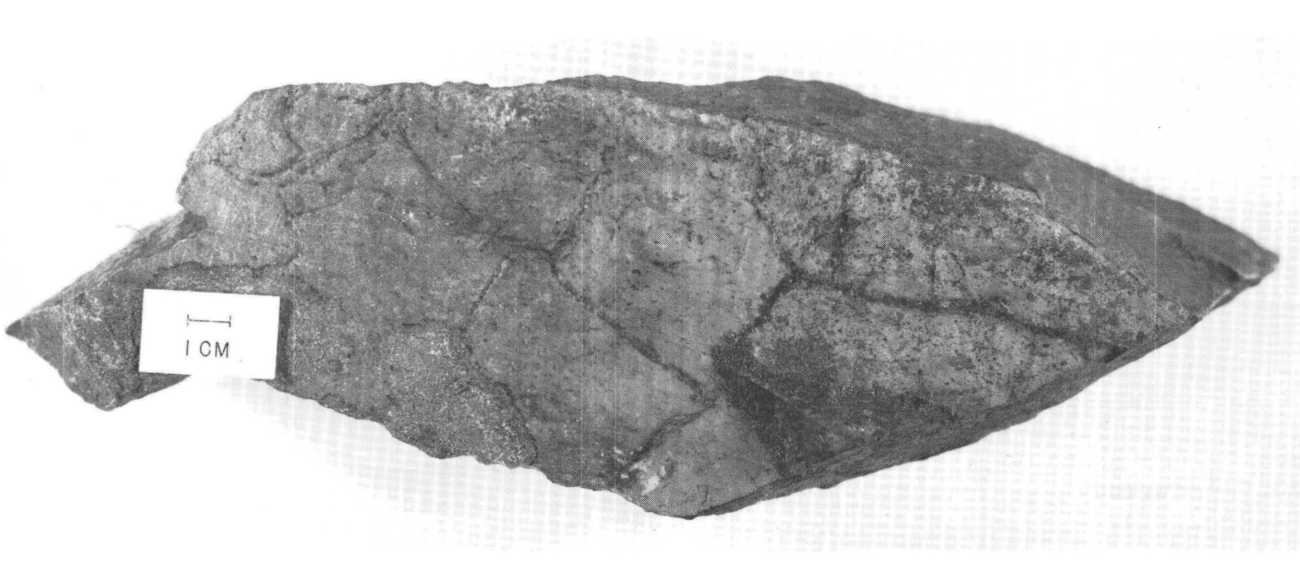


Figure 2. Mud-cracked siltstone of the Yellowjacket Formation from outcrop about 1 km east of Yellowjacket Creek near Beagle Creek.

turbidite interpretation is correct, a marked facies change occurs between the belt of outcrops described in this report and the belt of Yellowjacket outcrops in the vicinity of the Blackbird mine. Bennett (1977) has proposed that the Yellowjacket in the vicinity of the Blackbird mining district represents a younger sequence than the rocks exposed farther south that are contiguous with rocks mapped herein as Yellowjacket (pl. 1, Yy). The rocks of the Yellowjacket Formation are tightly folded between the two areas and are much closer together now than when they were originally deposited. Furthermore, Hughes (1983) and Hahn and Hughes (1984) have argued that the rocks that they consider to be older Yellowjacket, south of the Blackbird mine (fig. 1), may have had a source to the southwest, whereas the rocks in the Blackbird mining district and northeast of the Blackbird district had a source to the northeast. The possibility exists that the sequence described in this report at the Yellowjacket mine extending eastward through Iron Creek (fig. 1) represents a shallower marine (essentially shelf or miogeocline) facies and that the rocks in the Blackbird mine area represent a considerably deeper water assemblage (see Hughes, 1983). Photographs of graded beds along Blackbird Creek shown by Sobel (1982), however, are not compelling, and the rocks described by Sobel (1982) and Hughes (1983) differ considerably from classic turbidites. The principal difference is the general paucity of excellently graded beds in the Yellowjacket and the presence of too many clean, quartz-rich quartzites in which there is no internal grading and in which the grains show considerable rounding. Many of these quartzite beds, like beds in the Hoodoo Quartzite, are massive and without visible bedding, and they have sharp upper contacts as well as lower. They obviously are not proximal turbidites.

The mud cracks in the Yellowjacket Formation in the Yellowjacket area, at Hoodoo Creek, and at Musgrove Creek clearly point to shallow-water conditions. The overall similarities of the Yellowjacket Formation with the Apple Creek Formation of the Lemhi Group imply that these two formations were deposited under very similar depositional environments. Ruppel (1975) has presented considerable evidence that shows the Apple Creek to be a product of shallow-water deposition. I infer the same conditions for that part of the Yellowjacket Formation described in this report. Certainly the Hoodoo Quartzite is not a turbidite. The conclusion that the Hoodoo Quartzite is in transitional contact with the Yellowjacket Formation is soundly based. Both lithologies must be products of shallow-marine deposition. The arguments presented for deep-marine turbidite deposition in the Blackbird mine area by Hughes (1983), Sobel (1982), Hahn and Hughes (1984), and Lopez (1982) are imaginative and may be entirely correct. If so, the conditions of deposition during Yellowjacket time changed dramatically from the Yellowjacket area northeastward to the Blackbird mine and Salmon.

The Yellowjacket Formation in the vicinity of the Yellowjacket area and southward toward Sleeping Deer Mountain (fig. 1, pl. 2) has been intruded by various igneous rocks that are probably of widely differing ages (Ross, 1934; Fisher and others, 1983). The entire area is probably underlain by a Tertiary batholith (Criss and others, 1984), and the Yellowjacket Formation and Hoodoo Quartzite probably have been repeatedly thermally metamorphosed. The argillaceous Yellowjacket is virtually a biotite hornfels and, in many places, is partly or completely chloritized. The biotite and chlorite occur in matted aggregates with only rough parallelism (Ross, 1934, p. 17). Thin sections show that the grains of biotite, chlorite, and sericite commonly occur in typical decussate fabric (unoriented grains—not haphazard but to relieve stress according to Harker, 1956, p. 35). The thermal metamorphism destroyed the original sedimentary texture in some rocks, but in others, the original texture has actually been enhanced by the metamorphism.

Hoodoo Quartzite

The Hoodoo Quartzite was named and described by Ross (1934, p. 98) for exposures on the west slope of Hoodoo Creek, a tributary of Yellowjacket Creek (pl. 1, fig. 1). According to Ross, the Hoodoo Quartzite is typically nearly white with a tinge of "vinaceous gray," but joint surfaces tend to be light brownish because of their films of limonite. The rock contains about 85 percent quartz in interlocking grains about 0.2 mm in diameter, but grains as large as 0.75 mm are fairly common. Feldspar, consisting of microcline and albite, makes up about 10 percent of the rock; and muscovite and chlorite make up the remainder. Bedding is mostly indistinct, but crossbedding is evident in many localities. In addition to these lithologic descriptions, Ross (1934, p. 18–19) has pointed out that near the base of the formation along Yellowjacket Creek, "there appears to be a gradation into the Yellowjacket formation * * *. Rock resembling the Yellowjacket formation is interbedded with the nearly white quartzite in beds from a fraction of an inch to several feet thick * * *. The top of the Hoodoo Quartzite is overlain by a banded, somewhat calcareous quartzite. The contact here also appears to be gradational."

The general characteristics of the Hoodoo Quartzite as observed during this present study will be described by areas from west to east.

Yellowjacket and Hoodoo Creeks

Attitudes and top directions in the exposures along Yellowjacket Creek (pl. 1) show that the Hoodoo beds strike parallel to the beds in the Yellowjacket and that the beds in both sequences are consistently younger toward

Figure 3. Steep bedding in lowest exposed Hoodoo Quartzite just south of mouth of Meadow Creek. Quartzite dips 85° to right (north) of observer. Bedding is easily confused with southwest-dipping, closely spaced joints in this vicinity. Note conspicuous joint surfaces to right of steep bedding plane.

the northeast. According to Ross (1934, p. 16), the Hoodoo in these exposures is 3,600 ft (1,100 m) thick, and the contact with the underlying Yellowjacket is transitional. I feel that considerable strike-slip fault movement has taken place along this contact but, as will be pointed out on later pages, the Hoodoo section is virtually complete. The dip of the beds at the contact is vertical or nearly so (fig. 3) but decreases northeastward to 40° or less (pl. 1).

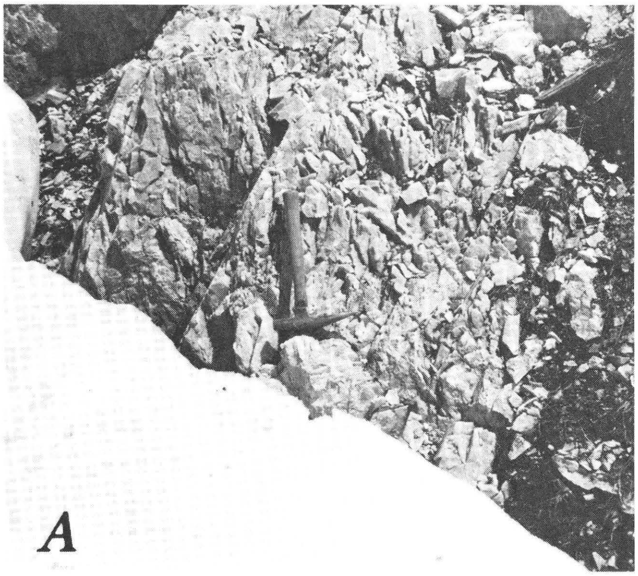
The Hoodoo Quartzite exposed along Yellowjacket Creek and also in the Hoodoo Creek drainage is light gray to white (fig. 4), but in both places it grades to brownish white or very light brownish gray and locally contains beds of somber gray. The gray and dark-gray beds probably originally had a greater abundance of silt, which was subsequently metamorphosed to very fine grained iron oxide, biotite, and sericite. The quartzite is massive, and bedding is generally indistinct; but beds 0.3–1 m thick can be found that are distinctly crossbedded (fig. 5). The crossbedding is defined by white laminae alternating with gray and dark gray. Both oscillatory and current ripple marks occur throughout the unit. The quartzite is intricately jointed and, in places, the jointing can easily be confused with bedding (fig. 3). In most places the rock is intensely fractured, and the quartzite weathers to hackly fragments that obscure the contact with the subjacent Yellowjacket. Because of the jointing and other fracturing, the originally obscure bedding is difficult to see in many places; large outcrops exist, especially in the middle part of the quartzite unit, within which no reliable bedding attitudes can be obtained.

Thin sections of the Hoodoo from the vicinity of Yellowjacket and Hoodoo Creeks show that quartz averages about 85 percent; feldspar, consisting mostly of microcline and orthoclase but with variable amounts of albite, ranges from about 5 to as much as 15 percent; and sericite and biotite range from near 0 to 10 percent. The quartzite is, in general, not well sorted, but this characteristic varies considerably. One thin section shows two distinct size fractions—a framework consisting of quartz grains that vary in size from 0.5 to 1.5 mm and a matrix consisting almost entirely of quartz about 0.1 to 0.3 mm. This particular thin section contained only trace amounts of feldspar and sericite. A thin section of distinctly laminated quartzite showed layers of quartz grains about 0.1 to 0.5 mm in diameter with little or no matrix, interlayered with very fine grained dirty quartzite or siltite consisting of quartz grains 0.1 mm or less in a matrix of biotite and sericite. All thin sections show a sutured mosaic fabric, and the quartz grains are severely strained.

Lithology of Basal Part

The Hoodoo Quartzite shows some extreme lithologic variations in basal exposures extending from Yellowjacket Creek on the southeast to Lake Creek and Wilson Creek on the northwest (pl. 1). Calcareous beds are thick and conspicuous in two localities in this belt, and quartzites typical of the Hoodoo Quartzite are interbedded with quartzites typical of the Yellowjacket Formation in the canyon and tributaries of Lake Creek.

Although no calcareous rocks were noted at the base of the Hoodoo Quartzite in most of the area studied, they are locally conspicuous in exposures at Wilson Creek and the Black Eagle mine on Black Eagle Creek (pl. 1). The calcareous zone in these localities consists of layers of quartzite a few centimeters thick that contain little or no calcite, which alternate with layers containing more calcite and calc-silicate minerals than quartz. Depending on nearness to dikes and other intrusive masses, the calcareous rocks may contain actinolite-tremolite, scapolite, epidote, and diopside. About 2 km southeast of the Black Eagle mine (pl. 1) and extending northwestward



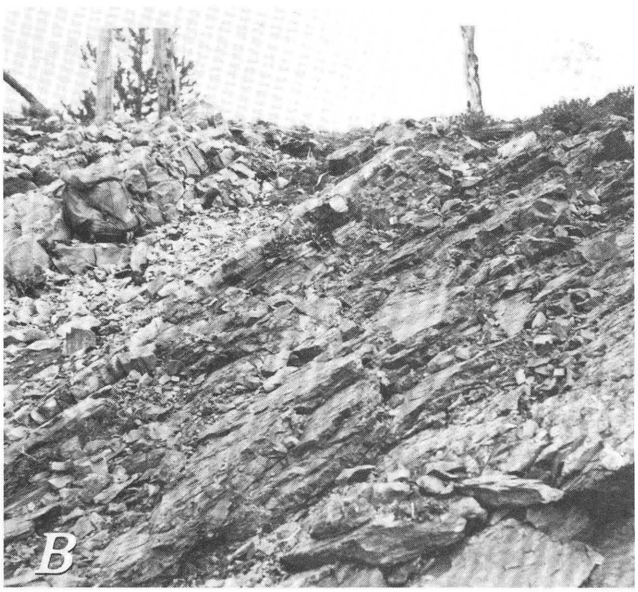


Figure 4. Views of Hoodoo Quartzite near Hoodoo Creek. *A*, Highly crackled light-gray quartzite (compare with white snow) in ridge south of Jack Creek between a northwest-striking right-slip fault and a northeast-striking left-slip fault. *B*, Outcrop about 2 km east of *A* showing gray, Yellowjacket-like, argillaceous quartzite within the Hoodoo Quartzite on west limb of anticline just above head of East Fork of Lake Creek. *C*, Outcrop on east limb of anticline showing essentially flat lying Hoodoo, here also with a gray Yellowjacket-like bed. *D*, View to northeast near head of East Fork of Lake Creek showing Hoodoo Quartzite (white) above Yellowjacket Formation. Beds in both sequences dip away from the observer about 35°.

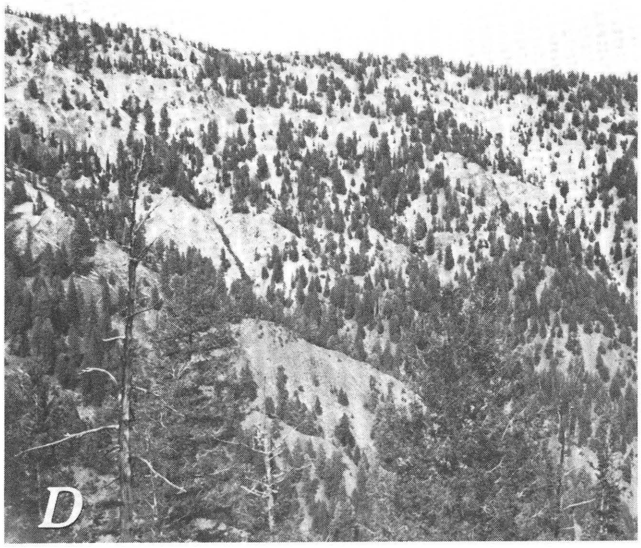


Figure 5. Crossbedded Hoodoo Quartzite interbedded with dark siltstone in outcrop in approximate middle of sequence on ridge between Meadow and Beagle Creeks.

through the Black Eagle area, calcareous beds (pl. 1, Yhc) appear to be continuous and, at the mine, they may be as much as 200 m thick. There, the beds are highly contorted, but the average strike and dip of the least contorted strata approximate the attitudes in the overlying quartzite and underlying Yellowjacket. The contact of calcareous rock with the overlying quartzite is gradational; the concealed contact with the underlying Yellowjacket apparently is sharp, and I infer that the sharp contact is a strike-slip fault (see pl. 1). The calcareous zone possibly is a local lens that may originally have been elongated in an easterly direction; the possibility exists, therefore, that the zone at the Black Eagle mine has been displaced right laterally about 4 mi (6.4 km) from the vicinity of Wilson Creek.

The calcareous beds near the Black Eagle mine and near Yellowjacket Creek are heavily iron stained locally and have been intensely prospected, probably for gold and silver. The lack of any extensive diggings indicate, however, that very little of value was found.

The basal part of the Hoodoo Quartzite in the Lake Creek drainage area (pl. 1) contains very little calcareous strata. Instead, the basal part is marked by a transitional zone at least 200 m thick consisting of thin beds of dark-gray argillaceous quartzite and siltite and fine-grained gray quartzite typical of the Yellowjacket that alternate with thin beds of light-gray, brownish-gray, and white clean quartzite typical of the Hoodoo (fig. 6). This zone is exposed also north of Middle Fork Peak (pl. 1, fig. 1), but it is thicker and better exposed in the East Fork of Lake Creek (a tributary of Yellowjacket Creek). Ross noted the transitional zone exposed along the East Fork; nevertheless, he concluded that the Hoodoo-Yellowjacket contact was a thrust fault (1934, p. 74). The peculiar nature of the thrust fault, however, was evident to Ross, and he observed that in places the "thrust had to lie within the Yellowjacket Formation." In other words, Ross' "thrust fault" at Lake Creek is an intraformational thrust fault that locally places younger Yellowjacket Formation as well as Hoodoo Quartzite over older Yellowjacket Formation and, therefore, is not regionally significant.

Taylor Mountain

The lithology of the Hoodoo Quartzite does not change across the Panther Creek graben westward to Taylor Mountain (pl. 2). Most of the rocks at Taylor Mountain contain 85–94 percent quartz, and the grains range in size from 0.2 to 1.5 mm—about the same size range as at Hoodoo and Yellowjacket Creeks. The colors also remain virtually the same. The rocks on Taylor Mountain are mostly white (fig. 7) or off-white with a brownish to yellowish cast. Locally, they are light gray, light yellowish gray, pale tan, dark gray, and black. The last two colors were noted in the lowest exposed rocks near the south end of the quartzite massif in the slopes and channel of the Middle Fork of Hat Creek.

The dark-gray and black rocks all show a strongly foliated fabric in thin section, unlike the sutured, weakly foliated mosaics that characterize the rock in the vicinity of Iron and Opal Lakes (pl. 2) and in the belt of outcrops farther west. Thin sections show that larger quartz grains (0.5–0.8 mm long) have been elongated parallel to foliation planes, and it is not clear whether the smaller quartz grains (0.1–0.3 mm in diameter) were formed by breakage and recementation or whether they constituted an original smaller fraction. Two samples of quartzite from the Middle Fork of Hat Creek that show a strong foliation in thin section but only subtly in outcrop were found to contain 88 and 90 percent quartz, 1.6 and 2.2 percent albite, 3.4 and 6 percent nonperthitic orthoclase, 1 percent each microcline, about 3 percent tiny

Figure 6. Lowest exposed Hoodoo Quartzite on west limb of anticline at East Fork of Lake Creek. Note even bedding and alternating light and dark beds. This is the transitional facies of Ross (1934).

flakes of biotite, and the same amount of sericite. One slide contained about 1 percent fresh metamorphic zoisite and amphibole. The amphibole showed anomalous blue-green pleochroism. A thin section of a nearly black vitreous quartzite, also from the Middle Fork of Hat Creek, showed that the black color was due to 10 percent tiny flakes of biotite in foliation planes and as thin films partly enclosing the quartz grains. This rock contained only 75 percent quartz ranging in size from 0.1 to 0.5 mm; it is representative of only a small part of the rock exposed in the vicinity of Taylor Mountain and, having been sampled from one of the lowest exposed outcrops, may represent a transitional facies with the underlying Yellowjacket Formation (fig. 7*C*). This thin section also contained a few grains of fresh amphibole, but these grains did not show anomalous pleochroism.

The quartzite at Taylor Mountain contains numerous flakes, clots, and fracture coatings of specular hematite. These occurrences of shiny "iron" prompted the names Iron Lake and Iron Creek.

Argillaceous Quartzite

The argillaceous quartzite above the Hoodoo Quartzite is well exposed along Shovel Creek and along the south fork of Porphyry Creek. These beds are highly fractured; they slump easily and weather hackly. As a consequence, good stable outcrops showing reliable attitudes are rare, especially on ridge tops and north-facing slopes. Ross (1934, p. 15–16) did not indicate precisely where he picked the top of the Hoodoo at his measured section along Yellowjacket and Shovel Creeks (the principal reference locality of this report) and for good reason. The Hoodoo grades upward through a vertical distance of several hundred meters from clean quartzite into rock containing so much argillaceous quartzite and siltite that it clearly is a separate stratigraphic unit (fig. 8). On plate 1, this contact was placed where argillaceous quartzite and siltite appear to predominate over clean quartzite, which is typical of the Hoodoo, but the contact is arbitrary at best. Ross (1934, p. 18) noted that the overlying gradational quartzite was somewhat calcareous.

Top directions determined from crossbedding exposed in roadcuts along Shovel Creek (Yellowjacket Creek of Ross, 1934) and in outcrops on the ridge east of Shovel Creek (pl. 1 and fig. 1), show that the beds are unequivocally younger toward the northeast. Therefore, although the contact between the Hoodoo Quartzite and the unnamed sequence above is arbitrary, the age relations of the strata are straightforward. The beds above the gradational contact with the Hoodoo, like those below the Hoodoo, are predominantly argillaceous fine-grained quartzites and siltites. The quartzites above are cleaner, have a greater tendency to weather hackly, and are lighter colored than the quartzite beds in the Yellowjacket Formation below the Hoodoo. Instead of the somber dark gray and black of the Yellowjacket beds below the Hoodoo, the beds of argillaceous quartzite above tend to be light bluish gray, brownish gray, and gray. The interbeds of siltite, however, are consistently dark gray. The interbeds of quartzite are as thick as 5 m and are generally coarser grained than they are in the Yellowjacket below the Hoodoo. Cursory examination with a pencil magnet suggests that the beds of argillaceous quartzite and siltite above the Hoodoo contain less magnetite than do the corresponding Yellowjacket beds below the contact.

The sequence above the Hoodoo Quartzite in the principal reference locality exposures along Shovel Creek actually resembles both the Hoodoo Quartzite and Yellowjacket Formation. Bennety (1977) mapped the sequence as part of the Hoodoo Quartzite. I mapped the sequence as part of the Yellowjacket Formation (Fisher and others, 1983).

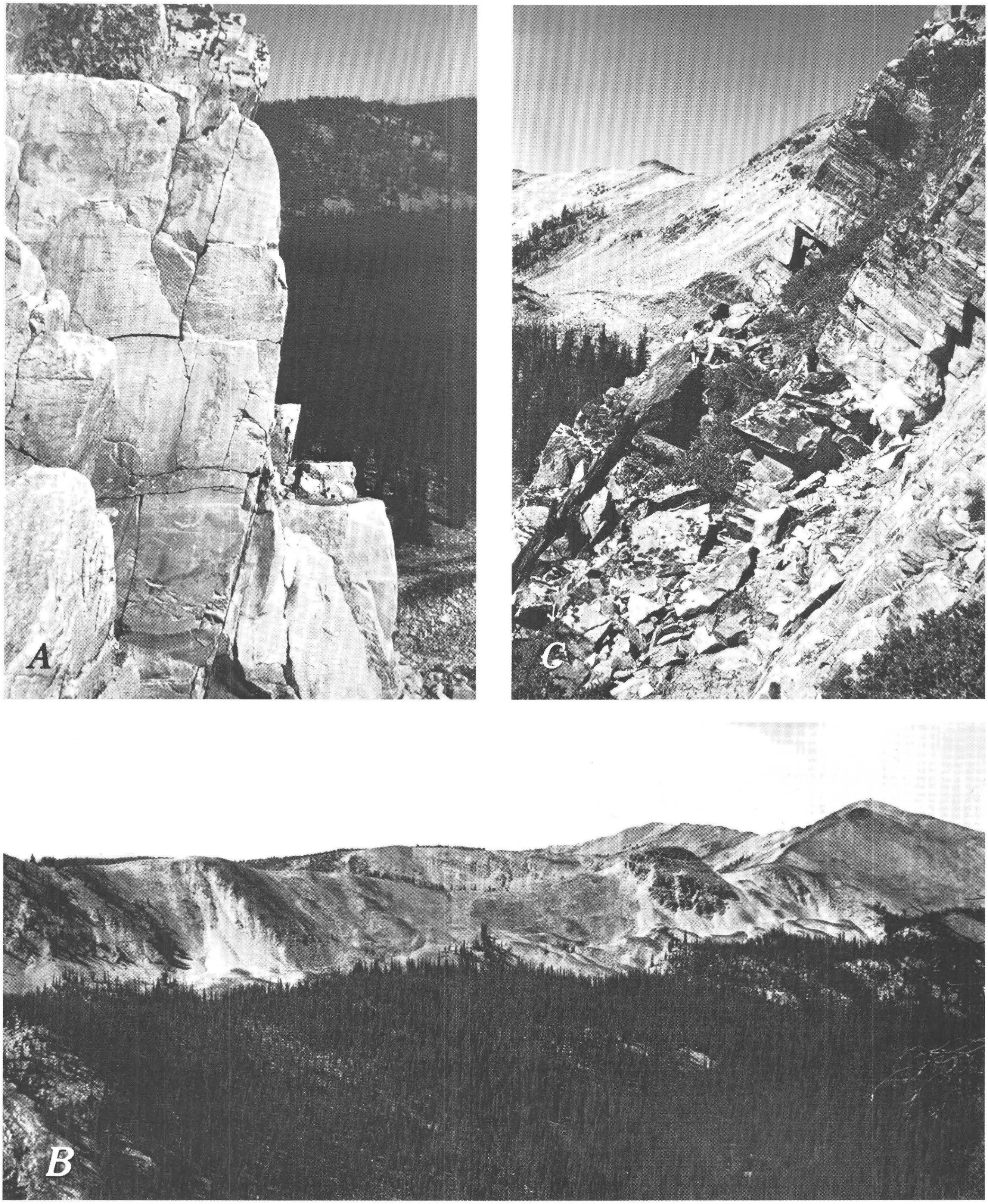


Figure 7. Hoodoo Quartzite on Mount Taylor. *A*, Indistinctly bedded, blocky-weathering white quartzite in exposures at head of Hat Creek. *B*, View to northwest of Mount Taylor (note lookout tower on highest peak). All rock in this view is glaciated, blocky-weathering Hoodoo Quartzite. Glacial striae, preserved locally on the top of Mount Taylor, show that it was covered with ice. *C*, Lowest exposed Hoodoo Quartzite near head of Middle Fork of Hat Creek. Even-bedded, thin-bedded, dark-gray, and white quartzite. Dark beds contain abundant biotite after argillaceous material. White beds are nearly pure orthoquartzites. Compare with figure 6.

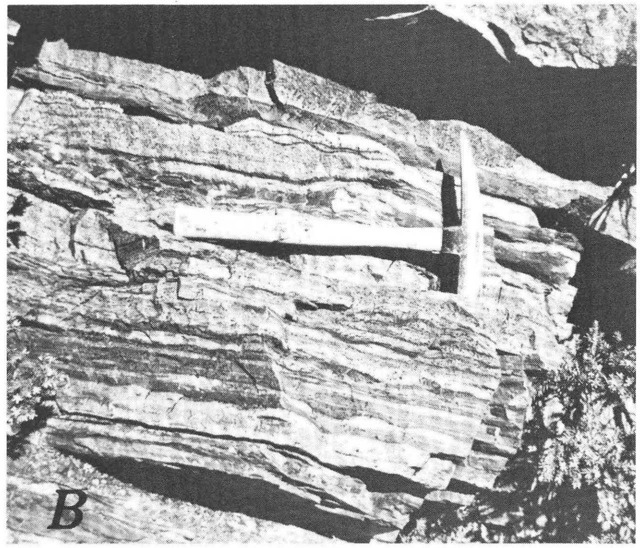


Figure 8. Argillaceous quartzite beds in unnamed sequence above Hoodoo Quartzite. Both photos are from outcrops along or near Shovel Creek (fig. 1). *A*, Even-bedded, light-gray and gray, fine- to medium-grained quartzite in transitional zone near contact. *B*, White, thin-bedded, ripple-marked, clean quartzite interlayered with gray, very fine grained, argillaceous quartzite. Outcrop is several hundred meters above the top of Hoodoo Quartzite.

Age of Yellowjacket Formation, Hoodoo Quartzite, and the Unnamed Quartzite Sequence

The Yellowjacket Formation, Hoodoo Quartzite, and the closely related unnamed quartzite sequence that lies gradationally above the Hoodoo are probably the oldest sedimentary rocks in the region. The sequence has never been found in depositional contact with other Proterozoic rocks. No bottom or top is known. Umpleby (1913) concluded that the Yellowjacket Formation and the quartzite—later named the Hoodoo Quartzite—belong to the "Belt series," and Ross (1934, p. 19) concurred. Cater and others (1973, p. 17) pointed out, however, that despite the fact that correlation with the Belt Supergroup (fig. 9) has long been assumed, specific correlations cannot yet be made. Ruppel (1975) suggested a possible correlation of the Yellowjacket Formation with the Prichard Formation, the lowest unit of the Belt Supergroup; this assignment was also followed by Lopez (1982). Data reported by Hobbs (1980, p. 11–12) based on the paleomagnetic studies of Elston and Bressler (1980) suggest the strong possibility that the Yellowjacket and Hoodoo were deposited wholly or in part during the same time span as the older rocks in the Belt Supergroup.

Rocks considered to be mafic tuffs in the Yellowjacket Formation near the Blackbird cobalt mine (fig. 1) have yielded zircon lead-uranium ages of 1.7 b.y. (Hughes, 1983)[1]. The Yellowjacket Formation in the Salmon area northeast of the Yellowjacket mine area was intensely folded and cleaved prior to intrusions of porphyritic granite that have been dated at $1{,}370 \pm 10$ m.y. (Evans and Zartman, 1981a).

Obradovich and Peterman (1968) interpreted an age of about 900 to 1,300 m.y. for the Belt rocks in western Montana. More recent studies suggest a minimum age of 1,450 m.y. for the basal part of the Belt (Zartman and others, 1982).

In summary, the Yellowjacket Formation and Hoodoo Quartzite are possibly as old as 1.7 b.y. (Hughes, 1983), and they were metamorphosed, tightly folded, and cleaved prior to 1.37 b.y. ago (Evans, 1986). They may be about the same age as the oldest rocks of the Belt Supergroup, but this correlation has not been positively established.

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[1]According to Karl Evans (USGS, oral commun., 1983) the two data points are discordant and not easily interpreted in terms of a simple lead-loss model. Rather, there is a suggestion of inherited radiogenic lead, which implies that the true age of crystallization is less than the values quoted. Without further analyses, the significance of the dates provided by Hughes (1983) is open to multiple interpretations.

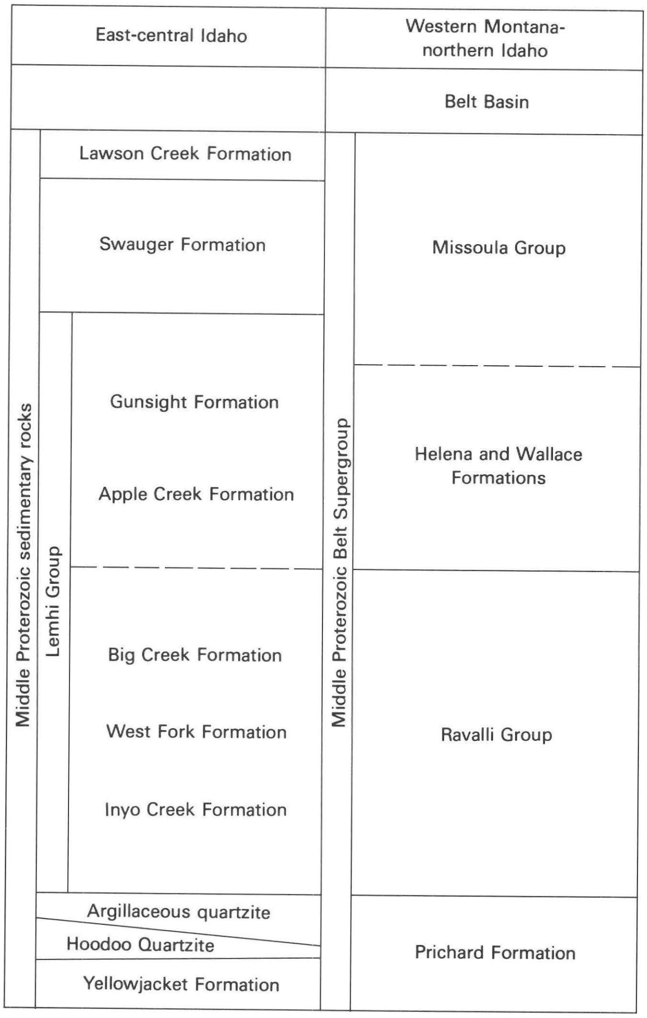

Figure 9. Possible correlations of Middle Proterozoic sedimentary rocks of east-central Idaho with rocks of the Belt Supergroup of western Montana-northern Idaho. Modified from Ruppel (1975) and Hobbs (1980).

STRUCTURE

Historic Summary

Beds of the Yellowjacket Formation and Hoodoo Quartzite in the region were first deformed during Middle Proterozoic time as evidenced, locally, by plutonic rocks dated at 1,370 m.y. B.P. apparently having been intruded into already folded and cleaved rocks of the Yellowjacket Formation (Evans and Zartman, 1981a). Recently obtained lead-uranium dates on zircons from syenite in map unit Od (pl. 2) indicate an Ordovician age for that pluton. Both the Yellowjacket and Hoodoo were extensively folded prior to the intrusion. According to Hobbs (1980), additional folding probably occurred in the region during the late Paleozoic (Antler) and Mesozoic (Sevier) orogenies. The rocks were undoubtedly further folded during the period of intense wrench faulting, as documented in the next section.

Latest Cretaceous or earliest Tertiary erosion (Ross, 1934; Anderson, 1953; Criss and others, 1982), that followed any Mesozoic (Sevier) folding and the emplacement of the Idaho batholith, removed all of the Paleozoic rocks that probably covered the Yellowjacket region, and exposed parts of the Idaho batholith. Wrench faulting comprising northwest-trending right-slip faults and northeast-trending left-slip faults, rifting, and volcanic eruptions probably commenced nearly simultaneously in early Eocene time, and volcanic and intrusive igneous activity continued unabated for a period of at least 6 m.y., from about 51 through about 45 m.y. ago (McIntyre and others, 1982). Faulting and tilting of strata have apparently continued intermittently to the present time.

Wrench Faulting

Of principal concern to this paper is the evidence that the region has been subjected to intense wrench-fault tectonism. As stated previously, this activity resulted in numerous northwest-trending right-slip faults and several northeast-trending left-slip faults.

The northwest-trending faults preceded the intrusion of pink granophyre, dated at about 44 m.y. B.P. (Fisher and others, 1983), and they are truncated by faults related to the Panther Creek graben, which started to form 47–48 m.y. ago. They probably are about the same age as oblique-slip faults in the southeastern Challis quadrangle that were in existence 48–51 m.y. ago (McIntyre and others, 1982). These ages suggest that the faults are at least of early Eocene or Paleocene age. The northeast-trending left-slip faults displace the northwest-trending set and therefore have moved a little more recently. I infer, however, that both sets are part of a conjugate first-order system.

Structural Details along the Hoodoo-Yellowjacket Contact in and Adjacent to Hoodoo Creek and the Yellowjacket District

The major faults and the attitudes of the strata along the Hoodoo-Yellowjacket contact are shown on the accompanying geologic map (pl. 1). In the vicinity of Hoodoo Creek and the East Fork of Lake Creek, the two formations have been folded and probably refolded into a complex anticline (or anticlinorium). The belt of Hoodoo Quartzite from the vicinity of Wilson Creek and the Black Eagle mine on the northwest and Meadow Creek on the southeast defines the northeast or east limb of this complex anticline (pl. 1); the Hoodoo outcrops between Middle Fork Peak and the East Fork of Lake Creek compose remnants of the west limb. Just north of Middle Fork Peak, the Hoodoo-Yellowjacket contact is well exposed in an arête between a tributary of Jack Creek on the west and Lake Creek on the east. In these clean exposures, the contact is clearly gradational with beds of Hoodoo-type quartzite alternating with beds of Yellowjacket siltite-argillite and fine-grained argillaceous quartzite. From this locality northeastward, the beds of Yellowjacket Formation are tightly folded. Adjacent to the northwest-trending fault, however, most of the beds show tops to the west or southwest; this orientation suggests that the strata, despite the occurrence of minor folds, are still on the west limb of the regional fold. Still farther northeast, the northwest-trending fault, which is obviously a high-angle fault based on its topographic trace, is cut and offset left laterally by a northeast-trending high-angle fault. In this locality the Hoodoo Quartzite is shattered and brecciated (fig. 4, *A*) and weathers to weird monoliths or hoodoos. Ross (1934, p. 74) interpreted the brecciation as supporting evidence for a deep-seated thrust fault. However, I infer that the brecciation is more likely to have been produced by the interaction of the two high-angle strike-slip faults that fractured the near-surface strata. The East Fork of Lake Creek breaches the core of the anticline (pl. 1, *A–A′*), and the fold is well defined by attitudes of strata in both the Hoodoo and Yellowjacket Formations. Locally, however, attitudes of bedding are steeper than the gently dipping contact. Ross (1934, p. 34) noted this discordance; he interpreted the "nearly flat contact" between the two formations as a thrust fault. He failed to observe, however, that gentle dips are common in this area in both the Yellowjacket Formation and Hoodoo Quartzite (fig. 4, *C*). He did note (1934, p. 74) that, "On the east fork of Lake Creek the base of the formation (Hoodoo) is exposed, as is shown by the gray beds resembling the quartzite of the Yellowjacket Formation interbedded with typical white Hoodoo Quartzite." He concluded, on the basis of this observation, that in places the inferred thrust fault had to lie beneath the Hoodoo and cut the upper beds of the Yellowjacket. In my opinion, the local discordance between attitudes of bedding and the contact can best be explained by a combination of disharmonic folding, probable refolding, and the presence of minor folds. Ross mapped the contact on both sides of the East Fork as a thrust fault, but farther east, in exposures overlooking Hoodoo Creek, southwest of section *A–A′*, he mapped the contact as depositional except where two high-angle normal faults (pl. 1) otherwise juxtapose the two formations.

The breached anticline exposed along the East Fork of Lake Creek is inferred to be continuous, except for a probable left-lateral shift, with the fold exposed to the northwest in the canyon of Jack Creek (pl. 1). The attitudes in the vicinity of Jack Creek are from Cater and others (1973), who mapped the Hoodoo-Yellowjacket contact as depositional from Jack Creek on the south through Wilson and Alpine Creeks on the north (pl. 1).

Along section *A–A′* (pl. 1) near the junction of Black Eagle Creek and Hoodoo Creek, Ross (1934) mapped a high-angle fault that drops the Hoodoo on the west against the Yellowjacket on the east. This fault was traced far to the north during the present study and was observed to splay into two faults. In the vicinity of the splay, a gray dacite or diorite porphyry crops out. Because of poor exposure, it is not clear whether the intrusive rock predates or postdates the fault. The Hoodoo beds west of the intrusive locality dip about 5° northward and are part of the same gradational assemblage as that exposed along the East Fork of Lake Creek. West of this area of gentle dip, the Hoodoo Quartzite is so badly shattered that attitudes are difficult to decipher and those shown on plate 1 may not be meaningful. My mapping to the northeast of the area of shattered rock and the mapping of Cater and others (1973) and Mitchell and Bennett (1979) show that both the Hoodoo and Yellowjacket rocks are intruded there by numerous apophyses and larger masses of Cretaceous rocks of the Idaho batholith.

In the vicinity of the Black Eagle mine, top directions, based on fine-scale crossbedding in the Yellowjacket and large-scale crossbedding in the Hoodoo, show conclusively that the strata are younger from southwest to northeast. The fault through the Black Eagle mine area was mapped by Anderson (1953), who considered it to be a northwest-trending high-angle normal fault displaced in two localities near the Yellowjacket mine area by younger high-angle normal faults of northeast trend. The more westerly of the two northeast-trending faults (pl. 1) also was mapped by Ross (1934) and by Carter (1981). Carter considered that the fault had considerable left slip. Both northeast-trending faults are primarily left-slip faults because of the unreasonably large vertical throw required to offset the steep northwest-trending fault (or contact) by up-down movement.

Whether or not significant right-slip has occurred along the Hoodoo-Yellowjacket contact from the Black Eagle mine on the northwest through Meadow Creek on the southeast (pl. 1), the topographic trace of the contact is very linear all the way to its termination against the fault that drops the Tertiary volcanic rocks down on the east, and the trace conforms well to the generally steep attitudes observed in both formations. In exposures along Yellowjacket, Shovel, and Beagle Creeks, however, it is obvious that the top of the Hoodoo dips more gently toward the northeast than does the base, as was observed earlier by Ross (1934, p. 16).

In Yellowjacket Creek north of the principal reference locality of the Hoodoo Quartzite, the strike of the Hoodoo changes from northwest to north and thence to northeast (Bennett, 1977; K. Evans, written commun., 1984). The northeast strike and south dips persist to Quartzite Mountain and are reflected also in the overlying argillaceous quartzite exposed directly south of the mountain. These attitudes define a broad, southeast-plunging, open syncline or synclinorium. Along Shovel Creek, however, these argillaceous beds define an open syncline plunging to the northwest. Farther southeast in Fourth of July Creek, two attitudes suggest a syncline plunging very gently southeast. The overall scarcity of reliable attitudes in this region allows interpretations other than a broad, variously plunging syncline to be made, but one thing appears to be certain: The beds exposed within this structure must overlie the Hoodoo Quartzite. The broad syncline, in all probability, has been displaced southeastward by left-slip faulting at least 4 mi (6.4 km) from an original position nearer to Wilson Creek.

Because of a general absence of good top-direction data in the Yellowjacket Formation below the Hoodoo Quartzite in the areas just described, it is not at all clear what the intraformational structure really is. Is the structure actually homoclinal with minor overturning along Yellowjacket Creek as deduced by Ross (1934), or could the formation be tightly folded? If most of the bedding attitudes shown on plate 1 (exclusive of those beds whose crossbedding shows overturning) are of right-side-up beds, it seems inescapable that the Yellowjacket Formation along Yellowjacket and Black Eagle Creeks is tightly folded (pl. 1). As a consequence, the thickness of Yellowjacket measured by Ross (1934, p. 16) is excessive. Furthermore, the folding involving the thick, competent Hoodoo Quartzite must have been disharmonic, with the argillaceous Yellowjacket below the quartzite having been more tightly folded than the Hoodoo. After the original broad folds evolved, the Yellowjacket continued to respond plastically during perhaps several later compressional episodes, all probably with different stress orientations; the more brittle Hoodoo responded, however, by more open folding and by fracturing. Certainly, considerable fracturing and brecciation are evident within the Hoodoo throughout the area. Considerable internal slippage along numerous intraformational faults must also have taken place within the Hoodoo in several localities, for example, along Yellowjacket and Shovel Creeks where the unit goes from essentially vertical along the strike-slip fault to 25° near the contact with the upper Yellowjacket.

Structural Details in the Area East of Hoodoo Creek and the Yellowjacket District

The Hoodoo Quartzite east of the Yellowjacket mine, near the headwaters of Meadow Creek (pl. 1), is dropped down and deeply buried beneath thick Tertiary volcanics in the Panther Creek graben[2] (pl. 2). It reappears on Taylor Mountain east of the graben where it occupies the trough of the same syncline described above. The Hoodoo on Taylor Mountain is probably bounded by northwest-trending high-angle right-slip faults that have, in turn, been offset left-laterally by the Panther Creek graben fault system. The northwest-trending faults that bound Taylor Mountain were never actually observed, however, because of soil and alluvial cover, but some support for the high-angle right-slip interpretation is suggested by fractures on the west side of Iron Lake (pl. 2) that dip steeply to the west and east, parallel to the fault zone and show oblique slickensides plunging 30°–60° to the south (fig. 10). South of Iron Lake, in exposures along the Middle Fork of Hat Creek, beds of Apple Creek Formation striking northeastward are dragged into northwest strikes adjacent to a splay of this fault system (pl. 2). This drag, together with the oblique slickensides at Iron Lake, suggests a significant component of right slip along this fault zone, which bounds

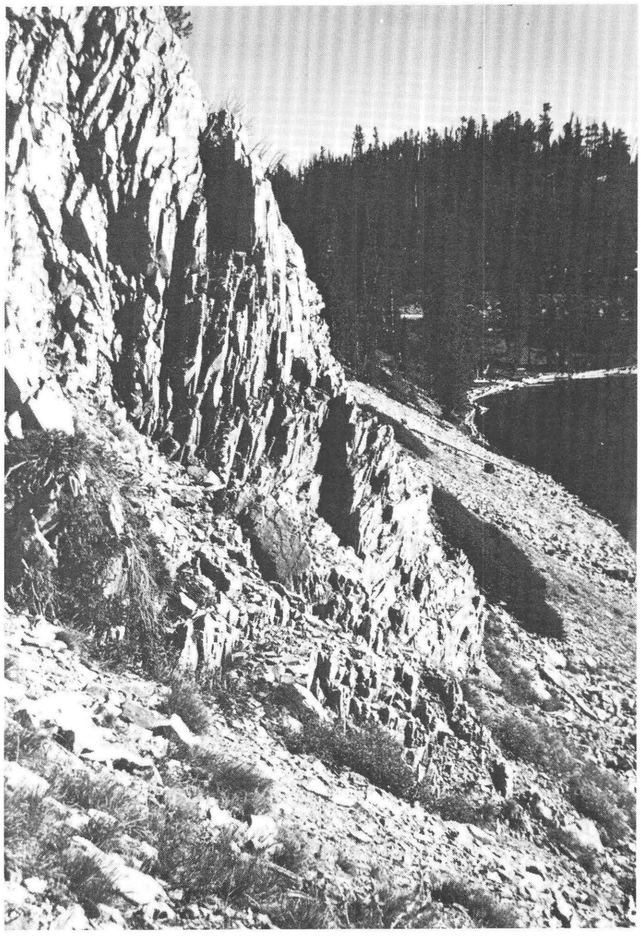

Figure 10. Close-spaced, near-vertical fractures in Hoodoo Quartzite on west side of Iron Lake. These fractures strike northwest, parallel to the fault that is inferred beneath the lake, and some show oblique-slip slickensides. These fractures are inferred to reflect the steep dip of the Iron Lake fault.

[2]The Panther Creek graben is asymmetric with only minor displacement on its west side and at least 2,000 m on its east side. Faults on the east side show oblique-slip slickensides in the Singheiser and Rabbit Foot mines (see later pages).

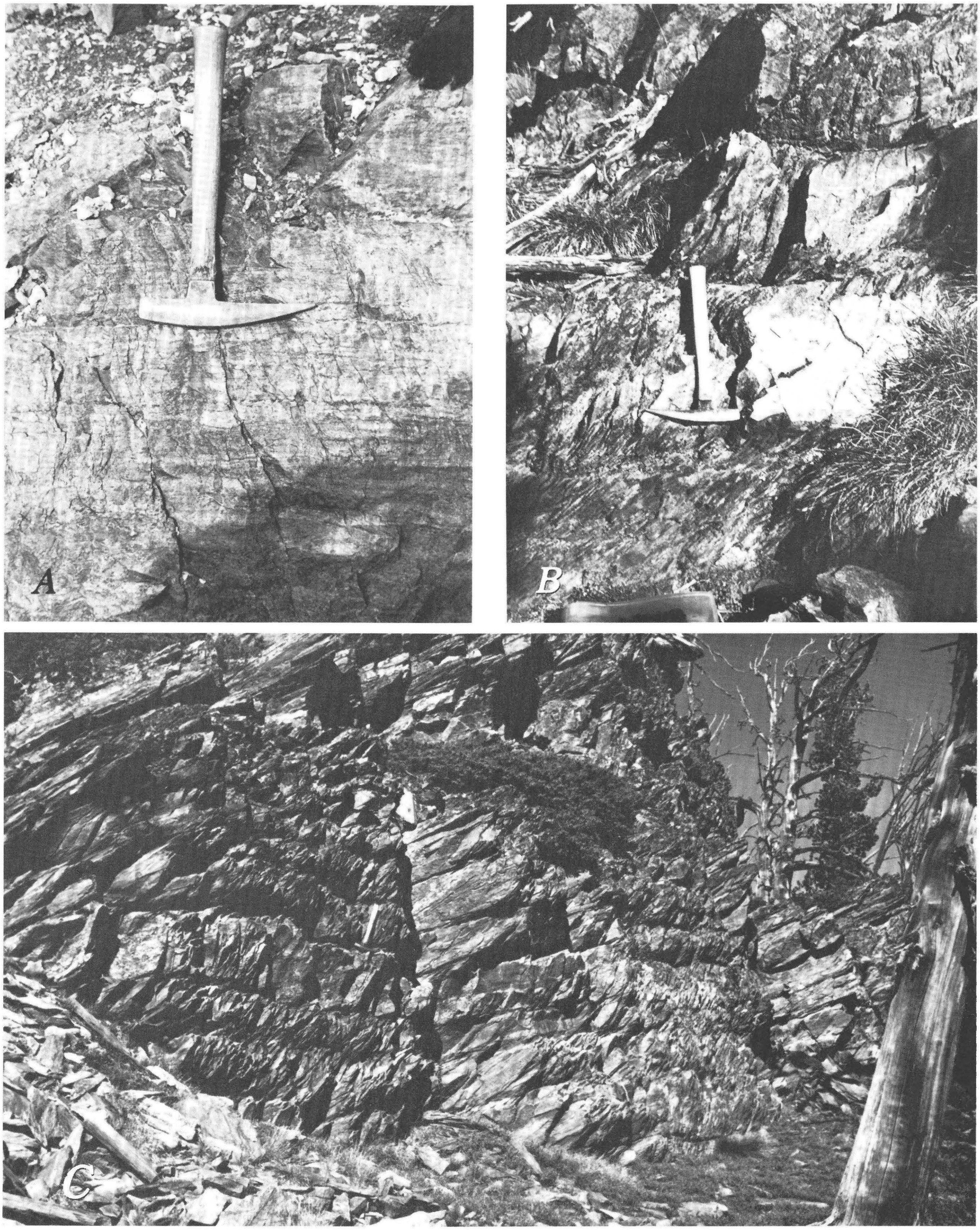

Figure 11. Argillaceous beds in Apple Creek Formation east of Iron Lake. This sequence was mapped as part of the Yellowjacket Formation in an earlier report (Fisher and others, 1983). *A*, Laminated white and light-gray, argillaceous, fine-grained quartzite. *B*, White, fine-grained, argillaceous quartzite and gray siltite-argillite in zone of strong slaty cleavage. Note refraction of cleavage at contacts between siltite and quartzite. *C*, Gray, even-bedded, strongly cleaved argillite and siltite.

Taylor Mountain on its northeast side. The topographic trace of the main splay of the fault through the Iron Lake vicinity, separating Hoodoo Quartzite from siltites of the Apple Creek Formation, indicates an average dip to the west of about 60°. This dip, together with the occurrence of younger rocks (mapped herein as Apple Creek Formation; fig. 11) to the east of the fault, suggests the possibility that the fault originated as a reverse fault and was reactivated as an oblique-slip fault during Tertiary time. It was interpreted as a thrust fault by C. D. Durgin (in Rember and Bennett, 1979).

Northwest of Iron Lake, in Moyer Creek, displacement along the Iron Lake fault apparently is principally normal or dip slip. The fault separates a thick Tertiary volcanic and graben-fill assemblage from west-dipping Yellowjacket. A strong fault that is part of the Panther Creek graben system extending northeastward from the Rabbit Foot mine (pl. 2) appears to end against the northwest-trending fault. The Rabbit Foot fault, which drops the volcanic and basin-fill assemblage against the Hoodoo Quartzite at Opal Creek, shows left-lateral oblique-slip slickensides in both the Rabbit Foot and Singheiser mines (pl. 2).

The fault along the west flank of the Taylor Mountain block is inferred to be the same fault as at the Black Eagle mine. It shows as an extremely sharp line unaffected by topography on aerial photographs, but it is concealed by alluvium and thin scree of Hoodoo Quartzite on the ground. Attitudes of bedding in the Hoodoo Quartzite at Opal Lake and in exposures farther south show that the fault parallels the strike of bedding as it does at the Black Eagle mine and Meadow Creek.

DISCUSSION, CORRELATIONS, AND CONCLUSIONS

The data presented here show that the base of Hoodoo Quartzite is transitional with the underlying Yellowjacket. Structural and stratigraphic discontinuities that exist locally at the base can be easily accounted for by disharmonic flexing, probable refolding, and the development of minor folds at the contact between two sequences having radically different physical properties. If actual thrusting has occurred anywhere in the belt of outcrops from Hoodoo Creek on the west to Taylor Mountain on the east, it is a local phenomenon without regional significance.

The gradational contact of the Hoodoo Quartzite with the Yellowjacket Formation and the occurrences of mudcracks in the Yellowjacket Formation together with thick carbonate zones in both formations indicate a shallow-marine, probable miogeoclinal environment for both formations in the vicinity of Hoodoo Creek and the Yellowjacket district. The Yellowjacket possibly grades northward and northeastward into a deep-marine turbidite environment, but the scarcity of well-graded beds in those areas and the occurrences of massive beds of clean quartzites, although only a few meters thick, make a turbidite origin uncertain.

The tentative correlation of the Hoodoo Quartzite with the Big Creek Formation of the Lemhi Group (Ruppel, 1975; Lopez, 1982) is incorrect. Lopez further postulated that the Hoodoo Quartzite at Hoodoo Creek is actually the Swauger Formation and that the quartzite on Taylor Mountain is either the Big Creek or the Swauger Formation. The two possibilities are both untenable on the basis of mineral content and megascopic characteristics. The Big Creek exposed along Patterson Creek near its type locality in the Lemhi Range (see Ruppel, 1975) is green gray, very feldspathic, and quite micaceous. Three thin sections from the Lemhi Range supplied by Lopez contained 7–40 percent sericite and 10–40 percent feldspar consisting of subequal albite and potassium feldspar. Quartz content ranged from 47 to 58 percent, averaging only 51 percent for the three thin sections and, except for a few scattered quartz "berries" as large as 1 mm and visible in hand specimen, the quartz averaged less than 0.3 mm in thin section. In contrast, the Hoodoo Quartzite on Taylor Mountain, except for a few thin interbeds of schistose biotite-rich siltite contains a minimum of 80 percent quartz, mostly about 90 percent, and the quartz grains commonly are as large as 0.8 mm. The Hoodoo is typically white or rarely, brownish white—not greenish gray, the typical color of the Big Creek Formation. The Hoodoo Quartzite at Iron Lake does not resemble either the Big Creek or the Gunsight Formations of the Lemhi Group, but does closely resemble the quartzite beds in the Yellowjacket Formation of the Lemhi Range (E. T. Ruppel, oral commun., 1981).

The Hoodoo Quartzite at Taylor Mountain is lithologically distinct from the Swauger Formation. According to Hobbs (1980) and McIntyre and Hobbs (1978), the Swauger is characterized by a distinctive pale-purple, light-pink, or pale-purple-red color; however, like the Hoodoo it is generally quite pure vitreous quartzite. Quartz grains (0.1–0.75 mm) make up from 80 to 97 percent of the quartzite beds and are generally well sorted in any one layer. Feldspar may range up to 10 percent, but is most commonly less abundant. The Hoodoo on Mount Taylor definitely is not the Swauger because it lacks the distinctive "Swauger color" (S. W. Hobbs, oral commun., 1979).

These facts indicate that the Hoodoo Quartzite can be distinguished from the Swauger Formation and formations of the Lemhi Group on the basis of mineralogy or color or both.

Ordovician lead-uranium dates on zircons from syenite that intrudes the Yellowjacket Formation and Hoodoo Quartzite in the vicinity of Middle Fork Peak (pls. 1 and 2) apparently indicate that the Hoodoo and Yellowjacket were extensively folded there prior to intrusions of various Ordovician syenite, quartz syenite, and diorite plutons (also see Evans and Zartman, 1981b).

Whether or not Proterozoic rocks younger than the Yellowjacket-Hoodoo sequence and Cambrian-Lower Ordovician rocks overlay the Yellowjacket and Hoodoo at the time the Ordovician intrusions occurred cannot be determined. Presumably, in central Idaho, all Proterozoic rocks younger than the Yellowjacket-Hoodoo sequence and all Paleozoic rocks are allochthonous with respect to the Yellowjacket and Hoodoo (Ruppel, 1975, 1978); therefore, their lithologies shed no light on the presence or absence of local Ordovician plutons autochthonous to this region. The possibility exists that the folded and intruded Yellowjacket-Hoodoo terranes may have stood as subaerial landmasses for long intervals during Late Proterozoic and early Paleozoic time. In essence, a considerable part of the geologic record in this region apparently is lost.

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