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Revision of Middle Proterozic Yellowjacket Formation, Central Idaho, and Revision of Cretaceous Slim Sam Formation, Elkhorn Mountains Area, Montana

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By R.G. Tysdal

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B. Revision of Cretaceous Slim Sam Formation, Elkhorn Mountains Area, Montana
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Contents

Figures

Table

Revision of Middle Proterozoic Yellowjacket Formation, Central Idaho

By R.G. Tysdal

Abstract

The Proterozoic Yellowjacket Formation is restricted to the strata originally assigned to it by Ross (1934). The Yellowjacket is conformable beneath the Hoodoo Quartzite, which in turn is conformable beneath an unnamed argillaceous quartzite unit. The three units constitute a genetically related sequence of strata that lies in a structural block delimited on the northeast by the Iron Lake fault. This fault and the strata northeast of it are truncated on the west by the younger Quartzite Mountain fault. Directly northeast of the Iron Lake fault, strata currently assigned by others to the lower subunit of the Yellowjacket are correlated with the Apple Creek Formation in the northern part of the Lemhi Range. The Yellowjacket name should not be applied to the lower subunit or to strata that lie above it.

Mapping in the western part of the Lemhi Range shows that the Apple Creek Formation lies depositionally above the Big Creek Formation and that no rocks of the Yellowjacket-Hoodoo-unnamed unit stratigraphic sequence are present. In contrast, in the area of the Yellowjacket mapped by Ross (1934) and the area directly northeast of the Iron Lake fault, the Big Creek Formation is absent, even though it is 2,700 m thick in the Lemhi Range. A small sliver of the Big Creek is present in the southeastern part of the Salmon River Mountains, however. These data indicate that the Iron Lake fault juxtaposed the Yellowjacket-Hoodoo-unnamed unit stratigraphic sequence against non-Yellowjacket strata to the northeast.

Introduction

This report builds on recent geologic mapping, stratigraphic, and sedimentologic studies in the northern part of the Lemhi Range. Its goal is to correlate Middle Proterozoic strata in the Lemhi Range with strata in the Salmon River Mountains and reconcile differences of interpretation and nomenclature. The initial correlation of the Proterozoic strata in these two ranges was made by Ruppel (1975) in conjunction with his mapping in the central part of the Lemhi Range. Ruppel (1975) set the stage for subsequent workers on Proterozoic stratigraphy in central Idaho by determining the stratigraphic succession during the course of his geologic mapping (Ruppel, 1968, 1980; Ruppel and Lopez, 1981). Although Ruppel conducted no detailed mapping in the northern part of the Lemhi Range, he (Ruppel, 1975, p. 5–6) interpreted strata there to be older than Proterozoic rocks to the south and to be the lowest Precambrian rocks exposed in central Idaho, which "...are here correlated on the basis of lithologic similarity with the Yellowjacket Formation of central Idaho as defined by Ross (1934, p. 16)." Subsequent mapping by Tysdal (1996a, 1996b) and Tysdal and Moye (1996) showed that the Proterozoic strata in the northern part of the Lemhi Range are contiguous with strata in the central part, comprised of the Lemhi Group (in ascending order, Inyo Creek, West Fork, Big Creek, Apple Creek, and Gunsight Formations) and the overlying Swauger Formation (table 1). Connor (1990a, 1991) previously had correlated some of these same strata in the northern part of the Lemhi Range with rocks in the Salmon River Mountains that he considered to be Yellowjacket Formation. This report discusses stratigraphic and structural data in the area in which the Yellowjacket was originally named by Ross (1934), bringing new geologic mapping and sedimentologic data into consideration to reinterpret application of the name Yellowjacket Formation and to refine stratigraphic correlations.

The Yellowjacket Formation was named by Ross (1934) for a sequence of clastic rocks present in the vicinity of the Yellowjacket mine and the townsite of the same name in the Salmon River Mountains of central Idaho (fig. 1). No strata are exposed beneath the Yellowjacket Formation, but it is overlain by the Hoodoo Quartzite, also named by Ross (1934), and is discussed herein because its history is directly related to that of the Yellowjacket.

Ross (1934) mapped about 50 km^2 of Yellowjacket and Hoodoo strata south of lat 45°N. in the vicinity of the townsite of Yellowjacket (fig. 1). His description of the two units was based on a section measured for "about 4.5 mi [7 km] along the road up Yellowjacket Creek" (Ross, 1934, p. 15), starting from the processing mill for the Yellowjacket mine, which is at the edge of the townsite of Yellowjacket (fig. 2). The route included about 2.5 km of traverse within his map area and extended about 5 km beyond, to the northeast. No type section or locality was formalized for either formation,[1] but Ekren (1988) designated the measured section of Ross (1934) as the principal reference section for both formations.

The upper contact of the Yellowjacket is transitional into the Hoodoo in the general area, but was reported to be a thrust fault in some places (Ross, 1934). Ekren (1988) concluded this contact is depositional except where the two formations are juxtaposed along high-angle faults, one of which is at the base of steeply dipping beds of Hoodoo in the measured section of Ross (1934). The high-angle faults display a component of lateral slip (Ekren, 1988).

[1] Naming of the Yellowjacket Formation preceded the necessity of designation of a type section according to the guidelines of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983).

Table 1. Correlation diagram for Middle Proterozoic rocks of east-central Idaho.

[Diagram is separated into upper and lower parts. Some workers interpreted the Yellowjacket Formation to underlie the Lemhi Group and superjacent strata; other workers considered the typeYellowjacket (of Ross, 1934) (leftmost column) to be separated by a fault from other rocks. I interpret the type Yellowjacket, Hoodoo, and unnamed overlying unit to be part of a structural block juxtaposed against the Lemhi Group and superjacent rocks. Upper part of diagram shows lateral correlation of rock units. Lower part of diagram shows lateral correlation of only the three units of Ross (1934); the other units of the lower part are a mix of units of Ross (1934) and units of the Lemhi Group and superjacent strata, as explained in the text. Dark shading indicates Yellowjacket Formation as defined and mapped by Ross (1934) and rock units of subsequent workers that I interpret to be the same formation. Light shading indicates Apple Creek Formation as defined and mapped by Anderson (1961) and rock units of subsequent workers that I interpret to be the same formation. Interpretation is necessary because maps of authors locally or regionally include rocks that I believe are of formations other than those to which they were assigned due to unrecognized faults, contacts, misinterpretation of contrasting depositional environments, or names introduced subsequent to an author's mapping. No thickness of formations is implied. “Height” of boxes is greater for some units to accommodate different nomenclatures and (or) subdivisions of formations]

Ross (1947), upper column. Ross (1934), lower column.	**Ruppel (1975)**	**Lopez (1981)**	**Ruppel and Lopez (1988)**	**Bennett (1977)**	**Connor and Evans (1986); Connor (1990A); Evans and Connor (1993); Evans (1999)**	**Ekren (1988)**	**Winston and Link 1993)**	**Tysdal and Moye (1996), Tysdal (1996a, b, 2000) and THIS REPORT**	**Tietbohl (1981, 1986)**	**Anderson (1961)**
			Lawson Creek Fm				Lawson Creek Fm	Lawson Creek Fm		
Swauger Fm	Swauger Fm	Swauger Fm	Swauger Fm				Swauger Fm	Swauger Fm		Swauger Fm
	Gunsight Fm		Gunsight Fm				Yellow- Mem E	Gunsight Fm		Lemhi Quartzite
	Apple		Apple				Mem B, C, D	Apple *c. siltite*	Apple Creek Fm	Apple
Lemhi	Creek		Creek				jacket	Creek *diamictite*	diamictite	Creek Fm
Quartzite	Fm		Fm				Fm	Fm *f. siltite*	Big	
	Big		Big				Big		Creek	
	Creek Fm		Creek Fm	Hoodoo Quartzite			Creek Fm	Big Creek Fm	Fm	
	West Fork Fm		West Fork Fm				West Fork Fm	West Fork Fm		
	Inyo Creek Fm		Inyo Creek Fm				Inyo Creek Fm	Inyo Creek Fm		
								FAULT		
Unnamed unit	**THRUST FAULT**	**FAULT**	**THRUST FAULT**			Unnamed unit		Unnamed unit		
Hoodoo Quartzite						Hoodoo Quartzite		Hoodoo Quartzite		
Yellowjacket Fm	Yellow-	Yellow- Mem E	Yellow- Mem E	Yellowjacket	Yellow- U	Yellowjacket Fm		Yellowjacket Fm		
		Mem D	Mem D	Fm Phylite L	M					
	jacket	jacket Mem C	jacket Mem C		jacket L					
		Mem B	Mem B		Hoodoo Quartzite L					
	Fm	Fm Mem A	Fm Mem A		Fm L					

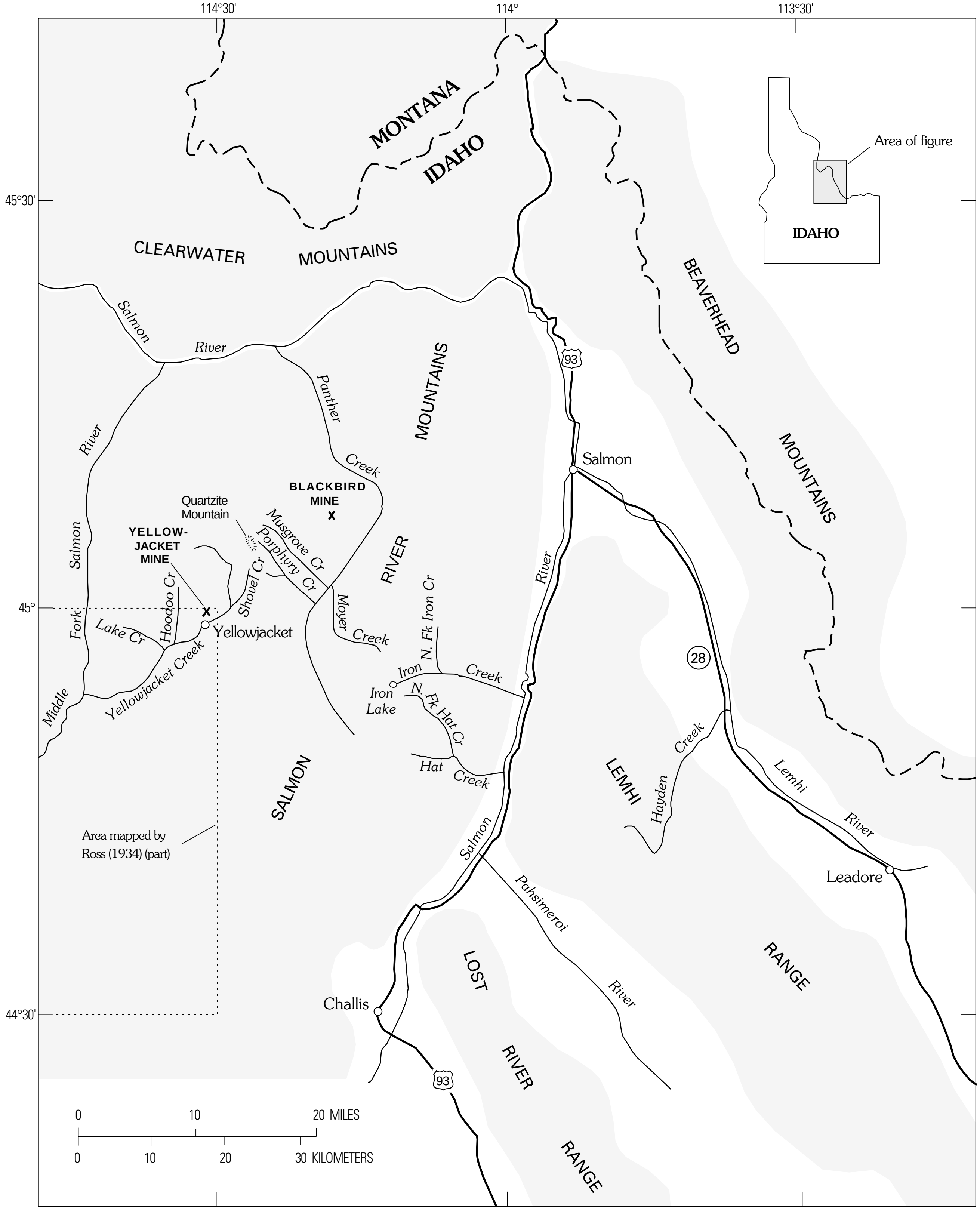

Figure 1. Index map of east-central Idaho, showing major geographic features. Shading indicates mountain ranges.

The upper contact of the Hoodoo along the measured section was found to be gradational into a unit of banded, slightly calcareous quartzite. The quartzite unit is not present in the 50 km^2 area mapped by Ross, although present north of his map area, and was not assigned a formal name; Ekren (1988) did not apply a formal name to the unit either. The conformable succession of the Yellowjacket of Ross (1934), Hoodoo Quartzite, and the overlying unnamed unit constitute a genetically related sequence of strata mainly deposited in shallow subtidal, intertidal, and perhaps supratidal environments.

North and east of the area of Ross' (1934) work, several authors (Vhay, 1948; Bennett, 1977; Hughes, 1983; Hahn and Hughes, 1984; Lopez, 1981; Connor and Evans, 1986; Ekren, 1988; Fisher and others, 1992; Evans and Connor, 1993; and Evans, 1999) applied the Yellowjacket name to strata in an extensive area of the Salmon River Mountains (table 1). Application of the Yellowjacket name in this extensive area is called into question for the following reasons: (1) The stratigraphic sequence of the Yellowjacket, Hoodoo, and overlying unnamed unit lies in a structural block (sheet?) delimited on the northeast by the Iron Lake fault and on the west by the Quartzite Mountain fault (fig. 2). (2) Rocks of the stratigraphic sequence were deposited in shallow subtidal to upper intertidal environments in contrast with deeper water turbidite strata directly north and east of the faults and in contrast with the turbidites that constitute some of the rocks described by Lopez (1981), Sobel (1982), Hughes (1983), and Hahn and Hughes (1984) and assigned to the Yellowjacket in the general area that includes the Blackbird mine and the North Fork of Iron Creek (figs. 1, 2). (3) North of the Iron Lake fault and east of the Quartzite Mountain fault, the lower subunit of the Yellowjacket, as used by Connor and Evans (1986), Connor (1990a), and Evans and Connor (1993), is correlatable with the Apple Creek Formation (named by Anderson, 1961) in the northern part of the Lemhi Range (Connor, 1990a, 1991). Mapping in the Lemhi Range (Tysdal, 1996a, 1996b, in press; Tysdal and Moye, 1996) revealed that the Apple Creek lies depositionally above the Big Creek Formation (named by Ruppel, 1975) and that no "type" Yellowjacket, Hoodoo, or unnamed post-Hoodoo strata are present. The Big Creek, about 2,700 m thick in the Lemhi Range, is absent from the area of the Yellowjacket as mapped by Ross (1934) and from the area directly north of the Iron Lake fault near its junction with the Quartzite Mountain fault. Two slivers of the Big Creek are present in the southeastern part of the Salmon River Mountains, one of which is in fault contact with the Swauger Formation (fig. 2, long 114°W., near Lem Peak fault).

The purpose of this paper is to restrict the Yellowjacket name to the strata beneath the Hoodoo Quartzite, as the name was applied originally by Ross (1934). Strata directly above the Hoodoo remain unnamed. The most recent maps of the extensive area of the Salmon River Mountains directly north of the Iron Lake fault are those of Connor and Evans (1986), Connor (1990a, 1991), and Evans and Connor (1993). These maps were completed prior to mapping and other studies in the northern part of the Lemhi Range (Tysdal, 1996a, 1996b, 1996c, in press) that permit correlation and reconciliation of strata in the two mountain ranges. The nomenclatural changes advocated here reflect this more recent work. Strata mapped and assigned to the lower subunit of the Yellowjacket by Connor and Evans on their maps here are reassigned to the Apple Creek Formation, with which they are contiguous (table 1), as Connor (1990a, 1991) recognized. No correlation of the post-Apple Creek strata previously assigned to the Yellowjacket Formation is undertaken here, and the middle and upper units of the Yellowjacket, as the name is used by Connor and Evans in their papers, are not renamed. The Yellowjacket name should not be applied to them, however, because the mapping and other work of Connor and Evans determined that these strata constitute a conformable sequence above their lower subunit of the Yellowjacket.

The change in status of the name Yellowjacket Formation advocated in this report restricts the name to the strata to which it was applied originally by Ross (1934). An alternative is to raise the name Yellowjacket to Supergroup status, thus including all of the rocks to which the Yellowjacket name is now applied, and including the Lemhi Group as a subdivision. This latter approach has merit because the Yellowjacket name has been applied to virtually all of the strata within the Salmon River Mountains, including correlatives of units of the Lemhi Group that lie within the Salmon River Mountains and some units within the Lemhi Range and Beaverhead Mountains as well. However, this approach still requires that a new name be applied to each mappable unit that presently has Yellowjacket in its name (for example, lower subunit of Yellowjacket Formation). Furthermore, a new name would have to be applied to strata of the Yellowjacket Formation as originally mapped by Ross (1934). Restricting the Yellowjacket name to the stratigraphic unit to which it was applied originally requires less revision of nomenclature than elevating the name to Supergroup status.

A brief description of the formations discussed in this report is presented first, followed by structural and stratigraphic arguments that led to the interpretations presented here; this is followed by a section that reconciles the interpretations presented with previous interpretations of other workers. Measurements in this manuscript are reported in metric units. English units are given, in parentheses following metric units, only where an original measurement was in English units.

Stratigraphic Units

The brief descriptions of stratigraphic units presented here are separated into those (1) in the vicinity of the townsite of Yellowjacket to Quartzite Mountain to the Iron Lake area of the Salmon River Mountains, and (2) in the western part of the Lemhi Range (fig. 2). Formations described under the Salmon River Mountains heading occur only in those mountains; the other formations described are present in both the Lemhi Range and the Salmon River Mountains.

Yellowjacket–Quartzite Mountain–Iron Lake Area of Salmon River Mountains

Yellowjacket Formation (Restricted)

The Yellowjacket Formation (restricted) is the formation as delimited originally by Ross (1934) who described it as consisting of about 2,743 m (9,000 ft) of strata, of which the lower 518 m (1,700 ft) are calcareous beds, the remainder quartzitic beds. The calcareous beds were described as containing differing amounts of carbonates and lime silicates, intertonguing with quartzitic beds, and dying out along strike. The strata have been metamorphosed to the upper greenschist facies. Some beds are banded, others are mottled with clusters of dark metamorphic minerals, including scapolite. Carter (1981) determined that the calcareous rocks form discrete lenses. The quartzite beds above

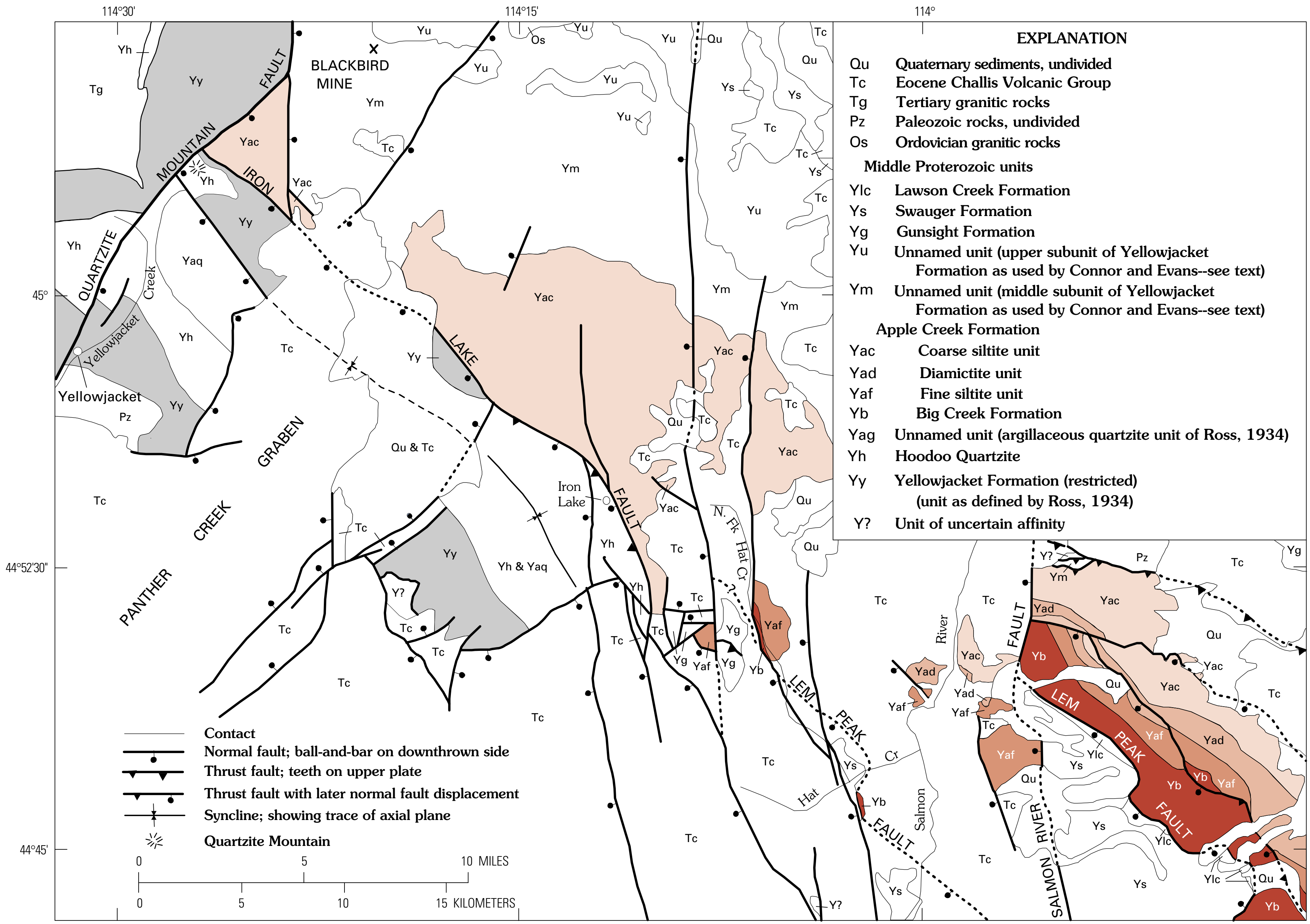

Figure 2. Geologic map of contiguous areas in western part of Lemhi Range and southern part of Salmon River Mountains. Compiled from Bennett (1977), Connor (1990a), Connor and Evans (1986), Ekren (1988), Evans and Connor (1993), Fisher and others (1992), Tysdal (1996a, 1996b, unpub. mapping), Tysdal and Moye (1996).

the calcareous sequence are dark gray, dark bluish gray, or locally white and, in general, contain about 70 percent quartz, 15 percent biotite (or chlorite altered from biotite), with the remainder mainly feldspar (Ekren, 1988). Reconnaissance examination of some of the lower strata of the Yellowjacket in the principal reference section led to the recognition of metaevaporite strata (Tysdal and Desborough, 1997).

The upper few hundred meters of the Yellowjacket Formation (restricted), that is, the Yellowjacket Formation of Ross (1934), was examined in several places by the author. These strata consist of fine- to medium-grained siltite, and several-meter-thick sequences of interbedded siltite and 2- to 10-mm-thick layers of argillite (metaclaystone). The most characteristic feature of the upper strata is ripple crosslamination. Other common features include mudchips, fluid-escape structures, local herringbone crosslamination, climbing ripples, mudcracks, and syneresis cracks. Load casts only a few millimeters thick also are present. Some argillite layers show “pull-apart” structures, as if clay layers shrank and pulled apart while drying. Locally, mudchips are imbricated in opposing directions, suggesting reversing currents.

From examination of Yellowjacket (restricted) strata in the vicinity of Yellowjacket Creek, Ekren (1988) concluded that the rocks were deposited in a shallow-marine environment, thus agreeing with Ross (1934), Anderson (1953), and Carter (1981). The sedimentary structures and sharply bounded beds of (1) finely laminated argillite and mudcracked argillite alternating with (2) coarse-grained ripple crosslaminated siltite is indicative of deposition from currents of alternating flow intensities, suggesting a tidal environment.

The name Yellowjacket Formation as used henceforth in this report refers to the unit as restricted to the sequence named by Ross (1934). For other strata that have been assigned to the Yellowjacket, the name will be qualified: for example, the Yellowjacket of Connor and Evans (1986).

Hoodoo Quartzite

The Hoodoo Quartzite was named by Ross (1934) for strata exposed near Hoodoo Creek, northwest of the townsite of Yellowjacket (fig. 1). Ross (1934) measured 1,085 m (3,560 ft) of the Hoodoo Quartzite in his section along Yellowjacket Creek. Ekren (1988) stated that the Hoodoo averages about 85 percent well-rounded quartz grains, 5–15 percent feldspar, and 0–10 percent biotite and sericite, indicative of upper greenschist facies metamorphism. The unit is generally light gray to white but locally is brownish gray to somber gray. The quartzite is massive, beds indistinct, but crosslamination is distinct. Oscillatory and current ripples are present throughout the unit. Ekren (1988) described local thin units of marble interbedded with calcareous quartzite in the basal part of the formation. He stated that the units consist of quartzite a few centimeters thick, with little or no calcite, that alternate with strata containing more calcite and calc-silicate minerals than quartz.

Near Lake Creek (fig. 1, about 7 km west of the townsite of Yellowjacket), Ekren (1988) determined the basal part of the Hoodoo is transitional throughout a 200-m interval into the underlying Yellowjacket. The Hoodoo transition zone consists 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. The Hoodoo also is demonstrably transitional into the Yellowjacket near McEleny Mountain (about 5 km northwest of the Yellowjacket mine, fig. 1) (K.V. Evans, oral commun., 1997). The Hoodoo is interpreted as a shallow subtidal to intertidal deposit. The absence of silt and clay, and the ubiquitous high-angle crosslamination, suggest high-energy conditions.

Unnamed Argillaceous Quartzite

Lower strata of the post-Hoodoo rocks form the uppermost strata in the measured section of Ross (1934, p. 16). He recognized these rocks as being different from the formations below and did not apply a formal name to them. Ross described these rocks, which lie outside his map area (fig. 1), as distinctly banded, gray, slightly calcareous quartzites that are conformable above the Hoodoo. The rocks have been metamorphosed to the upper greenschist facies. Ekren (1988, p. 8), who also left the unit unnamed, described the change from the Hoodoo as transitional through “several hundred meters.” He stated that the unit is mainly bluish-gray to gray, argillaceous, fine-grained quartzite and siltite. My observations show abundant cross-beds, ripple crosslaminations, and local rip-up clasts. The unit contains beds of quartzite and quartz-rich metasandstone that are interlayered with beds of fine- to medium-grained argillaceous siltite. These alternating lithologies reflect contrasting energy conditions and, combined with the sedimentary structures, suggest intertidal deposition.

Western Part of Lemhi Range

Big Creek Formation

The Big Creek Formation is generally light-gray, coarse-grained siltite to medium-grained and locally coarse-grained metasandstone composed of quartz, feldspar, and auxiliary tourmaline with lesser other heavy minerals. Distinguishing characteristics throughout much of the formation include carbonate laminae that are oxidized to pale yellowish brown, and dark-gray heavy mineral laminae (tourmaline and zircon), typically only 1–2 grains thick. Cross-beds are widespread and record both northeast and southwest transport. Dark-gray argillaceous siltite zones a few meters thick are present in the upper part and display flaser and lenticular bedding. Beds commonly are about 1 m thick. The upper contact is unconformable, marked by the abrupt appearance of gray-green fine siltite of the Apple Creek Formation. The formation is about 2,700 m thick, deposited in shallow subtidal and intertidal environments (Tysdal, 2000).

Apple Creek Formation

The Apple Creek Formation was named by Anderson (1961) for strata near Hayden Creek on the northeast flank of the central part of the Lemhi Range (fig. 1). The original name was the Apple Creek Phyllite. Tietbohl (1981, 1986) separated a unit of diamictite from the Apple Creek, studied its depositional environment, and mapped part of its extent. Tysdal (1996a) remapped the diamictite and other rocks of the Apple Creek of Anderson (1961) and contiguous rocks to the west (Tysdal, 1996b; Tysdal and Moye, 1996).

Within the Apple Creek Formation, the geologic map of Anderson (1961) included three genetically related gravity-flow units as well as strata of the Big Creek Formation that are in fault contact with the Apple Creek. Tysdal (1996a, 1996b; Tysdal and Moye, 1996) mapped the three units separately and referred to them as informal units, which in ascending order are as follows: fine siltite unit, diamictite unit, and coarse siltite unit. The fine siltite unit is unconformable above the Big Creek Formation (Tysdal, 1996a, 1996b; Tysdal and Moye, 1996). In the central part of the Lemhi Range, the map of Ruppel (1980) generally included the fine siltite unit in the upper part of the Big Creek Formation, but Ruppel did not describe its character as being distinct from that of most of the Big Creek (Ruppel 1975; Ruppel and Lopez, 1988). The diamictite unit, conformable above the fine siltite unit (Tysdal, 1996b), was assigned to the lower subunit of the Yellowjacket strata by Evans (1999). The coarse siltite unit, conformable above the diamictite unit, correlates with the lower subunit of the Yellowjacket Formation of Connor and Evans (1986), Connor (1990a), Evans and Connor (1993), and Evans (1999) in the Salmon River Mountains west of the Lemhi Range, as Connor (1990a, 1991) recognized previously.

Fine Siltite Unit

The fine siltite unit is greenish-gray to olive-gray, planar-laminated and ripple crosslaminated, fine-grained siltite and argillaceous siltite. In some beds, planar laminations grade upward to small-scale (1–3 cm) sets of ripple crosslaminated siltite. Water-escape structures are present locally in planar-laminated strata. Many beds are graded, with 1- to 2-cm-thick strata of light-gray, medium- to fine-grained siltite grading upward into dark-gray fine-grained siltite. The upper part of unit contains sparse, local, matrix-supported, gravel-size argillite clasts in horizons 1–2 clast diameters thick. The fine silt and clay content is greater in the upper part of the unit than in the lower part. The upper contact is conformable, marked by the abrupt appearance of beds of diamictite. The thickness is estimated at 1,000 m.

Diamictite Unit

The diamictite unit is generally intensely cleaved, obscuring sedimentary features, and is composed of gray-green argillite, argillaceous siltite, and fine- to medium-grained siltite. Graded beds are obvious where deformation is not intense. Pebbly strata form sequences a few meters thick that alternate with nonpebbly argillite and siltite. Pebbles are dispersed, matrix-supported, and typically 1–5 cm in diameter. The upper contact is gradational into the coarse siltite unit. The thickness is uncertain due to deformation but is estimated to have a range of about 600 m on the west (fig. 1, near the Salmon River) to 1,000–1,500 m in the east (Hayden Creek area) (Tysdal, 2000).

Coarse Siltite Unit

The coarse siltite unit is composed of gray-green medium- to coarse-grained siltite and fine-grained sandstone, metamorphosed to lower greenschist facies. It contains distinctive, erosionally based, graded beds, as thick as 50 cm, of light-gray quartz-rich coarse-grained siltite to fine-grained metasandstone that grades upward into gray-green, medium-grained siltite. These beds are most abundant in the lower part of the unit. Upper strata of the unit generally are fine- to medium-grained siltite that locally contain soft-sediment deformation structures. The preserved thickness of the unit is about 2,000–2,500 m (Tysdal, 2000).

Gunsight Formation

The description of the Gunsight Formation is summarized from McBean's (1983) study of the type section in the central part of the Lemhi Range. The Gunsight, 1,800+ m thick, is mainly a sandstone unit comprised of feldspar and quartz that is metamorphosed to the lower greenschist facies. The feldspar content ranges from 25 to 55 percent, although in the uppermost 100+ m, transitional into the Swauger Formation, the formation is 80–90 percent quartz. The matrix content ranges from 0 to 8 percent, except in the lower 450 m where it is 2–40 percent and the formation is comprised of interbedded siltite, argillite, and very fine grained metasandstone. The remaining 1,375 m of the Gunsight is pale brown to gray, very fine grained to medium-grained metasandstone that coarsens upward through the section. Sedimentary structures include trough and planar cross-laminated strata; parallel ripple and climbing ripple laminations; dewatering structures; straight-crested, asymmetrical ripples and oscillation ripples. Heavy minerals also are present. McBean (1983) concluded that the sequence was deposited in a nearshore environment; however, reconnaissance examination of all but the lower and uppermost part of the type section of this formation suggests a fluvial depositional environment (D.A. Lindsey, oral commun., 1996). The lowest part, with its higher content of fines, may represent subtidal and intertidal environments.

Swauger Formation

The Swauger Formation is light-gray, pale-green, to pale-red-purple, medium- to coarse-grained orthoquartzite (at least 95 percent quartz) or quartzite (90 percent or more quartz), metamorphosed to lower greenschist facies. Quartz grains are well rounded, well sorted, tightly cemented, and glassy. Beds are about 1 m thick and appear massive or display foresets of crosslamination. Current ripples are present on some bedding planes, and partings of dark-gray siltite or argillite separate beds in some areas (Tysdal, 2000). The lower contact is gradational with the underlying Gunsight Formation. The thickness in the Lemhi Range was estimated at 3,100 m (10,000 ft) by Ruppel (1975, 1980).

Structural and Stratigraphic Patterns

Regional Patterns

The stratigraphic sequence of the Yellowjacket Formation (restricted), Hoodoo Quartzite, and overlying unnamed unit in the southern part of the Salmon River Mountains has never been found in depositional contact with other Proterozoic rocks, and no bottom or top is known (Ekren, 1988, p. 10). Rocks of this sequence were deposited mainly in shallow-water and tidal-flat environments, in strong contrast to the turbidites that constitute some of the strata assigned to the Yellowjacket Formation by other workers in the general area that includes the North Fork of Iron Creek and the Blackbird mine (figs. 1, 2). A change in rock types takes place along the northeast side of Quartzite Mountain (fig. 2), across a northwest-trending normal fault (Ekren, 1988, pl. 1) at the northeast limit of the stratigraphic sequence. Bennett (1977, pl. 1 and p. 30) previously mapped a 2.5-km-long segment of this fault northwest of the Panther Creek graben (fig. 2), considering the fault to be a thrust that dips southwest. Evans and Connor (1993) showed this fault as a nearly vertical structure of limited extent. The Panther Creek graben is 11 km wide and contains a thick sequence of volcanic rocks of the Eocene Challis Volcanic Group (Fisher and others, 1992; Fisher and Johnson, 1995; Janecke and others, 1997).

The Iron Lake fault, mapped in the Iron Lake area east of the graben by Ekren (1988), is on the same trend as the fault northeast of Quartzite Mountain and displays the same structural and stratigraphic relationships. These two faults are here considered segments of a single structure, and the Iron Lake name is applied to both. This interpretation is in concert with the findings of Ekren (1988) that the Hoodoo Quartzite, deformed into a faulted syncline southwest of Quartzite Mountain, is an extension of the southeast-plunging syncline in the Hoodoo Quartzite of the Iron Lake area southeast of the graben. (My mapping in the Quartzite Mountain area shows the syncline contains an axial plane fault, not recognized as such by Ekren (1988); the synclinal axis is not shown on the geologic map of fig. 2.)

Correlation of the coarse clastic unit of the Apple Creek Formation in the Lemhi Range with part of the lower subunit of the Yellowjacket Formation of Evans and Connor (1993) indicates that, adjacent to Quartzite Mountain, strata are missing from between the Apple Creek Formation northeast of the Iron Lake fault and the Hoodoo-overlying unnamed unit southwest of the fault (fig. 2). These missing strata are the Big Creek Formation and the fine siltite and diamictite units of the Apple Creek Formation, which lie beneath the coarse clastic unit in the northern part of the Lemhi Range (Tysdal, 1996a, 1996b, in press; Tysdal and Moye, 1996) (table 1). (The Inyo Creek and West Fork Formations, which underlie the Big Creek Formation in the Lemhi Range, are not discussed here because they occur southeast of the area of my mapping, shown in fig. 2.) The diamictite unit thins westward in the Lemhi Range and could be absent due to nondeposition in the southeastern part of the Salmon River Mountains (except for a small outcrop area adjacent to the Salmon River, fig. 2) and westward in the Quartzite Mountain area. It is unlikely that the fine siltite unit of the Apple Creek Formation and the underlying Big Creek Formation are absent due to nondeposition in the Quartzite Mountain area, however, because the two units combined total about 3,700 m of strata in the western part of the Lemhi Range. Further, about 500 m of the fine siltite unit is present 2–5 km east of the Iron Lake fault in the Iron Lake area of the Salmon River Mountains (fig. 2), as discussed below.

The stratigraphic-structural succession mapped in the western part of the Lemhi Range also occurs in the southeastern part of the Salmon River Mountains. (The succession in the Salmon River Mountains is offset southward from that in the Lemhi Range along the north-south Salmon River normal fault at the western edge of the Lemhi Range (fig. 2) (Tysdal and Moye, 1996).) From south to north in the western part of the Lemhi Range (fig. 2, east of long 114°W.), the stratigraphic-structural succession is Swauger Formation–Lawson Creek Formation–Lem Peak normal fault (south side down)–Big Creek Formation–Apple Creek Formation (fine clastic unit, diamictite unit, coarse clastic unit) (Tysdal, 1996a, 1996b; Tysdal and Moye, 1996). The same stratigraphic-structural succession is present in the southeastern part of the Salmon River Mountains (fig. 2, long 114°W.), where its westernmost extent is about 2–5 km southeast of Iron Lake, directly east of the Yellowjacket-Hoodoo-unnamed unit stratigraphic sequence delimited by the Iron Lake fault (fig. 2).

In the southeastern part of the Salmon River Mountains, much of the Swauger, and all of the Lawson Creek, have been cut out along the Lem Peak normal fault: only the lower part of the Swauger Formation and upper strata of the underlying Gunsight Formation are present in the area about 8 km southeast of Iron Lake (fig. 2) (headwaters of North Fork of Hat Creek, fig. 1). The Lem Peak fault itself is concealed beneath volcanic rocks in most of this area, but the stratigraphic succession requires that it be present.

In one of the isolated exposures in the area east of the Iron Lake fault (fig. 2), about 50 m of the upper part of the Big Creek Formation and about 500 m of the depositionally overlying fine siltite unit of the Apple Creek Formation are present. These isolated exposures of Proterozoic rocks reflect not only erosion through extensive volcanic cover but also the intersection of the pre-volcanic, northwest-trending Lem Peak normal fault and the syn- and post-volcanic, north-south normal faults of the area. The isolated exposures in the vicinity of the North Fork of Hat Creek were first mapped by Ekren (1988, pl. 2; Fisher and others, 1992). The formations recognized within the isolated outcrop areas differ in part from the formation names assigned to them by Ekren (1988), however, who made his interpretations before the stratigraphy and sedimentology of the strata in the western part of the Lemhi Range had been worked out.

Iron Lake Fault

The Iron Lake fault is discussed at some length in this section because the structure is a key feature in reconciling the stratigraphy of the Yellowjacket and associated strata of the type area with the stratigraphy of the non-Yellowjacket rocks that have been assigned to the formation in the Salmon River Mountains and the Lemhi Range. The Iron Lake name was introduced by Ekren (1988) for the fault east of the Panther Creek graben, taking precedence over Moyer Creek thrust fault that Connor (1990a) applied to a segment of it. The name Porphyry Creek thrust fault was given by Bennett (1977) to a 2.5-km-long segment of the fault northwest of the graben. Although this name is the first used, Ekren (1988) recognized the continuity of the fault and the strata southwest of it; thus, the Iron Lake name is preferred for the entire structure. In the vicinity of Iron Lake (fig. 2), the Iron Lake fault appears to be a thrust fault that underwent later normal (back-slip) displacement. Such a reversal of movement is a pattern observed along some faults in the Lemhi Range (Tysdal, 1996a, 1996b; Tysdal and Moye, 1996). Farther west along the Iron Lake fault, from the Panther Creek graben to near Quartzite Mountain, the Iron Lake fault is nearly vertical and the youngest movement is down on the southwest side.

The Iron Lake fault delimits the northeastern extent of the Hoodoo Quartzite in the vicinity of Iron Lake, where it displaced Hoodoo Quartzite northeastward over strata here assigned to the Apple Creek Formation (fig. 2) (Ekren, 1988; Fisher and others, 1992). Ekren (1988, p. 13, pl. 2) labeled it a reverse fault and determined that fractures on the west side of Iron Lake suggested a component of right-slip displacement that occurred after reverse movement. South from Iron Lake, the north-south segment of the Iron Lake fault dips 60° southwest. The fault previously was interpreted as a southwest-dipping thrust on the map of Rember and Bennett (1979). The footwall of the Iron Lake fault is characterized by closely spaced macroscopic folds that strike at a small angle to the fault (Ekren, 1988, pl. 2). This is a pattern typical for the footwall plate of thrust faults in the Lemhi Range (Tysdal, 1996a, 1996b) and probably in the Salmon River Mountains as well.

An area of interstratified scapolite-rich rock and metalimestone (marble) is present along Moyer Creek, about 8 km northwest of Iron Lake (figs. 1, 2). Connor (1990a, fig. 2a) placed these strata at the leading edge of a thrust plate, later downdropped locally by northeast-trending faults of the Panther Creek graben. Mapping of Tysdal and Desborough (1997) determined that the unit of interstratified scapolite-rich rock and metalimestone is bounded on the northeast by a nearly vertical normal fault. A cross section (Connor, 1990a, fig. 3) showed the scapolitic rock and metalimestone to lie directly above the Hoodoo Quartzite. Connor (1990a, fig. 3) labeled these rocks as part of his lower subunit of the Yellowjacket Formation. However, the interbedded metalimestone and scapolite-rich rocks are unlike any of the strata within the unnamed unit that directly and conformably overlie the Hoodoo Quartzite. They are similar to strata present locally within the lower strata of the Yellowjacket Formation (restricted), as reported by Ross (1934), Carter (1981), and Ekren (1988), and observed by the author. The scapolite-rich rocks and metalimestone, therefore, are interpreted as strata of the Yellowjacket Formation (restricted), which lies conformably beneath the Hoodoo (Tysdal and Desborough, 1997).

On the northeast side of Quartzite Mountain, northwest of the Panther Creek graben, a 2.5-km-long segment of the Iron Lake fault was first mapped by Bennett (1977), who interpreted it as a southwest-dipping thrust. The fault was extended farther northwest by Ekren (1988), who interpreted it as a nearly vertical west-side-down normal fault. The fault was shown as a west-dipping thrust by Connor (1990a, fig. 2), later interpreted as a vertical fault by Evans and Connor (1993), who indicated a south-side-down relationship on the cross section of their reconnaissance map.

The Quartzite Mountain fault truncates the Iron Lake fault near the north end of Quartzite Mountain (fig. 2) (R.G. Tysdal, unpub. mapping, 1995). My mapping in the vicinity of Quartzite Mountain extended the Quartzite Mountain fault southwest from Musgrove Creek to connect with an unnamed fault that Ekren (1988, pl. 1) mapped from the area of Yellowjacket Creek southward to directly west of the townsite of Yellowjacket (fig. 2). The map of Ekren (1988, pl. 1), following Ross (1934), showed the unnamed segment of the Quartzite Mountain fault has a left-slip of about 1.5 km near the townsite of Yellowjacket, and two related faults (splays?) in the same area have an additional cumulative left-slip of about 1.5 km. Northeast from Yellowjacket Creek (fig. 2) to near Quartzite Mountain, I remapped the location of the fault and determined that Hoodoo Quartzite on the southeast side is structurally downthrown relative to Hoodoo and underlying Yellowjacket Formation (restricted) on the northwest.

The White Ledge shear zone (not shown on figs. 1 or 2) is the name applied by Shenon and others (1955) to a fault zone as wide as 250 m (800 ft) that was originally mapped by Vhay (1948). The zone trends north from the vicinity of the Blackbird mine (fig. 2) and southwestward from the mine toward Musgrove Creek. Bennett (1977) speculated that the southwestern end of the White Ledge fault connected with a 2.5-km-long segment of the Iron Lake fault (his Porphyry Creek thrust fault) that he mapped southeast from Quartzite Mountain (figs. 1, 2). Such an extension of the White Ledge fault zone would cross through strata of the Apple Creek Formation: no such fault connection is known to exist, as shown by my mapping (R.G. Tysdal, unpub. mapping, 1995) and mapping of Evans and Connor (1993). Further, Evans and Connor (1993) do not show the White Ledge shear zone to extend south of the Blackbird mine area, and unpublished mapping of R.G. Tysdal, K.V. Evans, and K.I. Lund (1997) indicates that the White Ledge shear zone does not connect with the Quartzite Mountain fault.

Previous Stratigraphic Interpretations

The previous sections of this report have focused on resolving the conflicting interpretations of stratigraphic units assigned to the Yellowjacket Formation in the Salmon River Mountains and the western part of the Lemhi Range. The foregoing stratigraphic and structural data set the stage for a closer examination of some specific previous usages, correlations, and miscorrelations of Yellowjacket strata. They are reviewed to aid workers in reconciling some previous concepts and ideas on Middle Proterozoic stratigraphy of central Idaho with those presented here.

Lopez (1981) made one of the first attempts to subdivide the Yellowjacket Formation, designating five informal members, A–E, in ascending order. Lopez's (1981) reference sections for members A and B were measured where Ross (1934) had measured his sections when naming the Yellowjacket, Hoodoo, and overlying unnamed unit. Lopez (1981) interpreted the Hoodoo to be the Swauger Formation and to be bounded above and below by faults. He considered Ross' (1934) unnamed unit as the oldest part of the Yellowjacket Formation and designated it his informal member A. The section of Yellowjacket measured by Ross (1934) along the road from the mill at the townsite of Yellowjacket northward to the fault at the base of Hoodoo Quartzite, was considered by Lopez (1981) to be a younger part of the Yellowjacket, and he designated it member B. Because the Yellowjacket-Hoodoo-unnamed unit stratigraphic sequence is a conformable sequence (Ross, 1934; Ekren, 1988), Yellowjacket member B of Lopez (1981) is older than member A, in contrast to the conclusion of Lopez.

During the late 1980's, a compilation of findings concerning Proterozoic rocks in the United States were summarized as part of the Decade of North American Geology (DNAG), sponsored by the Geological Society of America. Data on the Proterozoic rocks of central Idaho were compiled by Winston and Link (1993), within a necessarily limited timeframe to meet DNAG publication goals. Their summary was based on limited field study prior to mapping and sedimentological studies that led to the present report. Interpretations of Yellowjacket stratigraphy and correlation of rock units made by Winston and Link (1993, p. 502) during their compilation, necessarily built on limited (and therefore speculative) data, introduced some confusion into the stratigraphic picture. They correctly believed it probable that two quite separate units had been mapped as Yellowjacket Formation. They considered the type Yellowjacket in the vicinity of the townsite of Yellowjacket to constitute one unit, which they stated lay west of the White Ledge shear zone; the other unit lay east of the shear zone. Their regional map (Winston and Link, 1993, their fig. 10) shows a north-south orientation for the White Ledge shear zone, which they extended directly south from where Bennett (1977) mapped its southern end at Musgrove Creek. As stated previously, mapping (R.G. Tysdal, unpub. mapping, 1995) subsequent to the work of Winston and Link (1993) showed that the White Ledge shear zone does not extend south of the vicinity of the Blackbird mine (fig. 2) and that the northeast-trending Quartzite Mountain fault delimits the mutual contact of the "type" Yellowjacket Formation (on the west) and the Apple Creek Formation (on the east) northward from Quartzite Mountain. The Quartzite Mountain fault connects southwestward with a fault of Ekren (1988, pl. 1) that lies west of the area of the townsite of Yellowjacket. The principal reference section of the Yellowjacket Formation lies east of the Quartzite Mountain fault. The reference section would lie west of a southward projection of the White Ledge shear zone. To place the reference section west of the White Ledge shear zone, Winston and Link (1993) may have followed the suggestion of Bennett (1977, p. 30, pl. 1), and perhaps the map of Connor (1990a, fig. 2a), that show that the White Ledge shear zone and the southeast-trending segment of the Iron Lake fault near Quartzite Mountain are the same structure. In any case, Winston and Link (1993) knowingly excluded the type area of the Yellowjacket Formation as mapped by Ross (1934) from their "eastern Yellowjacket" rocks, an exclusion that is in agreement with the findings of this report.

Winston and Link (1993, p. 502) also stated that Lopez (1981) and Ruppel and Lopez (1988) subdivided the *eastern Yellowjacket* (emphasis added here) into five informal members. As noted above, Lopez (1981) did divide the Yellowjacket into five members, but he included strata both east and west of the theoretically connected White Ledge shear zone–Iron Lake fault. His members A and B lie west of the connected structures. Winston and Link (1993) were correct in excluding member A from the Yellowjacket, but erred in assigning it to the Hoodoo Quartzite because Lopez's (1981) key reference section for member A is in the same sequence that Ross (1934) measured for his unnamed unit, which is conformable above the Hoodoo. Winston and Link (1993, table 1) omitted member A from their "eastern Yellowjacket," but included member B at the base. This inclusion is spurious because (1) member B lies west of a theoretically connected White Ledge shear zone–Iron Lake fault, or on both sides of the Quartzite Mountain fault as I have mapped it, and (2) Lopez's (1981) key measured section for Yellowjacket member B is the same section that Ross (1934) measured when originally naming the Yellowjacket Formation. Winston and Link (1993, table 1) thus correlated the principal reference section of the Yellowjacket Formation with lowermost strata of the Apple Creek Formation, even though their stated intention was to restrict the type Yellowjacket to west of the White Ledge shear zone (west of a theoretically connected White Ledge shear zone–Iron Lake fault, as their intentions are interpreted here).

Winston and Link (1993) (table 1) equated the Yellowjacket Formation, exclusive of member A of Lopez (1981), with the Lemhi Group, correlating it with the Apple Creek and Gunsight Formations. I believe that exclusion of member B as well as member A of Lopez (1981) from their table, thus equating members C–E with the Apple Creek and Gunsight, is the correct correlation. Similarly, Lopez (1981, fig. 50, p. 147) measured a section along Hayden Creek on the northeast flank of the Lemhi Range (fig. 1) and assigned the strata to his member B of the Yellowjacket. These rocks, mapped by Tysdal (1996a), are in the upper part of the Big Creek Formation and the lower part of the overlying fine siltite unit of the Apple Creek Formation.

Connor (1990a, 1990b) correlated the Jackass mineralized zone (banded iron-formation and cobaltian pyrite) along the North Fork of Iron Creek (Salmon River Mountains, fig. 1) at the top of his lower subunit of the Yellowjacket Formation with strata near Hayden Creek in the Lemhi Range. Connor (1990a, p. 22) stated that, in the Lemhi Range, argillitic siltite remarkably similar to that of the Jackass mineralized zone intertongues with diamictite mapped by Tietbohl (1986) in the Lemhi Range. Connor (1990a) further noted that Tietbohl (1986) assigned the diamictite to the Lemhi Group, and stated "I prefer, however, to equate these Yellowjacket-like strata, at least in part, with the ... lower subunit of the Yellowjacket ...." Connor (1990a, 1990b, 1991) did not equate any part of his lower subunit of the Yellowjacket with the Big Creek Formation of the Lemhi Group as was stated by Winston and Link (1993, p. 503).

Comparing the text and maps of Lopez (1981, pl. 5) with the maps of Connor and Evans (1986), Connor (1990a), and Evans and Connor (1993), I find that, in general, Lopez's (1981) members C and D correspond with the post-Hoodoo lower, middle, and upper subunits of the Yellowjacket Formation of these authors. I am not sure about the correlation, or validity, of member E.

Ruppel (1975) and Ruppel and Lopez (1988) described biotite as a characteristic mineral of the Yellowjacket Formation and did not include it in their descriptions of other Proterozoic formations. Biotite cannot be used to distinguish the Yellowjacket from other formations. It is a metamorphic mineral that formed in other Proterozoic formations of appropriate composition and metamorphic conditions in the Lemhi Range. In any case, Ruppel (1980) did not apply the criterion rigorously because biotite is lacking from virtually all of the units shown as Yellowjacket in the Patterson 15-minute quadrangle in the Lemhi Range.

As a result of geologic mapping in the Lemhi Range, Ruppel (1975) designated several new Proterozoic formations and introduced the name Lemhi Group. He (Ruppel, 1975, p. 6) believed the Yellowjacket Formation to lie beneath the Lemhi Group and extended the Yellowjacket name to the Lemhi Range. Ruppel and Lopez (1988, p. 11) implied, and Winston and Link (1993, p. 502) stated, that Anderson (1956) extended the Yellowjacket name from its type area to Proterozoic strata in the Lemhi Range and Beaverhead Mountains. But Anderson (1956, 1959, 1961) applied only the name "Belt Series" to strata of the Lemhi Range. Ross (1962, p. 20) stated that "one is tempted to correlate ... with the Yellowjacket ... but this is not advisable until more mapping is done."

The Hoodoo Quartzite was shown to occur within the Yellowjacket on the map of Fisher and others (1992), but, in a discussion of the rocks of the map, Hobbs and Cookro (1995, p. 14) appear to consider the unnamed argillaceous quartzite unit to be the upper strata of the Yellowjacket. The Hoodoo was interpreted as a lens within the Yellowjacket Formation by Evans and Ekren (1985). Ekren (1988) apparently did not continue this interpretation—his stratigraphic succession showed the Yellowjacket to lie entirely beneath the Hoodoo. Connor (1990a) and Evans and Connor (1993) continued to interpret the Hoodoo as a lens within the Yellowjacket. The reconnaissance map of Evans and Connor (1993) miscorrelated the Yellowjacket Formation (restricted) beneath the Hoodoo (Yellowjacket Creek area, fig. 2), showing it to be contiguous with Yellowjacket strata (Apple Creek Formation of this report) along the northeast side of Quartzite Mountain, northeast of the Iron Lake fault. Then, in the area from southeast of Quartzite Mountain westward to Shovel Creek, these strata are contiguous with the post-Hoodoo unnamed unit of Ross (1934). This interpretation cannot be valid because the pre-Hoodoo Yellowjacket cannot be contiguous with post-Hoodoo strata, unless the nearly 1,100-m-thick Hoodoo becomes 0 m thick at both ends of the outcrop belt between Shovel Creek and the Yellowjacket Creek area to the northwest (fig. 2). It also is untenable on a sedimentological basis. The pre-Hoodoo strata of the Yellowjacket Formation were deposited in shallow water and tidal-flat environments, as were the strata of the post-Hoodoo unnamed unit. The map of Evans and Connor (1993), however, shows these two units are contiguous with turbidite strata, here assigned to the Apple Creek Formation, northeast of the Iron Lake fault, east of Quartzite Mountain.

The Hoodoo Quartzite was interpreted as Swauger Formation by Lopez (1981), probably because both units are composed of orthoquartzite. He believed the orthoquartzite of the Yellowjacket area to be fault bounded. The presence of two orthoquartzite units within the Middle Proterozoic strata of central Idaho raises an interesting question: could the Hoodoo and the Swauger be the same unit? If the Hoodoo and the Swauger are the same age, a possibility for which I have no evidence, then, theoretically at least, it is possible for the Hoodoo and Swauger to be lithic and time equivalents of one another. If the sequence of the Yellowjacket (restricted)-Hoodoo-unnamed unit was thrust into its present position from some distance to the west, then the units underlying and overlying the Hoodoo and Swauger need not be (and are not) lithic equivalents, but they could be time equivalents. Hence, stratigraphic names applied to the overlying and underlying units in the two areas cannot be the same. Strata of the Yellowjacket (restricted) beneath the Hoodoo and the unnamed unit that overlies the Hoodoo are unlike strata of the Gunsight Formation that lies beneath the Swauger or strata of the Lawson Creek Formation that overlies the Swauger.

Age of the Yellowjacket Formation (Restricted)

Because the Yellowjacket-Hoodoo-unnamed unit stratigraphic sequence mapped by Ross (1934) is on a structural block or thrust plate separate from that of other formations in the Salmon River Mountains, the original spatial and depositional relationships of the sequence relative to the Apple Creek and other Lemhi Group rocks to the northeast is uncertain. If the Iron Lake thrust fault follows a typical thrust pattern of older-over-younger displacement, then the stratigraphic sequence of the thrust plate is older than rocks of the Lemhi Group. However, if normal (back-slip) displacement took place later along the Iron Lake thrust fault, as it has along some thrusts in the northern part of the Lemhi Range (Tysdal, 1996a, 1996b; Tysdal and Moye, 1996), then the relative age is uncertain because the amount of thrust and (or) normal displacement on the Iron Lake fault is unknown. The Yellowjacket-Hoodoo-unnamed unit sequence may be older or younger than the Lemhi Group.

Application to Stratabound Mineralization

Restricting the Yellowjacket name as advocated here places the Co-Cu-Au deposit of the Blackbird mine area (figs. 1, 2) within strata that conformably overlie the coarse siltite unit of the Apple Creek Formation. The Co-bearing mineralized rocks in the vicinity of the North Fork of Iron Creek (fig. 1) lie within the coarse siltite unit of the Apple Creek or lower strata of the conformably overlying rocks, instead of the upper part of the lower subunit or lower part of the middle subunit of the Yellowjacket Formation, as is the case with the present nomenclature.

Conclusions

The Yellowjacket Formation, Hoodoo Quartzite, and overlying unnamed unit of Ross (1934) are a conformable sequence that is of shallow subtidal, intertidal, and perhaps supratidal strata. These strata are separate and distinct from the turbidites that have been assigned to the Yellowjacket by other workers.

With these observations in mind, the major conclusions of this report are as follows:

1. The name Yellowjacket Formation is restricted to the stratigraphic unit to which it was applied originally by Ross (1934).
2. The Hoodoo Quartzite is reconfirmed as a formation in its own right, changed from a unit within the Yellowjacket Formation.
3. The unnamed unit of argillaceous quartzite of Ross (1934), which conformably overlies the Hoodoo, is removed from the Yellowjacket Formation.
4. The turbidite-bearing strata of the lower subunit of the Yellowjacket Formation, as the name was used and mapped by Connor and Evans (1986) and Evans and Connor (1993) in the Salmon River Mountains, is correlated with the coarse siltite unit of the Apple Creek Formation of the Lemhi Group and is renamed to so indicate.
5. In the Salmon River Mountains, stratigraphic units that lie conformably above the strata here newly assigned to the Apple Creek Formation, and to which the Yellowjacket name has been applied previously, are removed from the Yellowjacket Formation. New names should be given to these units; they likely correlate with formations of the Lemhi Group and, perhaps, overlying units.

References Cited

Anderson, A.L., 1953, Gold-copper-lead deposits of the Yellowjacket district, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 94, 41 p.

———1956, Geology and mineral resources of the Salmon quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 106, 102 p.

———1959, Geology and mineral resources of the North Fork quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 118, 92 p.

———1961, Geology and mineral resources of the Lemhi quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 124, 111 p.

Bennett, E.H., 1977, Reconnaissance geology and geochemistry of the Blackbird Mountain–Panther Creek region, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 167, 108 p.

Carter, C.H., 1981, Geology of part of the Yellowjacket mining district, Lemhi County, Idaho: Moscow, University of Idaho, M.S. thesis, 131 p.

Connor, J.J., 1990a, Geochemical stratigraphy of the Yellowjacket Formation (Middle Proterozoic) in the area of the Idaho cobalt belt, Lemhi County Idaho, *with analytical contributions from* Bartel, A.J., Brandt, E., Briggs, P.H., Danahey, S., Fey, D., Hatfield, D.B., Malcolm, M., Merritt, V., Riddle, G., Roof, S., Stewart, K., Storey, J., Taggert, J.E., and Vaughn, R.B., Part A—Discussion, Part B—Geochemical data: U.S. Geological Survey Open-File Report 90-0234, 30 p.

———1990b, Large-scale mineral zonation in the Yellowjacket Formation (Middle Proterozoic), Lemhi County, Idaho [abs.]: Geological Society of America Abstracts with Programs, Rocky Mountain Section, v. 22, no. 6, p. 6.

———1991, Some geochemical features of the Blackbird and Jackass zones of the Yellowjacket Formation (Middle Proterozoic) in east-central Idaho, *with analytical contributions from* Bartel, A.J., Briggs, P.H., Carlson, R.R., Crock, J.G., Roushey, B.H., Papp, C.S.E., Siems, D.F., Taggert, J.E., Jr., and Welsch, E.P., Part A—Discussion [paper copy]: U.S. Geological Survey Open-File Report 91-259A, 25 p.

Connor, J.J., and Evans, K.V., 1986, Geologic map of the Leesburg quadrangle, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-1880, scale 1:62,500.

Ekren, E.B., 1988, 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, 17 p.

Evans, K.V., 1999, The Yellowjacket Formation of east-central Idaho, *in* Berg, R.B., ed., Belt Symposium III: Montana Bureau of Mines and Geology Special Publication 112, p. 17–30.

Evans, K.V., and Connor, J.J., 1993, Geologic map of the Blackbird Mountain 15-minute quadrangle, Lemhi County, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF-2234, scale 1:62,500.

Evans, K.V., and Ekren, E.B., 1985, Hoodoo Quartzite revisited—Stratigraphic relationships near Yellowjacket, Idaho [abs.]: Geological Society of America Abstracts with Programs 1985, v. 17, no. 4, p. 217.

Fisher, F.S., and Johnson, K.M., eds., 1995, Geology and mineral resource assessment of the Challis 1°×2° quadrangle, Idaho: U.S. Geological Survey Professional Paper 1525, 204 p., 23 maps.

Fisher, F.S., McIntyre, D.H., and Johnson, K.M., 1992, Geologic map of the Challis 1°×2° quadrangle, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1819, 39 p., 1 sheet, scale 1:250,000.

Hahn, G.A., and Hughes, G.J., Jr., 1984 Sedimentation, tectonism, and associated magmatism of the Yellowjacket Formation in the Idaho cobalt belt, Lemhi County, Idaho, *in* Hobbs, S.W., ed., The Belt: Montana Bureau of Mines and Geology Special Publication 90, p. 65–67.

Hobbs, S.W., and Cookro, T.M., 1995, Proterozoic terrane, *in* Fisher, F.S., and Johnson, K.M., eds., Geology and Mineral Resource Assessment of the Challis 1°×2° Quadrangle, Idaho: U.S. Geological Survey Professional Paper 1525, p. 12–17.

Hughes, G.J., Jr., 1983, Basinal setting of the Idaho cobalt belt, Blackbird mining district, Lemhi County, Idaho, *in* The Genesis of Rocky Mountain Ore Deposits—Changes with Time and Tectonics: Denver Region Exploration Geologists Society Symposium, p. 21–27.

Janecke, S.U., Hammond, B.F., Snee, L.W., and Geissman, J.W., 1997, Rapid extension in an Eocene volcanic arc—Structure and paleogeography of an intra-arc half graben in central Idaho: Geological Society of America Bulletin, v. 109, p. 253–267.

Lopez, D.A., 1981, Stratigraphy of the Yellowjacket Formation of east-central Idaho: U.S. Geological Survey Open-File Report 81-1088, 218 p.

McBean, A.J., 1983, The Proterozoic Gunsight Formation, Idaho-Montana; stratigraphy, sedimentology and paleotectonic setting: University Park, Pennsylvania State University, M.S. thesis, 235 p.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists, v. 67, p. 841–875.

Rember, W.C., and Bennett, E.H., compilers, 1979, Geologic map of the Challis quadrangle, Idaho: Idaho Bureau of Mines and Geology, Geologic Map Series, Challis 2° quadrangle, scale 1:250,000.

Ross, C.P, 1934, Geology and ore deposits of the Casto quadrangle, Idaho: U.S. Geological Survey Bulletin 854, 135 p.

———1947, Geology of the Borah Peak quadrangle, Idaho: Geological Society of America Bulletin, v. 58, p. 1085–1160.

———1962, Stratified rocks in south-central Idaho: Idaho Bureau of Mines and Geology Pamphlet 125, 125 p.

Ruppel, E.T., 1968, Geologic map of the Leadore quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-733, scale 1:62,500.

———1975, Precambrian Y sedimentary rocks in east-central Idaho: U.S. Geological Survey Professional Paper 889-A, 23 p.

———1980, Geologic map of the Patterson quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1529, scale 1:62,500.

Ruppel, E.T., and Lopez, D.A., 1981, Geologic map of the Gilmore quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1543, scale 1:62,500.

———1988, Regional geology and mineral deposits in and near the central part of the Lemhi Range, Lemhi County, Idaho: U.S. Geological Survey Professional Paper 1480, 122 p.

Shenon, P.J., Full, R.P. Snyder, D.M., and Bauer, H.L., 1955, Geologic study of the Blackbird–Big Deer Creek area, Blackbird mining district, Lemhi County, Idaho: unpublished consultant report for Northfield Mines, Inc.

Sobel, L.S., 1982, Sedimentology of the Blackbird mining district, Lemhi County, Idaho: Cincinnati, University of Cincinnati, M.S. thesis, 235 p.

Tietbohl, D.R., 1981, Structure and stratigraphy of the Hayden Creek area, Lemhi Range, east-central Idaho: University Park, Pennsylvania State University, M.S. thesis, 121 p.

———1986, Middle Proterozoic diamictite beds in the Lemhi Range, east-central Idaho, *in* Roberts, S.M., ed., Belt Supergroup: Montana Bureau of Mines and Geology Special Publication 94, p. 197–207.

Tysdal, R.G., 1996a, Geologic map of adjacent parts of the Hayden Creek and Mogg Mountain quadrangles, Lemhi County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-2563, scale 1:24,000.

———1996b, Geologic map of the Lem Peak quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1777, scale 1:24,000.

———1996c, Geologic map of part of May Mountain quadrangle, Lemhi County, Idaho: U.S. Geological Survey Open-File Report 96-537, scale 1:24,000.

———2000, Stratigraphy and sedimentology of Middle Proterozoic rocks in northern part of Lemhi Range, Lemhi County, Idaho: U.S. Geological Survey Professional Paper, 40 p.

Tysdal, R.G., and Desborough, G.A., 1997, Scapolitic metaevaporite and carbonate rocks of Proterozoic Yellowjacket Formation, Moyer Creek, Salmon River Mountains, central Idaho: U.S. Geological Survey Open-File Report 97-268, 26 p.

Tysdal, R.G., and Moye, Falma, 1996, Geologic map of the Allison Creek quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1778, scale 1:24,000.

Vhay, J.S., 1948, Cobalt-copper deposits in the Blackbird district, Lemhi County, Idaho: U.S. Geological Survey Strategic Minerals Investigations Preliminary Report 3-219, 26 p.

Winston, D., and Link, P.W., 1993, Middle Proterozoic rocks of Montana, Idaho, and eastern Washington—The Belt Supergroup, *in* Reed, J.C., Jr., Bickford M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and van Schmus, W.R., eds., Decade of North American Geology, Precambrian—Conterminous U.S.: Geological Society of America, The Geology of North America, v. C-2, p. 487–517.

Addendum

As this manuscript was in the process of final editing for publication, Link and others (1997) published an abstract in which they correlated the Yellowjacket Formation in the vicinity of the townsite of Yellowjacket (the “type” area) in the Salmon River Mountains with the West Fork Formation of the Lemhi Group, southwest flank of the Lemhi Range. The West Fork and conformably underlying Inyo Creek Formation occur below the Big Creek Formation on the southwest flank and are not discussed in the present report because they occur south of the area of mapping shown in fig. 2. Correlation of the Yellowjacket with the West Fork Formation does not appear to conflict with the general conclusions of this report.

In addition, these authors suggested that the Hoodoo Quartzite (plus unnamed argillaceous quartzite?) may correlate with the Big Creek Formation. (Bennett, 1977, also suggested correlation of the Hoodoo and Big Creek Formations.) If the Hoodoo and associated strata of the Salmon River Mountains were thrust into their present position from some distance to the west, then the Yellowjacket and Hoodoo plus unnamed unit need not be lithic equivalents of the West Fork and Big Creek Formations of the Lemhi Range, although they may be time equivalents. Hence, stratigraphic names applied to the units in the two areas should not be the same. I think that the orthoquartzite of the Hoodoo is sufficiently different from the Big Creek that the two formations should retain their current names, even if it is determined that they are time equivalents.

Structural setting needs to be considered with respect to strata of the Lemhi Range. Within the entire area of the range, the Inyo Creek and West Fork Formations are known only along the southwest flank, and only in the area northeast of the Pahsimeroi River (fig. 1). The flank is characterized by compressional faults and folds, followed by extensional normal faulting. This raises the possibility that these two formations constitute strata of the leading edge of a thrust plate that later was severed by normal faults, downdropped, and now lies largely concealed beneath sediments of the Pahsimeroi Valley. One needs to determine if the Inyo Creek plus West Fork sequence is in structural contact or in depositional contact with the Big Creek Formation before correlating the Hoodoo with the Big Creek because, in the thrusting scenario, the two formations would be on different plates.

Link, P.K., Winston, D., and Hathaway, N., 1997, The Yellowjacket is not the Prichard—Revised correlation of Lemhi Group, Yellowjacket Formation and Belt Supergroup, Mesoproterozoic, Montana and Idaho [abs.]: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A-408.

Revision of Cretaceous Slim Sam Formation, Elkhorn Mountains Area, Montana

By R.G. Tysdal

Revision of Middle Proterozoic Yellowjacket Formation, Central Idaho, and Revision of Cretaceous Slim Sam Formation, Elkhorn Mountains Area, Montana

U.S. Geological Survey Professional Paper 1601–B

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Contents

Figures

Revision of Cretaceous Slim Sam Formation, Elkhorn Mountains Area, Montana

By R.G. Tysdal

Abstract

The Upper Cretaceous Slim Sam Formation of the Elkhorn Mountains area is revised. Strata of the lower part correlate with the regionally recognized marine Telegraph Creek Formation and the overlying marine to marginal marine Eagle Sandstone. The Eagle in the region generally consists of upper and lower sandstone units separated by a shaly to coaly unit. Only the lower sandstone of the Eagle is present in the Elkhorn Mountains study area, and it is preserved discontinuously. The nonmarine volcanic and volcaniclastic rocks of the upper part of the Slim Sam as originally defined retain the name Slim Sam Formation. These rocks, mainly of sedimentary origin, are genetically related to the Elkhorn Mountains Volcanics. The lower contact of the Slim Sam (restricted) is unconformable above the Eagle Sandstone, or more commonly, above the Telegraph Creek Formation. The upper contact is conformable with the Elkhorn Mountains Volcanics.

Introduction

This paper is an outgrowth of mineral-resource-assessment studies conducted in the Helena National Forest of west-central Montana. The Elkhorn Mountains (fig. 1) of the southwestern part of the forest contain the Upper Cretaceous Slim Sam Formation, a stratigraphic name not used beyond the Elkhorn Mountains and adjacent area (fig. 2). This unit contains magnetite-bearing fossil beach-placer deposits in and adjacent to the forest. Examination of the stratigraphic sequence associated with the deposits revealed that the Slim Sam as originally defined by Klepper and others (1957) is comprised of the Telegraph Creek Formation, the younger Eagle Sandstone, and an overlying nonmarine volcanic and volcaniclastic unit.

The Slim Sam Formation was named by Klepper and others (1957, p. 28) for a sequence of fine- to coarse-grained clastic rocks present along the eastern flank of the Elkhorn Mountains. The type locality is in the Slim Sam Basin at the southeast corner of the mountain range. Klepper and others (1957) recognized a lower and an upper part to the Slim Sam. They described the lower part as consisting mainly of quartz-chert sandstone, containing crystal-lithic tuff, sedimentary tuff, and black shale that commonly includes thin lenses of coarse feldspar crystals, probably of sedimentary origin. Klepper and others (1971, p. 11) reported discontinuous occurrences of one or more beds of detrital titaniferous magnetite in the uppermost strata of the lower part. The upper part of the formation was described as crystal-lithic tuff, lithic tuff, volcaniclastic sandstone, and at least two intervals of hard mudstone (Klepper and others, 1957, 1971).

The geologic studies of Klepper and coworkers (Klepper and others, 1957, 1971; Freeman and others, 1958; Smedes, 1966) in the Elkhorn Mountains dates from the 1950's and remain the standard references for the area. The revision of the Slim Sam in this report builds on their careful mapping and related detailed studies and reflects subsequent areal, regional, and correlation work carried out by many people.

The Slim Sam Formation as defined by Klepper and others (1957) lies conformably beneath the Upper Cretaceous Elkhorn Mountains Volcanics and above a black shale unit of the Colorado Group (rank raised). The black shale is herein described and correlated with the Cody Shale that is present in the Livingston area and elsewhere in southwestern Montana. Reasons for assignment to the Cody rather than the Marias River Shale are presented in the section on the Cody Shale.

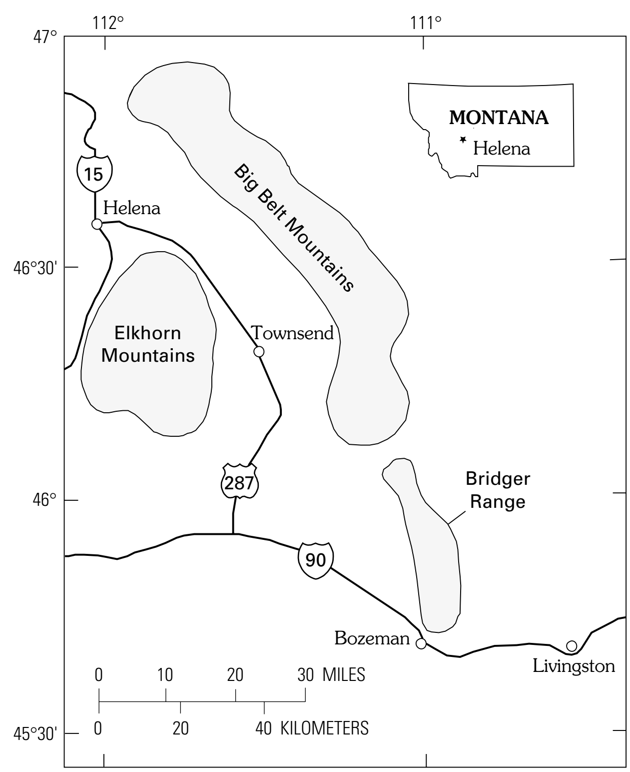

Figure 1. Index map showing location of Elkhorn Mountains, neighboring mountain ranges, and towns.

Figure 2. Geologic map showing outcrop area of Slim Sam Formation as originally defined by Klepper and others (1957) and as herein redefined to include the Telegraph Creek Formation, the discontinuously present Eagle Sandstone, and the Slim Sam Formation (restricted). The Indian Creek reference section of the Slim Sam (restricted) is indicated. Compiled from maps of Klepper and others (1957, 1971), Freeman and others (1958), Smedes (1966), and Knopf (1963).

The purpose of this paper is to redefine the Slim Sam, restricting the name to the volcanic and volcaniclastic rocks and applying the two regionally established formation names to the other units. The Slim Sam Formation (restricted), the Eagle Sandstone, and Telegraph Creek Formation are separated from the Slim Sam as originally defined—these formations and the Cody Shale beneath the sequence are described, correlated, and discussed in descending order in the following sections. All identifications of megafossils were made by W.A. Cobban.

Slim Sam Formation (Restricted)

The Slim Sam Formation (restricted) consists of medium-gray to gray-green nonmarine volcanic and volcaniclastic rocks that constitute the upper part of the Slim Sam as originally defined by Klepper and others (1957). The Slim Sam (restricted) contains a few beds of pyroclastic tuff but mainly consists of volcanic debris reworked by sedimentary processes. Some beds appear massive and are fine- to medium-grained epiclastic tuff composed almost wholly of angular grains of plagioclase, small fragments of fine-grained volcanic rocks, and less abundant grains of quartz, mica, hornblende, and opaque minerals, set in a microcrystalline groundmass altered to chlorite and sericite (Klepper and others, 1957, 1971). Sandstone beds commonly are amalgamated into units that are clearly stratified, exhibit both planar and trough crosslamination, local lenses of mudstone or rip-up clasts of mudstone, and zones of well-rounded volcanic pebbles. Some volcaniclastic sandstone units are laterally lenticular over several tens of meters. Scouring and channeling were noted by Smedes (1966) in the northwestern part of the outcrop area. The above described strata tend to be resistant and form outcrops. Poorly exposed sandstone, siltstone, mudstone, and locally porcellanite, form recessive strata. Most beds of the formation are noncalcareous.

Measured thicknesses include 155 m (508 ft) near Sheep Creek in the northwestern extent of the formation (Smedes, 1966) and 201 m (659 ft) near Indian Creek (this study) (fig. 2). The upper unit of the Slim Sam of Smedes (1966) represents the restricted Slim Sam of this study. Thicknesses measured by Klepper and others (1957) do not distinguish the upper part (Slim Sam as herein restricted) from the lower part (Eagle Sandstone and Telegraph Creek Formation). A readily accessible reference section for the Slim Sam (restricted) is the Indian Creek section of Klepper and others (1957, p. 30–31) (fig. 2; N½ SW¼ and S½ NW¼ sec. 6, T. 6 N., R. 1 E.), starting about 122 m (400 ft) above the base.

Eagle Sandstone

Rocks here assigned to the Eagle Sandstone constitute the uppermost strata of the lower part of the Slim Sam Formation as originally defined by Klepper and others (1957). The formation is described and discussed because (1) its local and regional character aid demonstration of the unconformable nature of the upper contact, thus providing a basis for interpreting the stratigraphic history of the sequence of rocks and for restricting rocks assigned to the Slim Sam, (2) it is used as the key stratigraphic unit for regional correlation, and (3) it hosts strandline placer deposits.

The Eagle was named by Weed (1899) from exposures in north-central Montana, where the formation consists of an upper thin-bedded buff-colored sandstone unit, a middle unit of coaly and carbonaceous rocks, and a lower ledge-forming unit of hard white sandstone. The lower sandstone unit later was named the Virgelle Sandstone Member (Bowen, in Stebinger, 1914). In the Elkhorn Mountains, only strata of the Virgelle and lowermost part of the middle unit are preserved.

The Eagle of the Elkhorn Mountains is here correlated with Eagle strata in the vicinity of Livingston, Mont. (fig. 1), where the Eagle has been carefully examined and mapped over a broad area (Roberts, 1972, and maps cited therein). In the Livingston area, the sandstones and intervening coal-bearing strata of the Eagle have been mapped separately from overlying somber-colored volcaniclastic strata, which were assigned to the conformably overlying Cokedale Formation of the Livingston Group (Roberts, 1972; Weed, 1893). The Eagle consists mainly of delta-plain and beach deposits. The basal sandstone, the Virgelle Sandstone Member, is as much as 34 m (110 ft) thick and is conformable with the underlying Telegraph Creek Formation (Roberts, 1972).

The Eagle Sandstone thins northwestward from the Livingston area, ranging from about 183 m (600 ft) in the southern part of the Bridger Range to about 30 m (100 ft) in the northern part (McMannis, 1955) (fig. 1). McMannis (1955, p. 1407) stated that the formation is prominent in the southern and middle parts of the range but becomes inconspicuous and difficult to locate in the northern part. The basal contact is not well exposed.

Northward, within and adjacent to the southernmost part of the Big Belt Mountains, Skipp and Peterson (1965) reported that the Eagle ranges from 30–91 m (100–300 ft) thick. The Eagle, and locally the underlying Telegraph Creek Formation, are unconformably overlain by volcanic and volcaniclastic rocks of the Maudlow Formation, which is considered to be an isolated remnant of the same volcanic field of which the Elkhorn Mountains Volcanics are a part (Skipp and Peterson, 1965; Skipp and McGrew, 1977).

It is clear from the above data that the basal sandstone of the Eagle decreases in thickness and prominence northwestward from the Livingston area toward the Elkhorn Mountains and that the formation is directly overlain by volcanic and volcaniclastic rocks. As noted by Roberts (1972, p. 31), rocks above the Eagle in central and western Montana range from marine to nonmarine, and, where they are nonmarine, the top of the Eagle generally is placed at the lithologic change where volcanic detritus becomes abundant. The restriction of the Slim Sam as defined herein follows this general relationship and parallels the stratigraphic and sedimentologic usage of the Livingston area in and adjacent to the southernmost part of the Big Belt Mountains.

In the Elkhorn Mountains, the basal Virgelle Sandstone Member of the Eagle is present only locally. The best exposure, and thickest known preserved sequence, is in a bulldozer trench west of Big Mountain (fig. 2). In the trench, and in the roadcut of the access road leading to it, the Eagle consists of feldspar-chert-quartz sandstone overlain by silty sandstone, and then medium-grained magnetite-bearing sandstone that also contains hornblende, chert, quartz, and feldspar. The latter intertongues with, and is overlain by, planar-bedded fine-grained sandstone that is devoid of trace fossils. Upward, this sandstone contains lenses of mudstone that display traces of plant rootlets. These uppermost exposed strata are interpreted as basal strata of the middle unit of the Eagle.

The magnetite-bearing sandstone and the sandstone with which it intertongues are interpreted as back-beach deposits. This interpretation is in agreement with that of Klepper and others (1957, 1971) and Houston and Murphy (1977) for magnetite-bearing deposits at the Iron Cross mine west of Radersburg (fig. 2), from which ore has been mined (Reed, 1951). The planar-bedded sandstone grades upward into the mudstone and rootlet-bearing strata interpreted as delta-plain deposits. Sandstone in the roadcut leading to the trench possibly also was deposited in a beach, but its poor and discontinuous exposure prevents making a reliable determination. Volcanic and volcaniclastic rocks of the Slim Sam overlie this sequence of rocks.

Foreshore (beach) deposits were observed about 1 km (0.6 mi) southeast of the top of Big Mountain and along the road directly south of Weston Creek (fig. 2). At both locations, the basal Eagle is light-gray, fine- to medium-grained, quartz and feldspar (“salt-and-pepper”) sandstone that has very little matrix and displays planar and trough crosslaminated beds. At these two localities, the lower Eagle is overlain by volcanic and (or) volcaniclastic rocks of the Slim Sam Formation (restricted). Upper foreshore deposits, such as magnetite-bearing sandstone and delta-plain strata, are absent.

Telegraph Creek Formation

The Telegraph Creek Formation is transitional between the Cody Shale and the overlying Eagle Sandstone. In the Elkhorn Mountains, the transitional position is reflected in the upward-changing makeup of the formation. The lower part consists of interbedded dark-gray mudstone and shale, similar to that of the underlying Cody Shale, and interbedded clayey and silty fine-grained sandstone. The sandstone content increases upsection; the grain size generally increases from fine to medium grained; and the clay and silt content of the sandstone decreases. Sandstone is calcareous throughout the formation. Trace fossils are common throughout the formation, changing in type upward and recording shallowing depositional conditions. Horizontal traces, indicative of lower shoreface and offshore environments (Pemberton and others, 1992), are common on sandstone beds in lower strata of the formation. In the upper strata, steeply inclined to vertical burrows of *Ophiomorpha* and *Diplocraterion*, indicative of middle and upper shoreface environments, and thoroughly burrowed (churned) sandstone units are interstratified with planar, unburrowed sandstone beds.

Cody Shale

Basal strata of the Telegraph Creek Formation are conformable and gradational with the underlying shale that was assigned to the upper black shale unit of the Colorado Group by Klepper and others (1957). This upper black shale unit is here correlated with the Cody Shale of the Livingston area (fig. 1), where it directly underlies the Eagle Sandstone. Three sections of the Cody measured by Klepper and others (1957, p. 28; their upper black shale unit of the Colorado Group) in the eastern part of the Elkhorn Mountains range from 81 to 119 m (265 to 390 ft) thick.

The black shale is assigned to the Cody rather than to the Marias River Shale that constitutes the upper shale of the Colorado Group in north-central Montana for the following reasons. The Marias River consists of four members, which, in descending order, are the Kevin, Ferdig, Cone, and Floweree Shale Members. The Floweree (mainly marine fissile shale) and Cone Members (chiefly calcareous shale) (Cobban and others, 1976) are absent in the Elkhorn Mountains. The Ferdig (mainly dark bluish-gray shale with a medial sandy shale—Cobban and others, 1976) also is absent in the Elkhorn Mountains. The time zone of the Ferdig is represented by sandstone, which is more similar to sandstone of the Frontier Formation than shale of the Ferdig. The Kevin lithology (mainly shale, bentonitic in the lower part, and containing limestone concretions of differing character in different parts of the member—Cobban and others, 1976) is present in the Elkhorn Mountains, where it contains more siltstone and fewer concretions than is reported to the north by Cobban and others (1976) and Schmidt (1978). This lithology also is typical of the Cody. The Cody name is used for the shale unit in the Elkhorn Mountains because (1) the Frontier is succeeded by the Cody Shale in southwestern Montana and the type sections of both formations in Wyoming, and (2) the Marias River Shale (or the Kevin Member) nomenclature is not used for rocks overlying the Frontier.

Age

Based on the limited data available at the time of their field studies, Klepper and others (1957, p. 37) stated that the basal part of the Elkhorn Mountains Volcanics could be as old as the Telegraph Creek Formation because the Slim Sam Formation (as originally defined), which contains “Niobrara” (age) fossils (i.e., Telegraph Creek age) in its lower part, “appears to have been deposited rapidly” and to grade upward into the volcanic rocks at some localities. Klepper and others (1971) later stated that the Slim Sam could be as young as the Eagle Sandstone, but no younger, because the overlying Elkhorn Mountains Volcanics are only slightly younger than the Eagle. We now know that the Elkhorn Mountains Volcanics are younger than the Eagle Sandstone and the Slim Sam (restricted). The Elkhorn Mountains Volcanics are above the Slim Sam (restricted) and lie unconformably on the Telegraph Creek and the Eagle; thus, they are younger than all of the clastic-bearing formations.

The maximum age of strata previously assigned to the Slim Sam Formation by Klepper and others (1957) is limited by the age of the Cody Shale, which underlies the Telegraph Creek Formation. The bivalve *Cremnoceramus deformis* (Meek) (previously *Inoceramus deformis*), from the basal middle Coniacian zone of *Forresteria alluaudi*, was collected from basal strata of Fauna recovered from somewhat higher in the Cody include *Scaphites ventricosus* Meek and Hayden and associated middle Coniacian fossils *Baculites asper* Morton, *Volviceramus umbonatus* (Meek and Hayden), and *Pseudoxybeloceras dispar* Kennedy and Cobban (Klepper and others, 1957; Kennedy and Cobban, 1991).

Fossils recovered from the Telegraph Creek range from middle Coniacian through upper Santonian (fig. 3). *Scaphites* cf. *S. ventricosus* Meek and Hayden was recovered from the basal 15 m (50 ft) of the Telegraph Creek (Slim Sam of Klepper and others, 1957) (Klepper and others, 1971). *Scaphites* sp. and *Magadiceramus subquadratus crenelatus* Seitz of the slightly younger *Scaphites depressus* zone were recovered during this study from shale near the base of the Telegraph Creek Formation southeast of Big Mountain (fig. 2). The pelecypod *Cymbophora arenaria* (Meek) (previously *Mactra arenaria*) was recovered from as high as 116 m (380 ft) above the base of the Telegraph Creek Formation (Klepper and others, 1957, p. 29), as well as about 60 m (200 ft) above the base at another locality (Klepper and others, 1971, p. 11–12). From near Big Mountain, *Cymbophora arenaria* (Meek) was recovered during this study from the uppermost exposed part of the Telegraph Creek Formation, about 20 m (66 ft) below the base of exposed strata of the Eagle Sandstone. (Strata within the 20 m (66 ft) is covered; hence, the base of the Eagle could be, and probably is, less than 20 m (66 ft) above the horizon that yielded *Cymbophora arenaria* (Meek).) *Clioscaphites* cf. *C. novimexicanus* (Reeside), an ammonite probably from one of the upper Santonian *Desmoscaphites* zones (W.A. Cobban, written commun., 1994), was obtained from about 22 m (72 ft) below the base of exposed Eagle strata at the same locality.

The above fauna from the Telegraph Creek Formation indicates that the Eagle Sandstone is no older than late Santonian. The preserved Eagle strata likely represent only a slightly younger age, but the time span of the eroded Eagle strata is not well confined. A minimum age for preserved Eagle Sandstone, the Slim Sam Formation (restricted), and the time span represented by the unconformity between the two is limited by the age of the overlying Elkhorn Mountains Volcanics. Eruption of these rocks took place from about 81 to 76 Ma (Rutland and others, 1989). The most recent radiometric dates on the volcanics are two potassium-argon determinations of Tilling and others (1968) from rocks within the lower member of the sequence. The dates are 79.6 and 80.2 Ma, and average 79.9 Ma (recalculated from 77.6 and 78.2, and 78.0±1.7 Ma, respectively, using decay constants of Steiger and Jager, 1977, and conversion tables of Dalrymple, 1979). With these radiometric dates, the time span between the base of the Eagle and rocks within the lower member of the Elkhorn Mountains Volcanics is about 4 m.y.

Tilling (1974, p. 1927) suggested that the Elkhorn Mountains Volcanics may have been reheated during intrusion of the Boulder batholith; thus, the dates may be reduced. However, unreheated volcanic rocks of the apparently genetically related rocks of the Maudlow Formation at the southern end of the Big Belt Mountains yielded a radiometric date of 80.9 Ma from the lower part of the formation (Skipp and McGrew, 1977) (recalculated from 78.9±1 Ma, using decay constants of Steiger and Jager, 1977, and conversion tables of Dalrymple, 1979). This date suggests that the dates on the Elkhorn Mountains Volcanics are reasonable.

Discussion and Conclusions

The nonmarine volcanic- and volcaniclastic-rich Slim Sam Formation (restricted) records early history of the Elkhorn Mountains Volcanics. The sandstones were formed of volcanic particles eroded from the initial extrusives and were redeposited by sedimentary processes. Even though the rocks are mainly of sedimentary origin, they are nonmarine strata genetically related to the Elkhorn Mountains Volcanics and not to marine strata of the Telegraph Creek Formation and marine to marginal marine delta-plain deposits of the Eagle Sandstone. This interpretation helps to explain the geographically variable thickness of the nonmarine Slim Sam (restricted); the variability of the sedimentary versus volcanic components of the unit; and internal discontinuities within the Slim Sam (restricted) in some areas, but apparent conformity in other areas. Further, the interpretation is consistent with the regional pattern of marine Eagle Sandstone being separate and distinct from directly overlying volcanic and volcaniclastic rocks.

The lower part of the sequence of strata that constituted the Slim Sam Formation as originally defined by Klepper and others (1957) is everywhere represented by marine strata of the Telegraph Creek Formation, deposited in the zone of transition between the offshore deposits of the Cody Shale and the strandline to lowermost delta-plain deposits of the basal part of the Eagle Sandstone. Regional data show the Eagle to consist of a basal and upper sandstone and an intermediate coaly to carbonaceous unit. Only the basal sandstone and lowermost strata of the middle part were observed in the Elkhorn Mountains, and they are preserved only locally. The absence of part or all of the Eagle, and deposition of the nonmarine rocks of the Slim Sam (restricted) directly on lower shoreface to offshore marine strata of the Telegraph Creek Formation throughout much of the area reveals that an unconformity lies at the base of the Slim Sam (restricted), even though no angular discordance is evident in some areas.

Klepper and others (1957, 1971) stated that the contact of the Slim Sam Formation (as originally defined) with the overlying Elkhorn Mountains Volcanics ranged from conformable to unconformable. They believed this contact was conformable along the eastern flank of the Elkhorn Mountains, northward from near Radersburg, Mont. (fig. 2). Southward from near Radersburg, and elsewhere in the Elkhorn Mountains, Klepper and others (1971, p. 21) stated that the Slim Sam and older rocks were folded and eroded before extrusion of the volcanics. Separation of the Slim Sam (as they defined the formation) into the

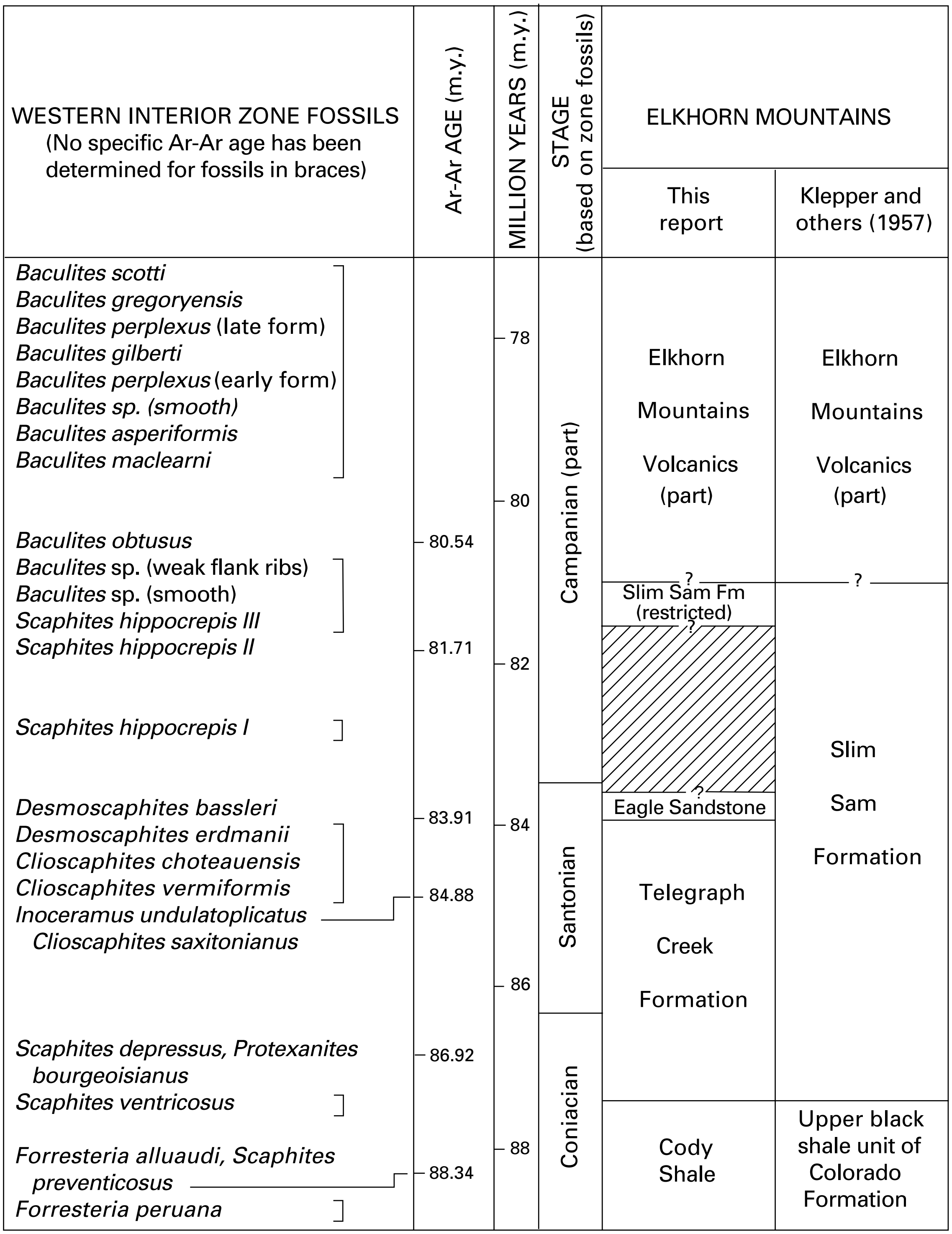

Figure 3. Correlation chart showing relationships in the Elkhorn Mountains. Boundaries of the Upper Cretaceous stages, Western Interior fossil zones, and 40Ar/39Ar radiometric ages are adapted from Obradovich (1993). Ages in the Ar-Ar column correspond to specific, indicated zone fossils in the column headed "Western Interior Zone Fossils." Fossils within braces in the latter column are not tied to specific ages, and no age (or age range) is implied other than biostratigraphic position within the sequence and the age constraints afforded by zone fossils that have been dated. Individual zone fossils, or sequences of zone fossils, within braces could be slightly younger or older than indicated by position in the figure. In the columns headed "Elkhorn Mountains," a query symbol indicates uncertainty in correspondence of the formation contact with a fossil zone or radiometric age. The column subheaded "Klepper and others (1957)" shows lithofacies correlation, but not necessarily age correlation, with the column subheaded "this report."

Telegraph Creek, Eagle, and Slim Sam (restricted) indicates that erosion, and probably folding, occurred before deposition of the Slim Sam (restricted). The reasoning is as follows.

The upper contact of the Slim Sam (restricted) is conformable with the overlying Elkhorn Mountains Volcanics along the east flank of the Elkhorn Mountains, as determined by Klepper and others (1957, 1971) and by my observations as well. The upper contact also is conformable in the northernmost part of the Elkhorn Mountains, in the Sheep Creek to Corral Creek area (fig. 2) (Smedes, 1966, p. 21). The upper contact is an angular unconformity along the southern flank of the Elkhorn Mountains, several kilometers west of Radersburg, where the Elkhorn Mountains Volcanics lie on the Slim Sam Formation (Klepper and others, 1957, pl. 1). Similarly, the upper contact is unconformable southward from near Radersburg, where the Elkhorn Mountains Volcanics lie directly on Slim Sam and older strata (Freeman and others, 1958, pl. 1). But the Slim Sam of the maps of Klepper and others (1957) and Freeman and others (1958) in both of these areas may be Telegraph Creek Formation, and the Slim Sam (restricted) could be absent. If volcanic rocks rest directly on Telegraph Creek strata in these areas, then deformation before or after deposition of the Slim Sam (restricted) cannot be determined from these areas.

The lower contact of the Slim Sam (restricted) is unconformable above older strata. In the Indian Creek area (fig. 2), it rests on lower shoreface deposits of the Telegraph Creek Formation. In the Crow Creek–Weston Creek area, and in the Big Mountain area, it rests on the Telegraph Creek and, locally, on lower strata of the Eagle Sandstone. These data show that the Slim Sam (restricted) does not represent continuous deposition from Telegraph Creek or Eagle strata and indicates that erosion and perhaps deformation took place prior to deposition of the Slim Sam (restricted). Further work in the Elkhorn Mountains may show that the strata remaining within the Slim Sam Formation may more properly be assigned to the Elkhorn Mountains Volcanics.

References Cited

Cobban, W.A., Erdmann, C.E., Lemke, R.W., and Maughn, E.K., 1976, Type sections and stratigraphy of the members of the Blackleaf and Marias River Formations (Cretaceous) of the Sweetgrass Arch, Montana: U.S. Geological Survey Professional Paper 974, 66 p.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558–560.

Freeman, V.L., Ruppel, E.T., and Klepper, M.R., 1958, Geology of part of the Townsend Valley, Broadwater and Jefferson Counties, Montana: U.S. Geological Survey Bulletin 1042-N, p. 481–556.

Houston, R.S., and Murphy, J.F., 1977, Depositional environment of Upper Cretaceous black sandstones of the Western Interior: U.S. Geological Survey Professional Paper 994-A, 29 p.

Kennedy, W.J., and Cobban, W.A., 1991, Coniacian ammonite faunas from the United States Western Interior: The Paleontological Association, Special Papers in Paleontology, no. 45, 96 p.

Klepper, M.R., Ruppel, E.T., Freeman, V.L., and Weeks, R.A., 1971, Geology and mineral deposits, east flank of the Elkhorn Mountains, Broadwater County, Montana: U.S. Geological Survey Professional Paper 665, 66 p.

Klepper, M.R., Weeks, R.A., and Ruppel, E.T., 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geological Survey Professional Paper 292, 82 p.

Knopf, Adolph, 1963, Geology of the northern part of the Boulder batholith and adjacent area, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-381, scale 1:48,000.

McMannis, W.J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, v. 66, p. 1385–1430.

Obradovich, J.D., 1993, A Cretaceous time scale, *in* Caldwell, W.G.E., and Kauffman, E.G., eds., Evolution of the Western Interior Basin: Geological Association of Canada, Special Paper 39, p. 379–396.

Pemberton, S.G., MacEachern, J.A., and Frey, R.W., 1992, Trace fossil facies models; environmental and allostratigraphic significance, *in* Walker, R.G., and James, N.P, eds., Facies Models—Response to Sea Level Change: Geological Association of Canada, p. 47–72.

Reed, G.C., 1951, Mines and mineral deposits (except fuels), Broadwater County, Montana: U.S. Bureau of Mines Information Circular 7592, 58 p.

Roberts, A.E., 1972, Cretaceous and Early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional Paper 526-C, 120 p.

Rutland, Carolyn, Smedes, H.W., Tilling, R.I., and Greenwood, W.R., 1989, Volcanism and plutonism at shallow crustal levels; the Elkhorn Mountains Volcanics and the Boulder batholith, southwestern Montana, *in* Hyndman, D.W., ed., Cordilleran Volcanism, Plutonism, and Magma Generation at Various Crustal Levels, Montana and Idaho: 28th International Geological Congress, Field Trip Guidebook T337, p. 16–31.

Schmidt, R.G., 1978, Rocks and mineral resources of the Wolf Creek area, Lewis and Clark and Cascade Counties, Montana: U.S. Geological Survey Bulletin 1441, 91 p.

Skipp, Betty, and McGrew, L.W., 1977, The Maudlow and Sedan Formations of the Upper Cretaceous Livingston Group on the west edge of the Crazy Mountains Basin, Montana: U.S. Geological Survey Bulletin 1422-B, 68 p.

Skipp, Betty, and Peterson, A.D., 1965, Geologic map of the Maudlow quadrangle, southwestern Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-452, scale 1:24,000.

Smedes, H.W., 1966, Geology and igneous petrology of the northern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geological Survey Professional Paper 510, 116 p.

Stebinger, Eugene, 1914, Titaniferous magnetite on the Blackfeet Indian Reservation, Montana: U.S. Geological Survey Bulletin 540-H, p. 329–337.

Steiger, R.H., and Jager, E., 1977, Subcommission on geochronology—Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.

Tilling, R.I., 1974, Composition and time relations of plutonic and associated volcanic rocks, Boulder batholith region, Montana: Geological Society of America Bulletin, v. 85, p. 1925–1930.

Tilling, R.I., Klepper, M.R., and Obradovich, J.D., 1968, K-Ar ages and time span of emplacement of the Boulder batholith, Montana: American Journal of Science, v. 266, p. 671–689.

Weed, W.H., 1893, The Laramie and the overlying Livingston Formation in Montana: U.S. Geological Survey Bulletin 105, 68 p.

———1899, Description of the Fort Benton quadrangle, Montana: U.S. Geological Survey Geological Atlas, Folio 55, 9 p.

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