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# Stratigraphy of the Yellowjacket Formation of East-Central Idaho

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature

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ABSTRACT

The Yellowjacket Formation is a 6,500-m to 8,000-m thick sequence of predominantly medium-gray to dark-gray argillaceous quartzite and sandy or silty argillite. In general, regional metamorphism is in the lower green schist range, and therefore, primary sedimentary features are easily identifiable. The age of the Yellowjacket is between 1.4 and 1.76 b. y.

Five members, A through E, have been distinguished. Member A consists of graded beds 10 cm to 1 m thick of coarse- to medium-grained quartzite that grades upward into fine- or very fine grained argillaceous quartzite and locally sandy argillite. Up-section this member becomes overall finer grained and darker in color. The thickness is about 700 m.

Member B is predominantly very fine grained argillaceous quartzite and siltite. Graded beds are 5 to 50 cm thick. Characteristic of this unit are beds and lenses of calcareous quartzite. The thickness is about 1,600 m.

Member C is characterized by couplets of light colored argillaceous quartzite and/or siltite and dark colored sandy argillite that occur together in graded laminae and beds from 2 mm to 15 cm thick. The thickness is about 1300 m.

Member D is predominantly very fine grained argillaceous quartzite in graded beds 10 cm to 1 m thick. The thickness is at least 2,500 m but may be as much as 3,500 m.

Member E contains quartzites with the lowest content of argillaceous matrix of all the formation. Graded beds are from 30 cm to 2 m thick. The exposed thickness of member E is about 1000 m.

The formation is interpreted as having been deposited in a deep-marine setting by turbidity currents.

The Yellowjacket occurs within the Lemhi Arch, which represents a structural inversion of the thick prism of Yellowjacket sediment. This arch controlled depositional patterns of all younger Precambrian and Paleozoic sedimentary rocks.

Economic interest in the Yellowjacket is because of the occurrence of cobalt and copper-cobalt mineralization. The restricted occurrence of cobalt mineralization in the Yellowjacket and the widespread 10 to 30 ppm cobalt content of Yellowjacket rock samples, suggest a syngenetic origin. But most known cobalt ore deposits appear to be vein deposits remobilized and concentrated from original syngenetic low-grade mineralization.

# INTRODUCTION

The Precambrian (Proterozoic) Y age Yellowjacket Formation of east-central Idaho is a sequence about 6,000 m thick of predominantly medium-gray to dark-gray argillaceous feldspathic quartzite and sandy argillite. The grain size of the quartzite is most commonly from silt to fine sand (0.0039-0.25 mm). Areal distribution of the formation is shown on figure 1 and plate 1. Only reconnaissance work has been published on the stratigraphy of the Yellowjacket and no regionally useful subdivision of the thick stratigraphic sequence has been reported.

The base of the Yellowjacket was not observed in the study area and has not been reported elsewhere in the literature. A northeast-trending high-angle fault in upper Big Deer Creek separates the Yellowjacket from higher grade metasedimentary rocks that occur in the Panther Creek-Salmon River area (pl. 1). These metasedimentary rocks may be older than the Yellowjacket or they may be a higher than normal metamorphic grade of the Yellowjacket.

No younger Precambrian or Paleozoic sedimentary rocks have been observed in depositional contact with the Yellowjacket Formation in the study area. Everywhere, the Yellowjacket is autochthonous relative to rocks of the Medicine Lodge thrust system (Ruppel, 1978; Ruppel and others, in press). In east-central Idaho, younger Precambrian rocks of the Lemhi Group and Swauger Formation are thrust over the Yellowjacket from the west on the order of 150 km (Ruppel, 1978; Ruppel and others, in press).

Plate 1 is a generalized geologic map of the region in which the Yellowjacket Formation occurs and its purpose is to illustrate the geologic relations between the Yellowjacket and the other formations in the region. Therefore, most of the units on plate 1 are not discussed in detail.

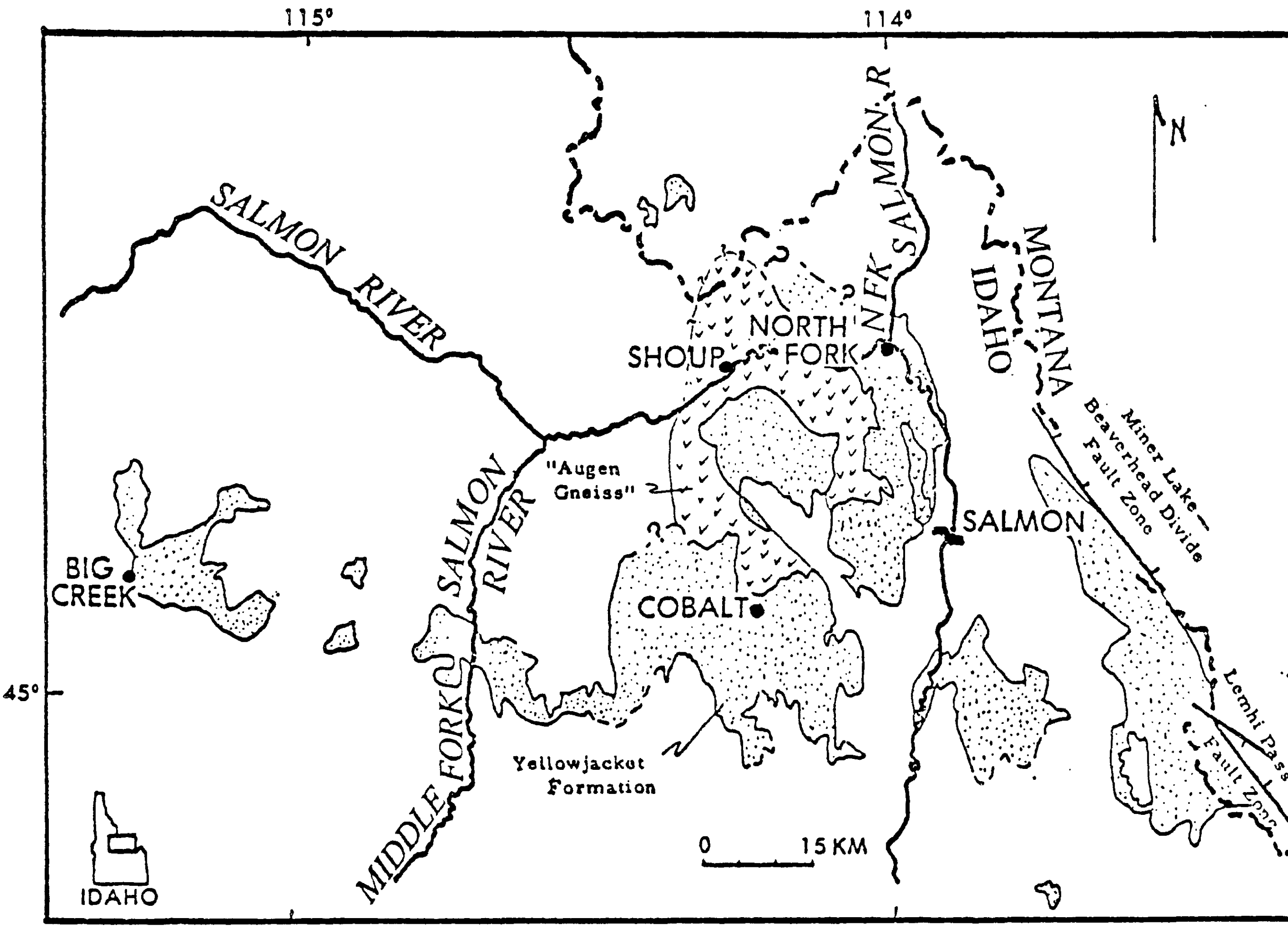


Figure 1.--Distribution of the Yellowjacket Formation, East-Central Idaho; Yellowjacket Formation shown in stippled pattern.

## Acknowledgements

Dr. Edward T. Ruppel suggested the problem of the Yellowjacket Formation and assisted in the field. His suggested improvements of the manuscript are appreciated.

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## Method of Study

The main purpose of this study is to describe and interpret the regional stratigraphy of the Yellowjacket Formation. Because of the structural complexity in the areas of outcrop, field mapping was necessary in order to establish the stratigraphic sequence. The area around North Fork, Idaho was mapped at a scale of 1:48,000 to decipher the stratigraphy and structure of the Yellowjacket. Reconnaissance mapping in the surrounding areas, where the Yellowjacket Formation is exposed was undertaken in order to piece together as complete a stratigraphic section as possible. After selecting areas for detailed stratigraphic study, sections were measured, described, and sampled. The locations of twelve measured sections are shown on plate 2. These include sections at Yellowjacket Creek, Shovel Creek, Panther Creek, North Fork of Iron Creek, Iron Creek, Hayden Creek, North Fork, Wagonhammer Creek, Deriar Creek, Stormy Peak Road, and Twelve-Mile Creek. Other areas studied but where sections were not measured are Porphyry Creek, Moyer Creek, Deep Creek, the Lemhi Pass area (Beaverhead Mountains), and along the Salmon River Mountain Road from Napoleon Hill south to where Lemhi Group rocks are encountered in thrust contact with the Yellowjacket about 10 km north of Iron Lake. Most sections were measured by determining width of outcrop and slope angles from USGS 1:24,000 scale topographic maps and converting to true thicknesses by correcting for dip and divergence of the line of section from the dip direction. Sections at North Fork, Wagonhammer Creek, and Twelve-Mile Creek were measured with tape and brunton. The Deriar Creek-Stormy Peak Road section was measured with a Jacob's Staff. Samples were taken on the average at every 150 m. Sampling was done at closer spacing in sections measured with tape or Jacob's Staff. Measured sections were not only sampled for lithologic study but also for analysis of trace-element chemistry to evaluate economic potential in relation to stratigraphic position. Analyses for trace elements were done for a standard 30 element suite by emission spectrometry by the the laboratories of the U.S. Geological Survey (Appendix 4. Zn analyses were done by atomic absorption spectrometry at the same laboratory.

About 150 samples were studied in thin section to determine modal compositions, textures, and size distribution. The modal composition classification used is that of Dott for terrigenous sandstones (1964, from Pettijohn and others, 1972)(fig. 2). Field lithologic terms used, because of

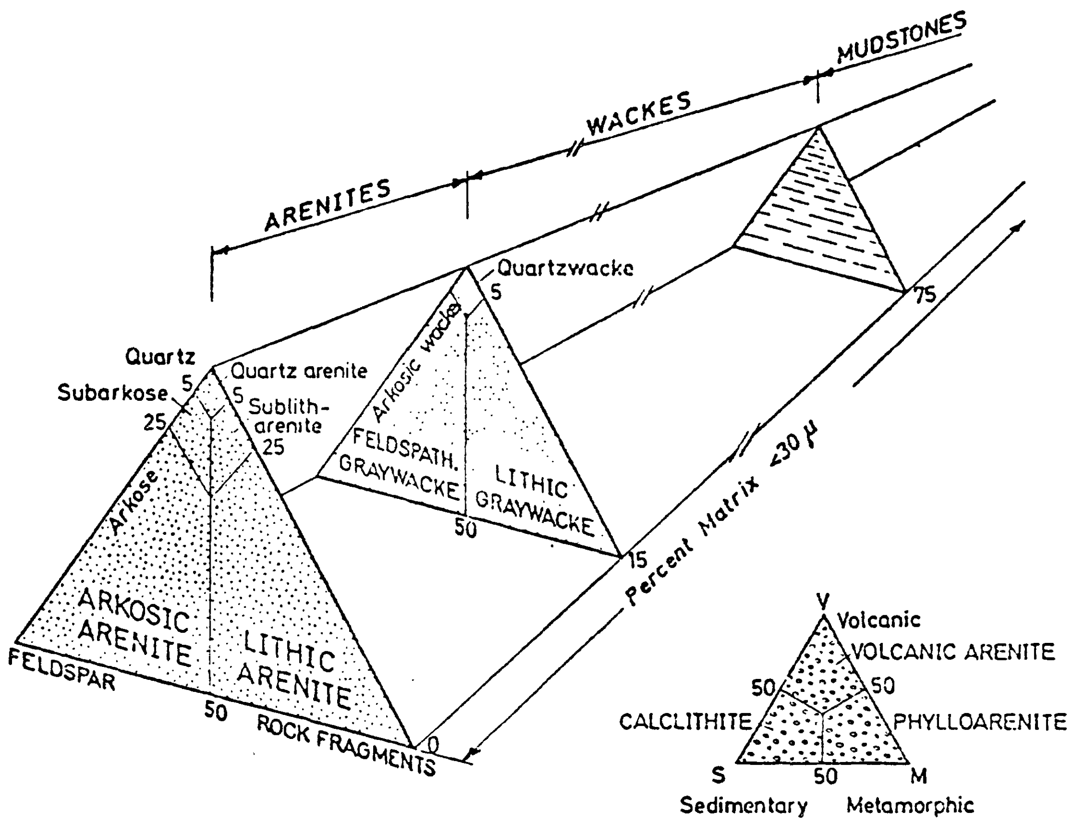



Figure 2.--Classification of terrigenous sandstones (from Pettijohn and others, 1972).

the low-grade metamorphism, are quartzite, combined with modifying terms feldspathic and argillaceous; siltite; argillite; and sandy and silty argillite. Quartzite is always feldspathic and is equivalent to subarkose of figure 2. Argillaceous quartzite is also always feldspathic and is equivalent to arkosic wacke. Argillite, which would be equivalent to shale, is rare. Sandy and/or silty argillite is more common and is equivalent to mudstone of figure 2. Siltite is not common but where present is argillaceous and is equivalent to arkosic wacke in composition but is made up of silt-size grains. Size distributions were determined by calibrating micrometer eyepiece spacings to the Wentworth size classes and counting the number of grains that fell within each of those size classes. The longest dimension of grains was measured, because long axis grain size distributions measured in thin section correspond best with sieve-grain size distributions (Friedman, 1958).

Sedimentary structures were studied in the field in order to interpret depositional environment. Transport direction data were collected from the orientation of cross laminations, and the attitudes of axial planes of recumbent penecontemporaneous slump folds. Additional data were obtained from the orientation of flute clasts.

## Summary of Previous Work

The Yellowjacket Formation was named and first described by Ross (1934) in the area of the town and mining district of Yellowjacket, Idaho. In the type area the Yellowjacket is about 2,700 m thick but includes numerous thick dikes some of which are 10's to 100's of meters thick. Included in the formation are "dark gray, more or less argillaceous quartzite...and lenses of metamorphosed calcareous material (Ross, 1934, p. 16). A section measured by Ross westward along Yellowjacket Creek, starting at the Yellowjacket Mill is shown in table 1.

Table 1.
Original Measured Section along Yellowjacket Creek (Ross,1934).

| Formation Name | Character | Thickness (ft) |
|---|---|---|
| Not exposed in quadrangle | Distinctly banded gray, somewhat calcareous quartzite | ............*865+ |
| Hoodoo Quartzite | White quartzite | ............3,560 |
| Yellowjacket Formation | Quartzite beds: | |
| | Dark bluish-gray quartzite | ............4,300 |
| | Dark-gray quartzite, in part very argillaceous | ............1,030 |
| | White quartzite | ............ 100 |
| | Dark-gray quartzite | ............1,650 |
| | Calcareous beds: | |
| | Banded and variegated gray, white, and green, more or less calcareous rocks, cut by numerous dikes | ...........1,700± |

*Top not reached

Ross described the quartzites in the Yellowjacket as being various shades of gray, fine grained (about 0.1 mm), and consisting mainly of quartz with subordinate amounts of plagioclase, biotite, chlorite, sericite, iron oxide, and scattered grains of epidote and zircon. Sedimentary structures described include ripple marks, and "crossbedded lenses rarely more than a fraction of an inch thick" (p. 17).

Ross considered the calcareous rocks to be in the lower part of the exposed section at Yellowjacket, but the entire section has an overturned dip, so these rocks are actually in the upper part of his section. He further described these rocks as lenses that intertongue with the quartzites, and include: 1) banded rocks with closely spaced irregular dark green, black, and gray beds; 2) nearly white rocks mottled with dark clusters of metamorphic minerals; and 3) argillaceous quartzites typical of the Yellowjacket but containing varying amounts of calcareous material. Detrital quartz 0.03 to 0.1 mm is the principle component in all three, but calcite, scapolite, biotite, epidote, chlorite, amphiboles, plagioclase, and apatite are also present (Ross, 1934).

Anderson (1956, 1957) mapped rocks in east-central Idaho now known to belong in the Yellowjacket Formation as part of the "Belt Series", and later (1959, 1961) applied the term Lemhi Quartzite of Ross (1947) to these rocks. He recognized that the rocks at the north end of the Lemhi Range are probably correlative with those in the Blackbird area (Anderson, 1956). Ross (1962) extended the term Yellowjacket Formation into east-central Idaho, thus correcting Anderson's correlations.

Kaiser (1956) mapped and described rocks belonging to the Yellowjacket in the Dump Creek--Buster Creek area but did not make any correlations with named units. He did state, however, that these rocks were typical of rocks of the Belt Series to the north in Idaho and Montana.

Shockey (1957) mapped two formations in the Leesburg Quadrangle, a phyllite formation and an impure gray quartzite formation. The phyllite formation was described as a 10,000-ft-thick unit consisting of gray phyllite, gray quartzite and minor black slate. The impure gray quartzite formation was estimated at about 22,000 ft in thickness and was described as typically lenticular impure crossbedded and ripple-marked siltstone and sandstone in beds 1 to 2 ft thick. Both of Shockey's formations are now considered to be parts of the Yellowjacket Formation. He stated that the Yellowjacket Formation of Ross (1934) may "lie across the contact of the phyllite and impure gray quartzite formations" (Shockey, 1957, p. 10).

Cater and others (1973, 1975) mapped and described the Yellowjacket Formation in the Idaho Primitive Area and adjoining areas as interbedded medium gray to dark gray, argillite and siltite, and fine-grained quartzite. They also described metavolcanic rocks in the Big Creek area, which may be part of the Yellowjacket Formation. They described a sequence of three units in the Big Creek Area: "[a] lower unit, at least 5,000 feet thick consists of thin-to-thick-bedded argillite and siltite with scattered interlayers of fine- to medium-grained argillaceous quartzite; [a] middle unit, about 2,500 feet thick, consists of interbedded sandy carbonate and quartzite; [and an] upper unit, about 500 feet thick, consist[ing] of three subunits of metavolcanic rocks. In sequence upward, these subunits are (1) porphyroblastic hornblende schist, (2) interlensed hornblende and biotite schist (derived from lavas?) and hornfels (from volcanic siltstone?), and (3) metamorphased volcanic breccia and conglomerate." (Cater and others, 1973, p.14).

Purdue (1975) mapped the southeast one fourth of the Blackbird Mountain quadrangle where he used the terms Panther Creek phyllite and Leesburg quartzite. These terms are approximately equivalent to Shockey's phyllite formation and impure gray quartzite formation, respectively.

Bennett (1977), in a reconnaissance study in the Cobalt area, divided the Yellowjacket into a phyllite member and quartzite member, again similar to Shockey's units (1957). Bennett correctly observed that the phyllite member is light gray to greenish in the lower part and that it becomes darker colored upward and contains increasing amounts of quartzite as it grades into the quartzite member.

The Yellowjacket Formation and other Precambrian sedimentary rocks of east-central Idaho have been removed from the Belt Supergroup and the stratigraphy has been revised by Ruppel (1975).

# STRATIGRAPHY

The aggregate thickness of the Yellowjacket Formation from all the areas and sections studied is about 6,300 m to 8,000 m, as shown in figure 3. Measured sections and detailed descriptions of specific areas studied appear in the appendix, and are shown graphically in plates 4, 6, 8-14).

The formation can be divided into five litho-stratigraphic units, identified from bottom to top as members A through E. The members are distinguished on the basis of a combination of lithologic features including grain size, thickness of graded beds, sedimentary structures, and the proportions of quartzite and argillite within individual graded genetic units. All the contacts between members are transitional through intervals of 100 to 200 m and no significant breaks were observed in the section.

## Member A

Member A, the stratigraphically lowest unit, occurs only along Shovel Creek about 1.2 km northeast of the Yellowjacket Mine (section 2, pl. 2, and fig. 34). The exposed thickness of this member is 700 m but the base is faulted. This member consists of feldspathic quartzite, argillaceous quartzite, and sandy argillite. Argillaceous quartzite is the predominant lithology. All three lithologies occur within individual graded genetic units. A genetic unit is a shortened form for process-controlled genetic unit of Weimer (1976) and as used here is a graded bed or laminae within which there is no indication of a break in deposition. Quartzite, where present in this member, occurs at the bases of graded beds and grades upward into argillaceous quartzite, which in turn grades upward into sandy argillite.

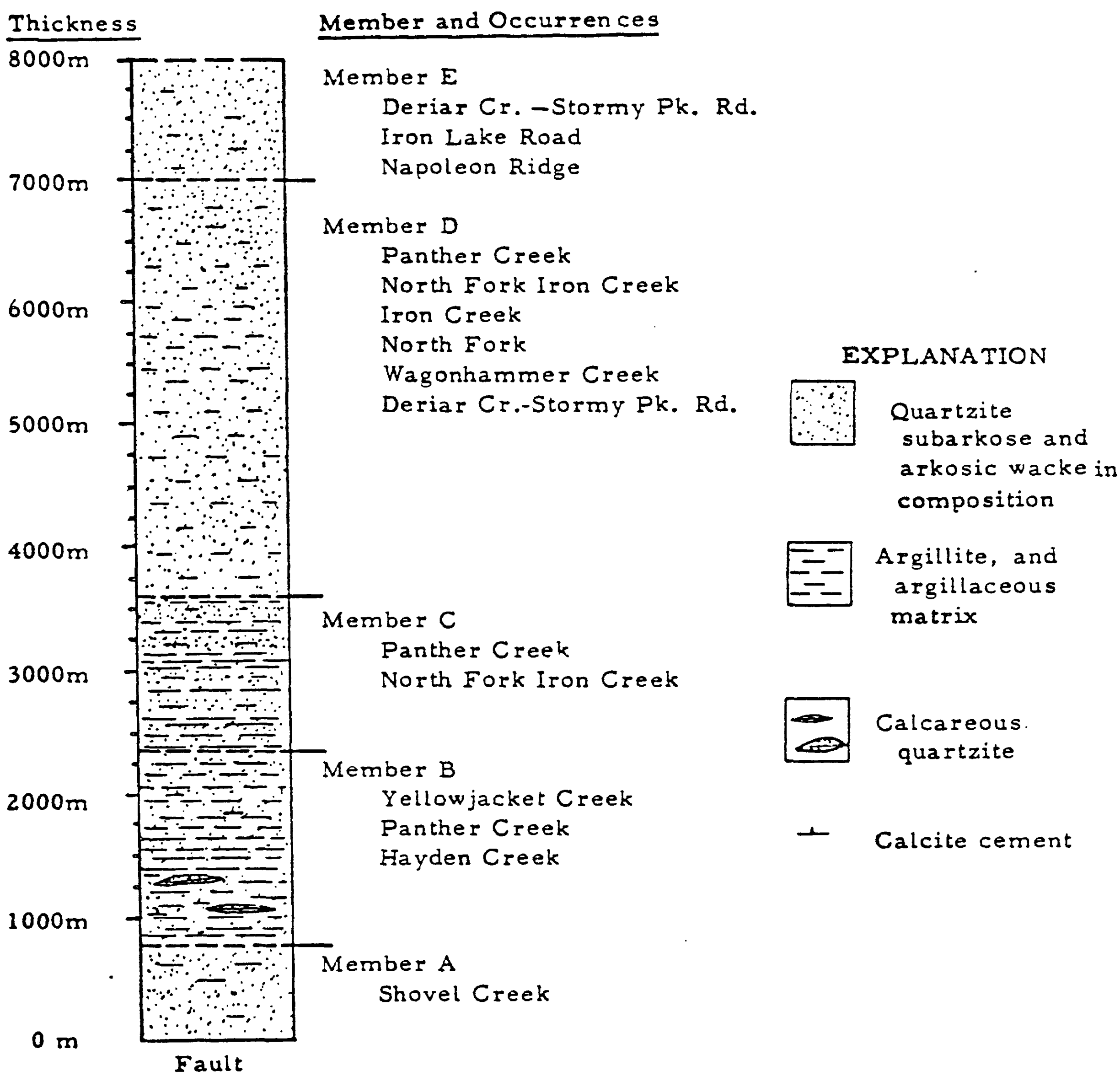



Figure 3.--Composite stratigraphic column of the Yellowjacket Formation, showing areas where each member was studied.

Figure 4 is a photomicrograph of a typical quartzite from the lower part of the member showing the range in grain size, mineralogy, and texture. Graded beds range in thickness from 5 cm to 1 m. Grading is exhibited by an actual decrease in maximum grain size from coarse or medium sand to very fine sand and locally to a mixture of sand, silt, and clay grain sizes. In contrast, grading in the other members is exhibited predominantly by the increase in the amount of argillaceous matrix in the rock, (content grading) whereas the maximum grain size remains constant or decreases only slightly. Colors range from light gray to dark gray (N7 to N3). In general, the lightest colors are at the base of graded beds and the darkest, are in the most argillaceous rocks near the top. Locally the coarsest grain fractions are pinkish gray (5YR8/1).

Within member A the overall grain size decreases upward to predominantly fine and very fine grained argillaceous quartzite in about the upper one-third of the member; sandy argillite becomes more abundant and occurs in beds up to 10 cm thick. Overall beds stratigraphically in the lower portion of member A are lighter in color than rocks in the upper portion. Minor amounts of dark-greenish-gray beds are common near the top of this unit.

Parallel laminations are the most common sedimentary structures. Ripple cross-laminations are common; some occur in combination with flaser bedding. Cross-laminations occur in sets from 1 to 5 cm thick, but are most commonly less than 2 cm thick. Rarely, climbing ripples were also observed. Tops of graded beds were typically scoured to varying depths (1-3 cm) during emplacement of the next overlying bed.

Thin-section examination reveals that the quartzites in member A contain 10 to 13 percent clay-size matrix. Compositionally, the quartzites are subarkose and quartz arenite (fig. 5). Quartz makes up 80 to 87 percent of the rock; plagioclase about 2 percent, orthoclase 2 to 5 percent, and

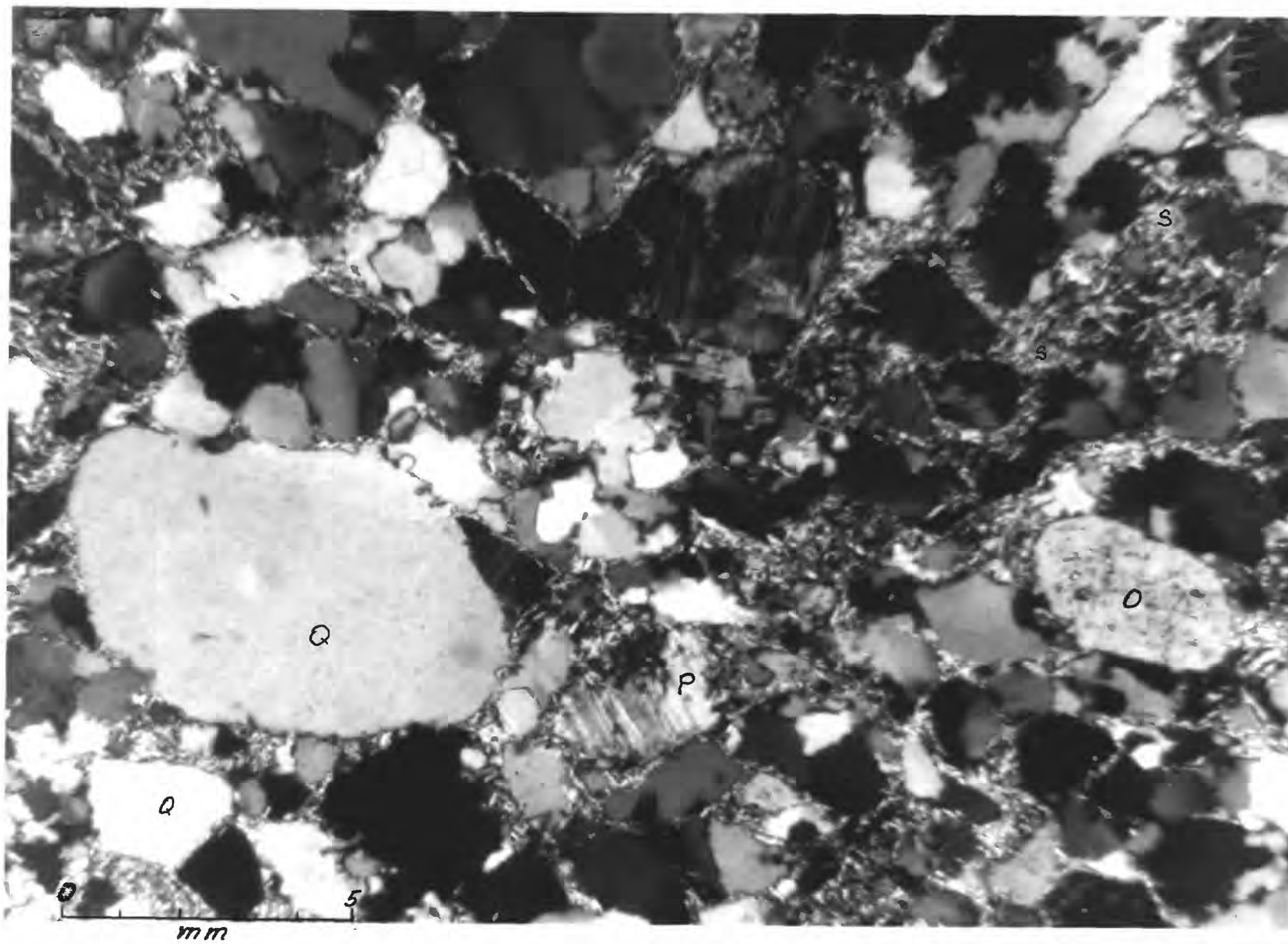



Figure 4.--Photomicrograph showing lithology typical of member A. Note wide range in grain size from clay to coarse sand. The composition is predominantly quartz and feldspar. Small bright grains in interstices between quartz and feldspar are grains of sericite. Note metamorphic effects including slightly sutured grain boundaries and recrystallization of argillaceous matrix as sericite. Crossed nicols. O = orthoclase; P = plagioclase; Q = quartz; S = sericite.

microcline only a fraction of a percent. Biotite makes up about 1 to 8 percent and muscovite and sericite combined make up about 4 to 10 percent.

The composition of the argillaceous quartzite is arkosic wacke and is plotted in figure 5. These rocks contain 25 to 55 percent clay-size matrix. Quartz makes up 50 to 68 percent of the rock. Plagioclase is present from trace amounts to 5 percent; orthoclase 4 to 9 percent; microcline in trace amounts; muscovite and sericite combined 15 to 25 percent; and biotite 2 to 17 percent. Chlorite locally makes up as much as 3 percent of the rock. Some specimens contain lithic fragments of fine-grained quartz arenite and subarkose, which are different from the enclosing rock.

Accessory minerals commonly present in all these rocks are opaque minerals, zircon, garnet, and toumaline, most of which are of detrital origin. Biotite, chlorite, and muscovite were crystallized during metamorphism.

This member grades upward into member B; the increasing occurrence upward of dark-colored and greenish-gray sandy argillite typical of member B reflects this gradation. The end of the measured section along Shovel Creek is approximately at the contact which is transitional through a zone about 200 m thick. The section was not measured higher stratigraphically because of a zone of folding combined with poor exposure.

## Member B

Member B, occurs in Moyer Creek, Porphyry Creek, Upper Shovel Creek, upper Panther Creek (near the mouth of Moyer Creek), Hayden Creek, the North Fork of Iron Creek, and Yellowjacket Creek (the type area of Ross, 1934) (pl. 2). In Panther Creek about 950 m of this member are exposed with the base faulted against Tertiary Challis Volcanics. In Hayden Creek the entire

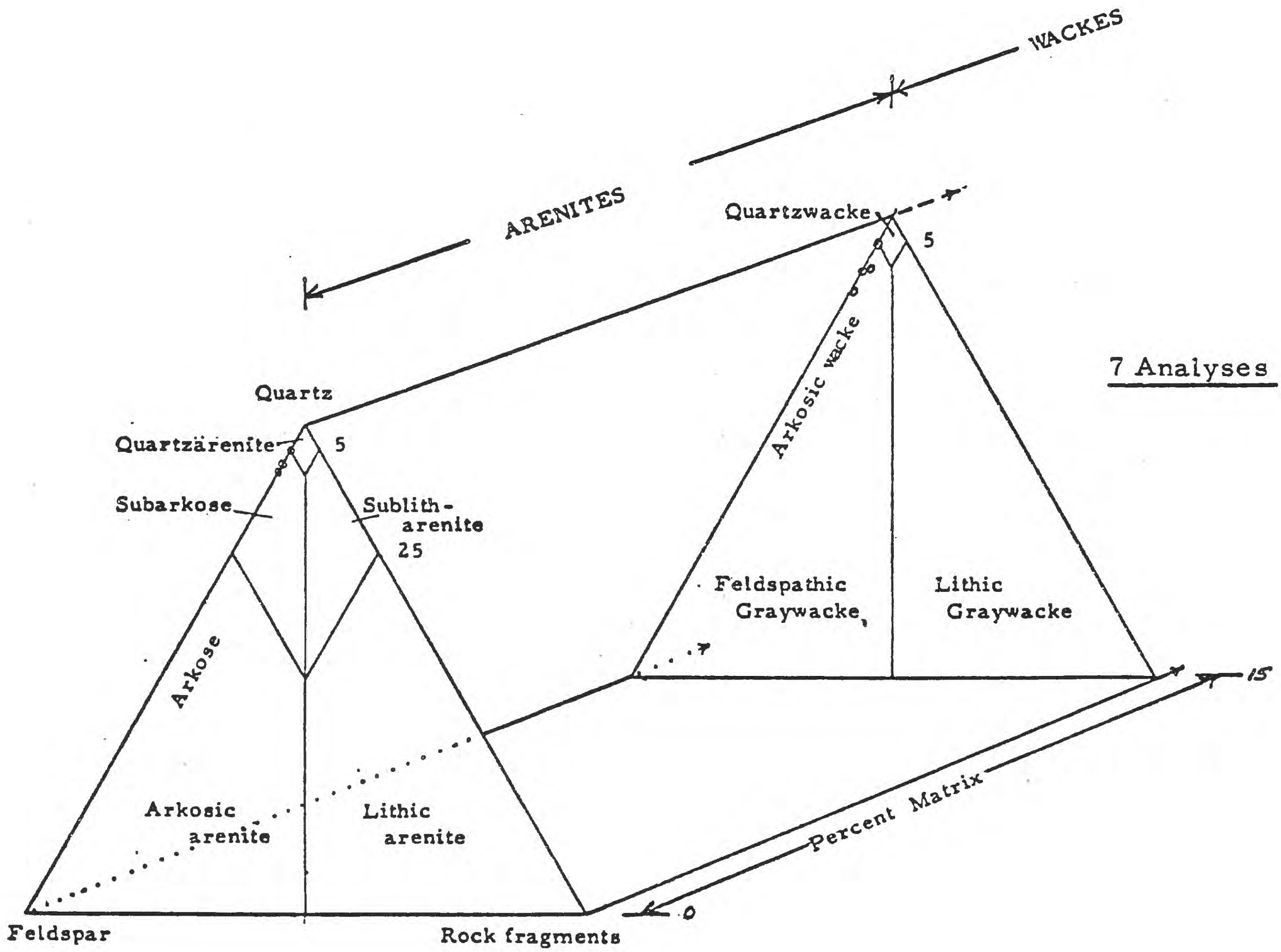



Figure 5.--Composition of rocks in the Shovel Creek Section, Yellowjacket Formation, member A. Modified from figure 2.

measured section of Yellowjacket, about 1,600 m, is within Member B and both upper and lower limits are fault contacts. Approximately 2,000 m of this member occur at Yellowjacket Creek but the thickness is uncertain due to a combination of poor exposure, structure, and the intrusion of numerous thick quartz latite porphyry dikes.

The predominant lithologies in this member are very fine grained, very argillaceous quartzite and siltite, the modal composition of which is arkosic wacke. Figure 6 is a photomicrograph illustrating the typical texture and mineralogy of this lithology. Locally, especially in Hayden Creek, these rocks are as coarse as medium sand. Sandy argillite is locally present that is compositionally mudstone (fig. 2). The argillaceous quartzites, siltites, and sandy argillites form graded beds 2 to 20 cm thick that show both fining upward and an upward increase in the percentage of argillaceous matrix.

Colors are predominantly medium dark gray to light gray. Greenish tints commonly occur in the siltstones and thin brownish-gray calcareous zones are common, especially in the coarsest fractions.

In addition to graded bedding, the most common sedimentary structures observed are parallel laminations and ripple cross-laminations. Other structures present include load casts, ripple marks, and cut-and-fill structures. Fluid-escape structures, climbing ripples and faint dish structures occur in the siltstones in the Hayden Creek area.

Thin-section modal composition of the quartzites and siltites is that of arkosic wacke (fig. 7). These rocks contain 40 to 60 percent clay-size matrix. The content of quartz ranges from 30 to 50 percent, plagioclase ranges from a fraction of a percent to about 20 percent; orthoclase 1 to 15 percent; microcline is absent; muscovite and sericite 10 to 50 percent; biotite 1 to 11 percent; and calcite from trace amounts to 10 percent.

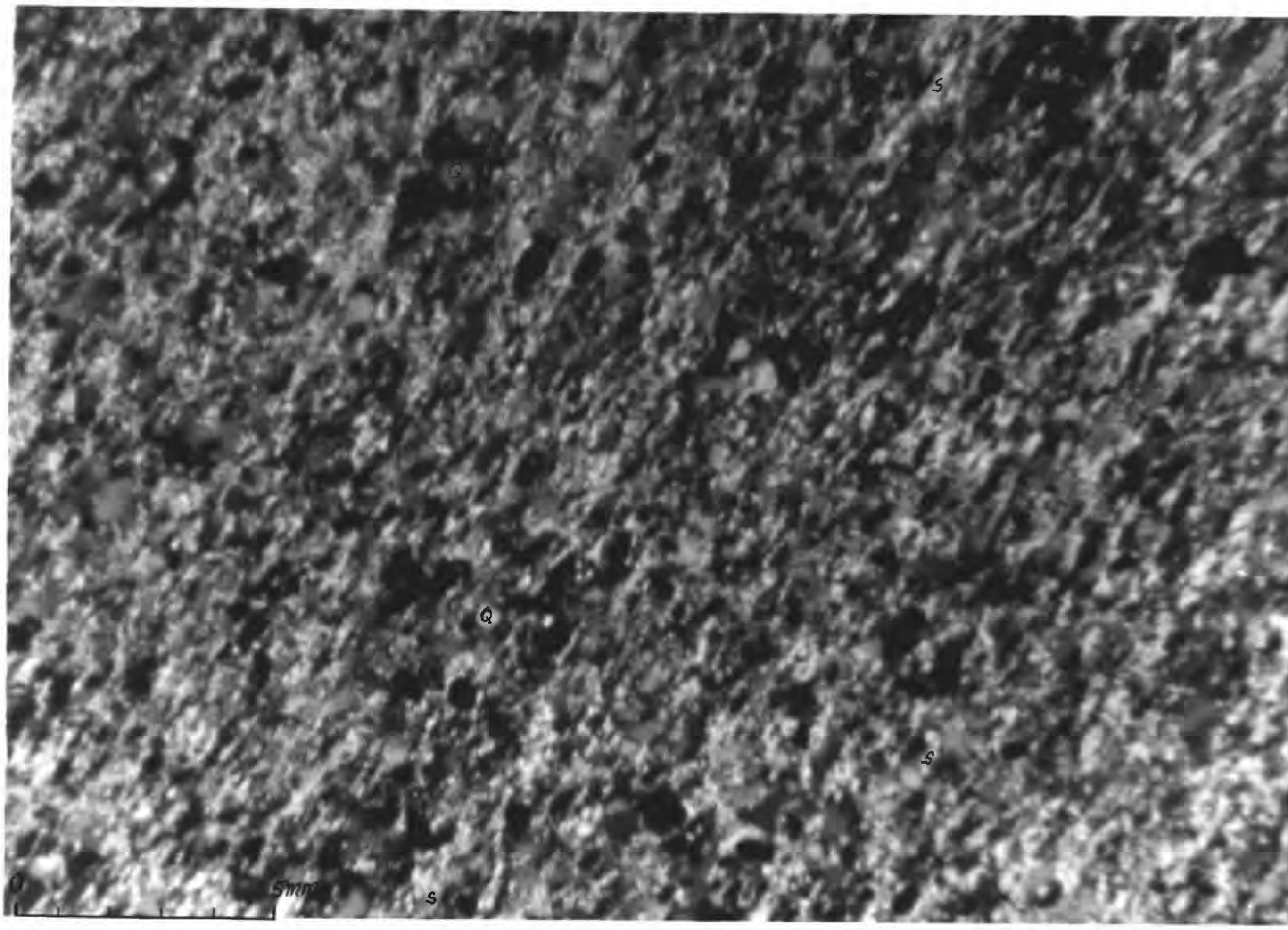



Figure 6.--Photomicrograph showing lithology typical of member B. The rock is compositionally a mudstone, consisting of very fine sand and silt size grains of quartz and feldspar in a matrix that is predominantly sericite. Bright moderately aligned grains are sericite. Note metamorphic effects including recrystallization of matrix as sericite and the strong crystallographic alignment of sericite. Crossed nicols. Q = quartz; S = sericite.

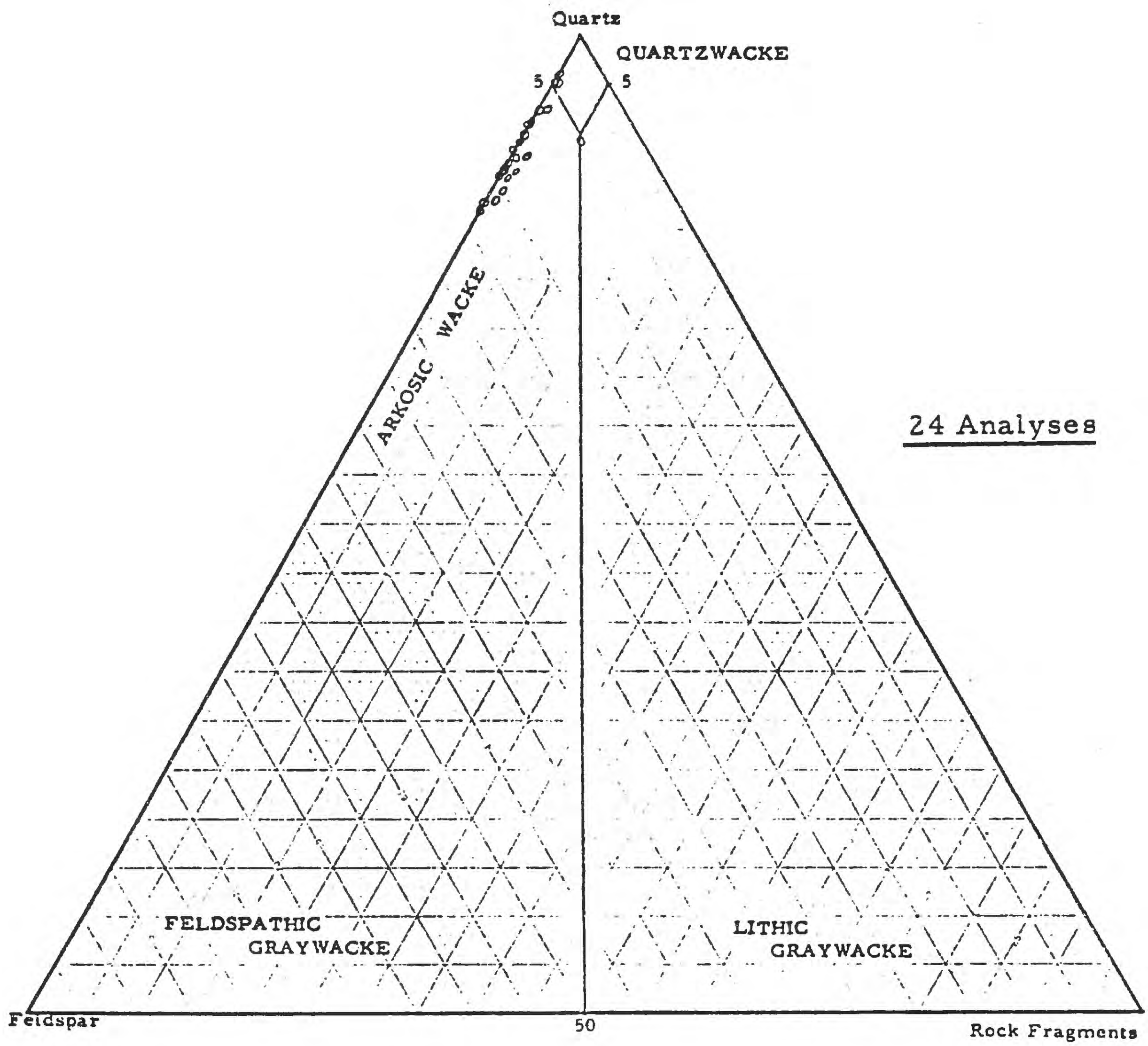



Figure 7.--Composition of rocks of member B, Yellowjacket Formation.

Locally chlorite is present up to 5 percent of the total and opaque minerals reach 5 percent of the rock. Accessory minerals present are tourmaline, zircon, garnet, and locally clinozoisite and epidote. Tourmaline, garnet, zircon, quartz, and the feldspars are all present as detrital grains. Muscovite, sericite, biotite, clinozoisite, and epidote are all of metamorphic origin. Opaque grains are in part detrital grains and in part secondary (possibly metamorphic).

A distinctive characteristic of this member is the occurrence of lenticular bodies of highly calcareous rocks, typically less than 15 m thick and 60 m wide. They include: 1) banded rocks with closely spaced irregular dark-green, black and gray laminae (fig. 8); and 2) nearly white rocks, commonly stained by iron oxide on weathered surfaces, mottled by dark clusters of metamorphic minerals. Figure 9 is a photomicrograph of lithology 1 above which is the most typical of these calcareous quartzites. The darkest laminae are typically noncalcareous and represent metamorphosed clay-rich laminae. The dark clusters in mottled rocks are commonly alined along bedding and were probably also initially clay-rich laminae but were much thinner than in the banded rocks. In all these calcareous rocks detrital quartz is the predominant constituent. Calcite cement makes up as much as 35 percent of the rock. Other minerals present are scapolite, biotite, muscovite, chlorite, epidote, amphiboles, orthopyroxene, and plagioclase. In the Yellowjacket Creek area, the calcareous quartzites contain pellet-like masses about 0.5 cm in diameter that in thin section are seen to be large crystals of scapolite choked with inclusions of quartz and feldspar (fig. 8).

The contact between member B and the overlying member C is transitional through a zone of about 100 to 200 m. The transition is marked by a decrease in the number of greenish-gray beds and an increase in the occurrence of thin

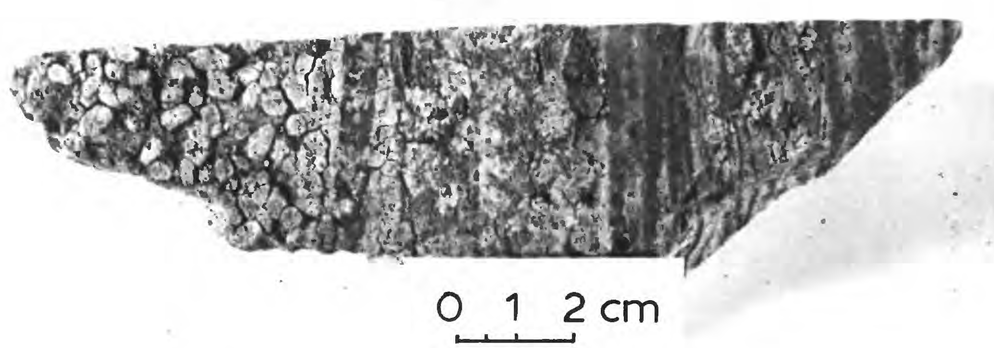



Figure 8.--Photograph of calcareous quartzite typical of member B. Specimen is from Yellowjacket Creek near the Yellowjacket Mill. Pellet-like structures visible in the lower part (left) of specimen are incipient crystal growths of scapolite.

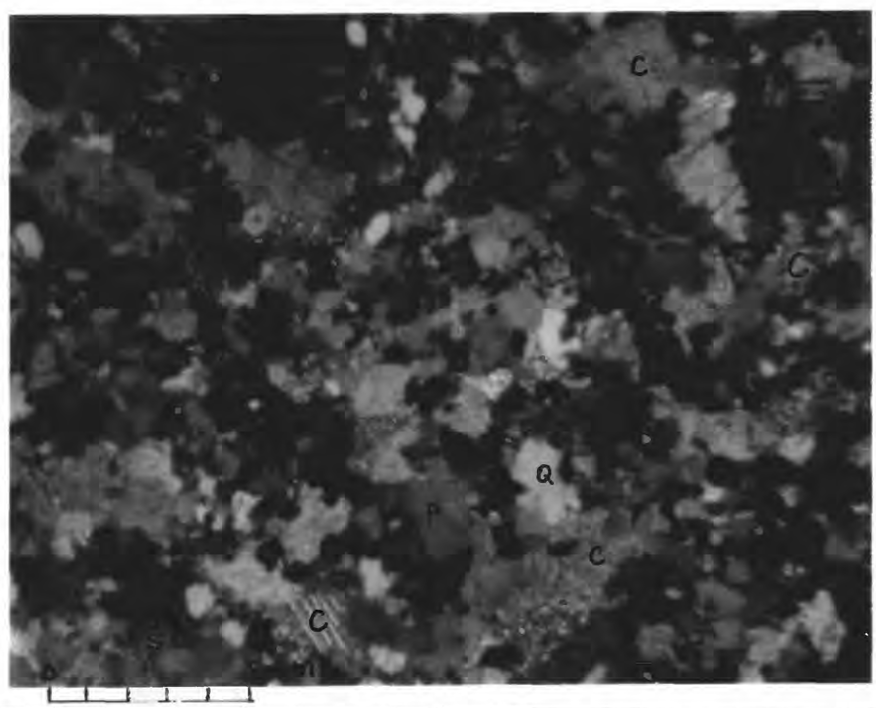



Figure 9.--Photomicrograph of calcareous quartzite from member B. Thin section was cut from about the center of the specimen in figure 8. The rock is composed predominantly of quartz and feldspar, with interstitial calcite and sericite. Crossed nicols. Q = quartz; P = plagioclase; C = calcite; S = sericite.

couplets of medium dark-gray argillaceous quartzite or siltite and dark-gray sandy argillite typical of member C. Due to the transitional nature of the contact, it can only be located approximately and was placed where thinly laminated dark-colored couplets make up at least 50 percent of the section. The transition was observed along Panther Creek just north of Musgrove Creek.

## Member C

Member C is widespread in the Panther Creek drainage between Moyer Creek and Copper Creek, and in the North Fork of Iron Creek (pls. 1 and 2). In the Panther Creek Section, a thickness of approximately 1,300 m of this member is present, but some uncertainty as to the thickness exists because of the presence of several isoclinal folds within the section. In the North Fork of Iron Creek this member is about 1,100 m thick.

Couplets of medium dark-gray argillaceous quartzite and/or siltite and of dark-colored sandy argillite are characteristic of this unit. These two lithologies occur together, forming graded intervals with the darkest most argillaceous materials at the top (fig. 10). The colors grade from medium gray at the base to dark gray at the top. Locally some greenish-gray beds occur. The grain size varies from very fine sand or silt at the base to predominantly clay with scattered very fine sand and silt-size grains at the top. In other words the grading is exhibited by an increase in the percentage of argillaceous material upward, whereas the maximum grain size remains nearly constant. Near the base of the section the graded intervals are laminae from several millimeters to 2 cm thick. Upward in the section, the thickness of graded intervals increases, and near the top the graded beds are 5 to 15 cm

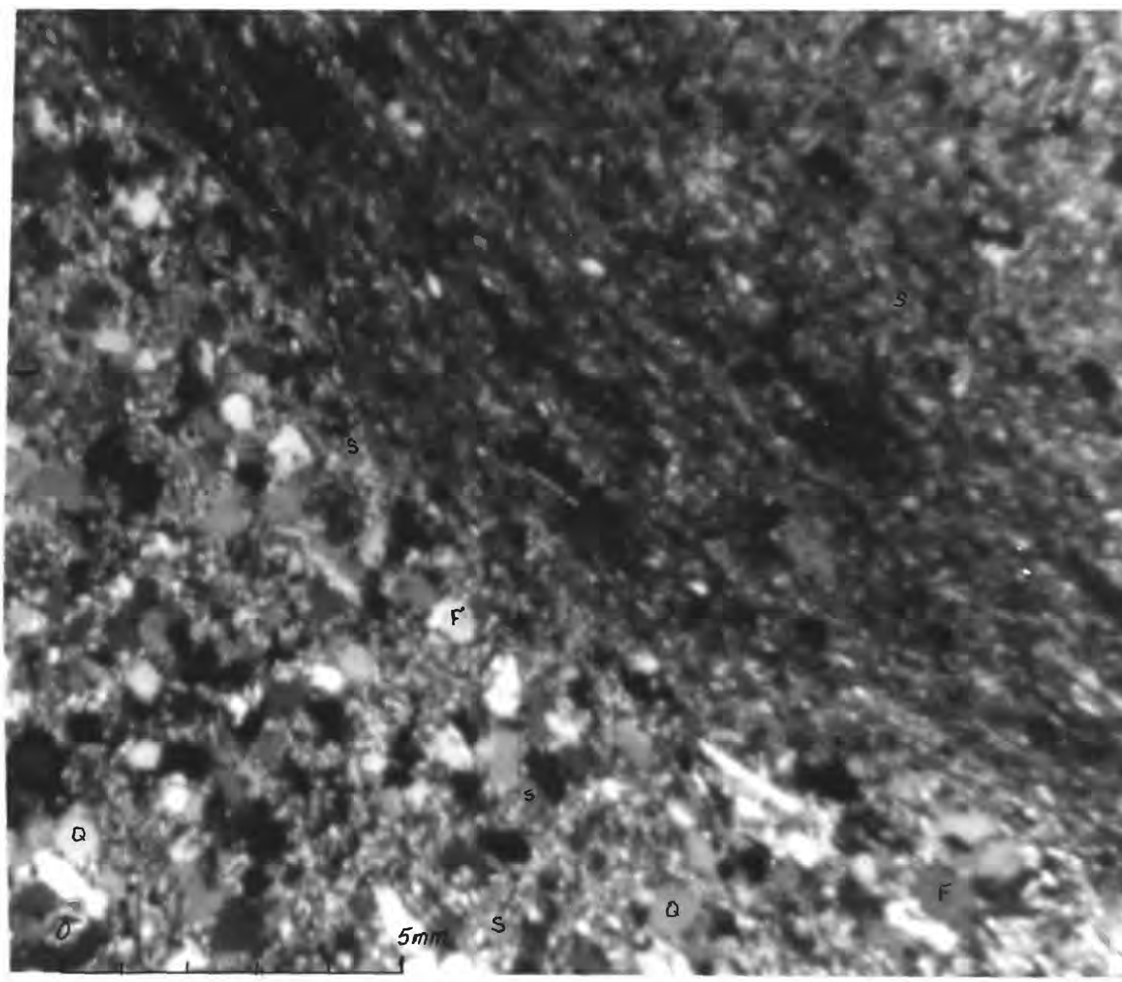



Figure 10.--Photomicrograph of lithology typical of member C. Note scale of lamination; on left is argillaceous siltite and on right silty argillite or mudstone. Crossed nicols. S = sericite; Q= quartz; F = feldspar.

thick; and the proportion of sand and silt to argillite increases from approximately 1:1 to about 2:1.

Parallel laminations are nearly ubiquitous structures in this member. A distinctive feature is the common occurrence of convolute laminations and other types of soft-sediment deformation such as sand-injection structures and fluid-escape structures (fig. 31). These are most common where the sand and silt to clay ratio is 1 or less, and where the thickness of the sand and silt laminae is about 2 to 5 mm. Also present are "pseudo-mudcracks" that are produced by the intersection of bedding planes with various soft-sediment deformational features like tight folds or injection features (fig. 35). In other cases these "pseudo-mudcracks" are produced where the rock breaks across several laminae at a slight angle to bedding producing a surface exhibiting an "outcrop pattern" at millimeter and centimeter scale. Other features present are ripple cross-laminations, current ripple marks, load casts, and ball-and-pillow structures.

Thin-section modal analysis indicates that the argillaceous quartzites and siltites of this member are arkosic wackes (fig. 11). The sandy argillites are very similar but contain more than 75 percent clay, which would place them in the mudstone field of figure 2. The percentage of matrix in the argillaceous quartzites is 45 to 70 percent. The quartz content is 30 to 60 percent; plagioclase, 1 to 3 percent; orthoclase, 3 to 11 percent; microcline is absent; muscovite and sericite, 10 to 40 percent; biotite, 5 to 20 percent. Accessory minerals present include tourmaline, zircon, garnet, chlorite, epidote, calcite, and opaque minerals. As in the members already described, quartz, feldspar, tourmaline, zircon, and garnet all occur as detrital grains. Biotite, muscovite, sericite, chlorite, and epidote are of metamorphic origin. Calcite was probably deposited originally as detrital grains but has been recrystallized during metamorphism.

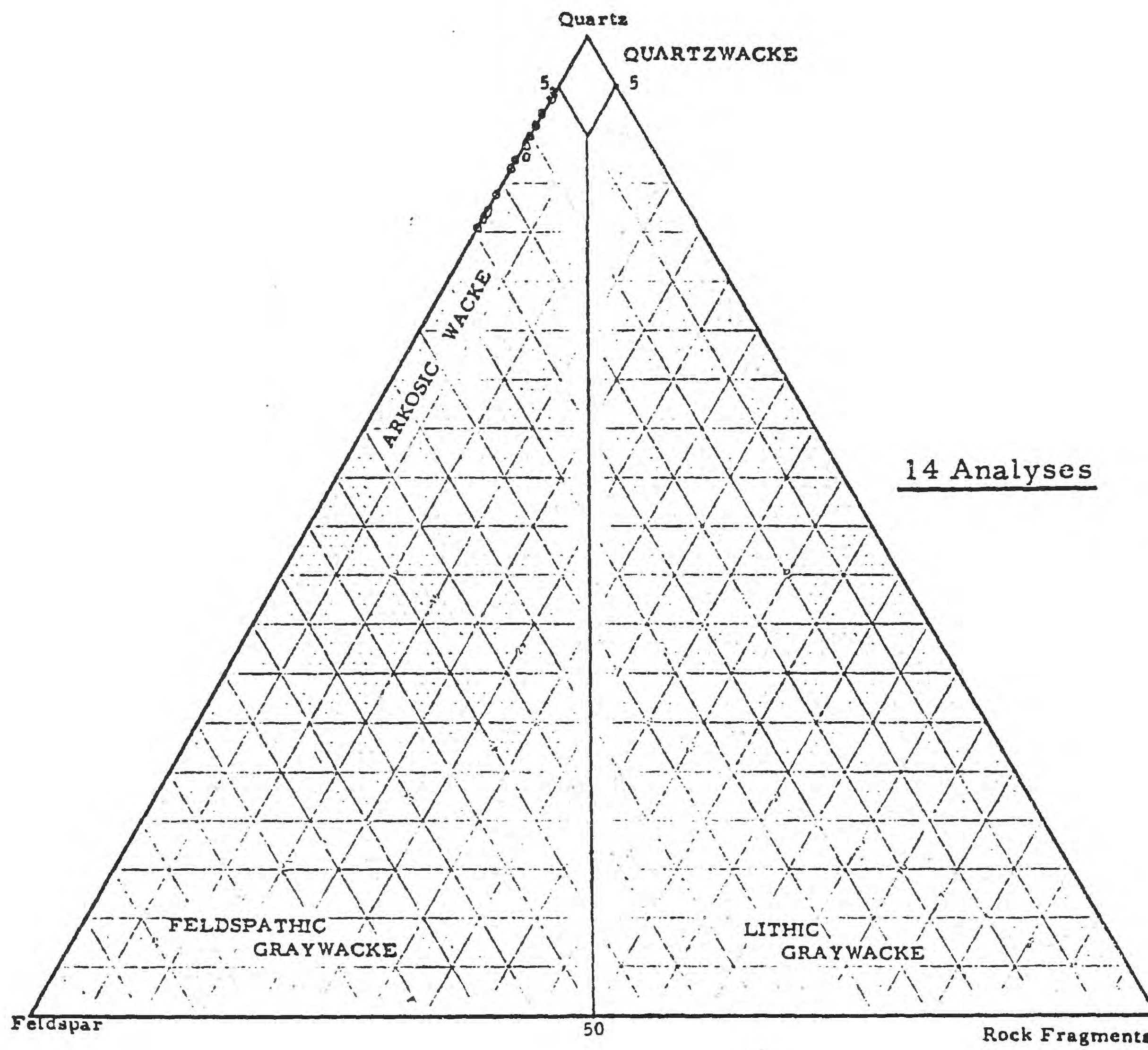



Figure 11.--Composition of rocks of member C, Yellowjacket Formation.

Member C grades upward into member D and the contact is placed where sandy argillite at tops of graded beds is minor or absent, and beds are most commonly 5 cm or more thick. The transition from member C to member D was observed along Panther Creek in the vicinity of Copper Creek (pl. 5). The two members also occur together in the North Fork of Iron Creek but the separation is more difficult to make.

## Member D

Member D is the most widespread unit of the Yellowjacket Formation. As illustrated in plate 1, most of the Yellowjacket north of the junction of Copper Creek and Panther Creek is in this unit. This includes the North Fork area, the Yellowjacket in the Beaverhead Mountains and at the northern end of the Lemhi Range. The upper half of the North Fork of Iron Creek Section is within this member as is all the Iron Creek Section. The entire section of member D is not exposed in any one area, therefore the section had to be pieced together from sections measured in widely separated areas, on the basis of similar lithology and lithologic successions. Based on such correlations, the thickness is at least 2,500 m but a more accurate thickness is probably about 3,500 m.

Very fine grained and rarely, fine- and medium-grained, argillaceous quartzite is the predominant lithology in member D (fig. 12). Sandy argillite rarely occurs at tops of graded beds. Colors range from light gray to dark gray. Graded bedding averages 30 cm in thickness but ranges from about 5 cm to 1 m. In general, the thickness of graded beds increases up section and argillite overlying graded beds is most common near the base of the section. Grading in this member is typically exhibited by an upward increase in the

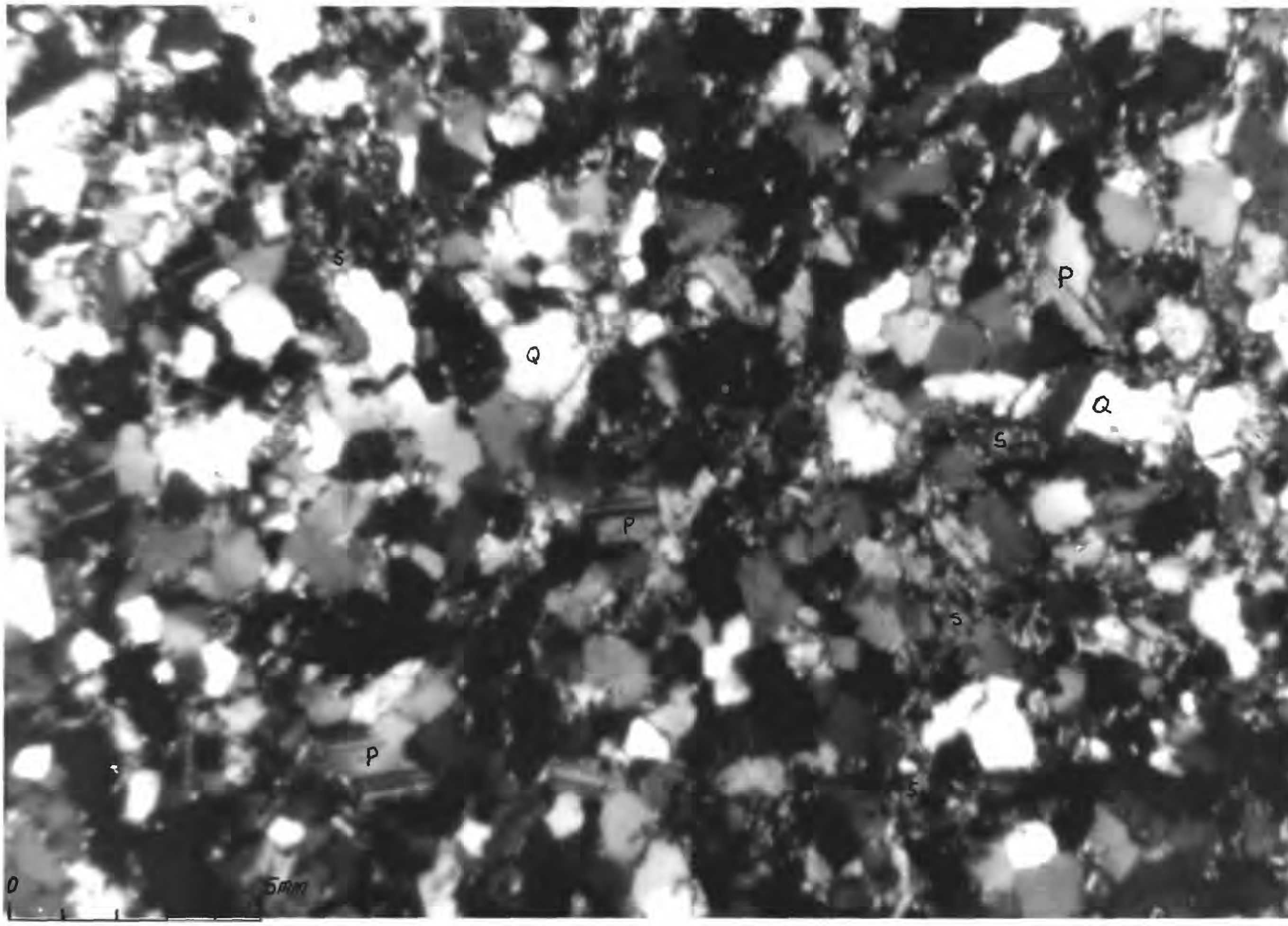



Figure 12.--Photomicrograph of lithology typical of member D. Grain size is very fine sand. Composition is arkosic wacke; most common minerals visible are quartz and feldspar. Matrix is composed of clay-size fragments of quartz and feldspar and crystals of sericite (bright grains). Note metamorphic effects including slightly sutured grain boundaries and recrystallization of argillaceous matrix to sericite. Crossed nicols. Q = quartz; P = plagioclase; S = sericite.

percentage of argillaceous matrix; locally the maximum grain size also decreases upward. Figure 13 illustrates a typical exposure of member D, and shows the character and apparent continuity of beds.

Parallel laminations are the most common sedimentary structures. Ripple cross-laminations are also common. Other structures observed include load casts and ball-and-pillow structures, flute casts, ripple marks, cut-and-fill structures, and penecontemporaneous slump folds.

The thin-section modal composition of argillaceous quartzite from this member is arkosic wacke and is shown in figure 14. The content of clay-size matrix ranges from 15 to 58 percent. Quartz makes up 40 to 70 percent of the total volume of the rock; plagioclase 1 to 3 percent; orthoclase 2 to 15 percent; microcline, trace amounts to 1 percent; muscovite and sericite 10 to 30 percent; biotite, 1 to 10 percent. Accessory minerals commonly present are tourmaline, zircon, garnet, sphene, clinozoisite, epidote, and chlorite. The quartz, feldspars, tourmaline, zircon, garnet, and sphene are all detrital in origin. Muscovite, sericite, biotite, chlorite, clinozoisite, and epidote are metamorphic in origin. Clinozoisite and epidote are especially abundant near large intrusive bodies of porphyritic quartz monzonite.

The contact with overlying member E is gradational and is exhibited by the increasing occurrence of medium-gray to light-gray quartzite and slightly argillaceous quartzite beds that are typically 50 cm to 2 m thick. The contact was placed where these lighter colored, thicker quartzite beds are predominant. The transition from member D to member E is well exposed only in the Deriar Creek--Stormy Peak Road Section (pl. 2 and fig. 55). Along the Iron Lake Road south of Williams Creek Summit, the gradation between members can be observed but the rocks are very poorly exposed (pl. 1). The only

Figure 13.--Photograph showing bedding character of the Yellowjacket Formation, member D. Exposure is near the North Fork Post Office, SW1/4, sec. 16, T. 24 N., R. 21 E. Distance between figures in the photograph is about 25 m.

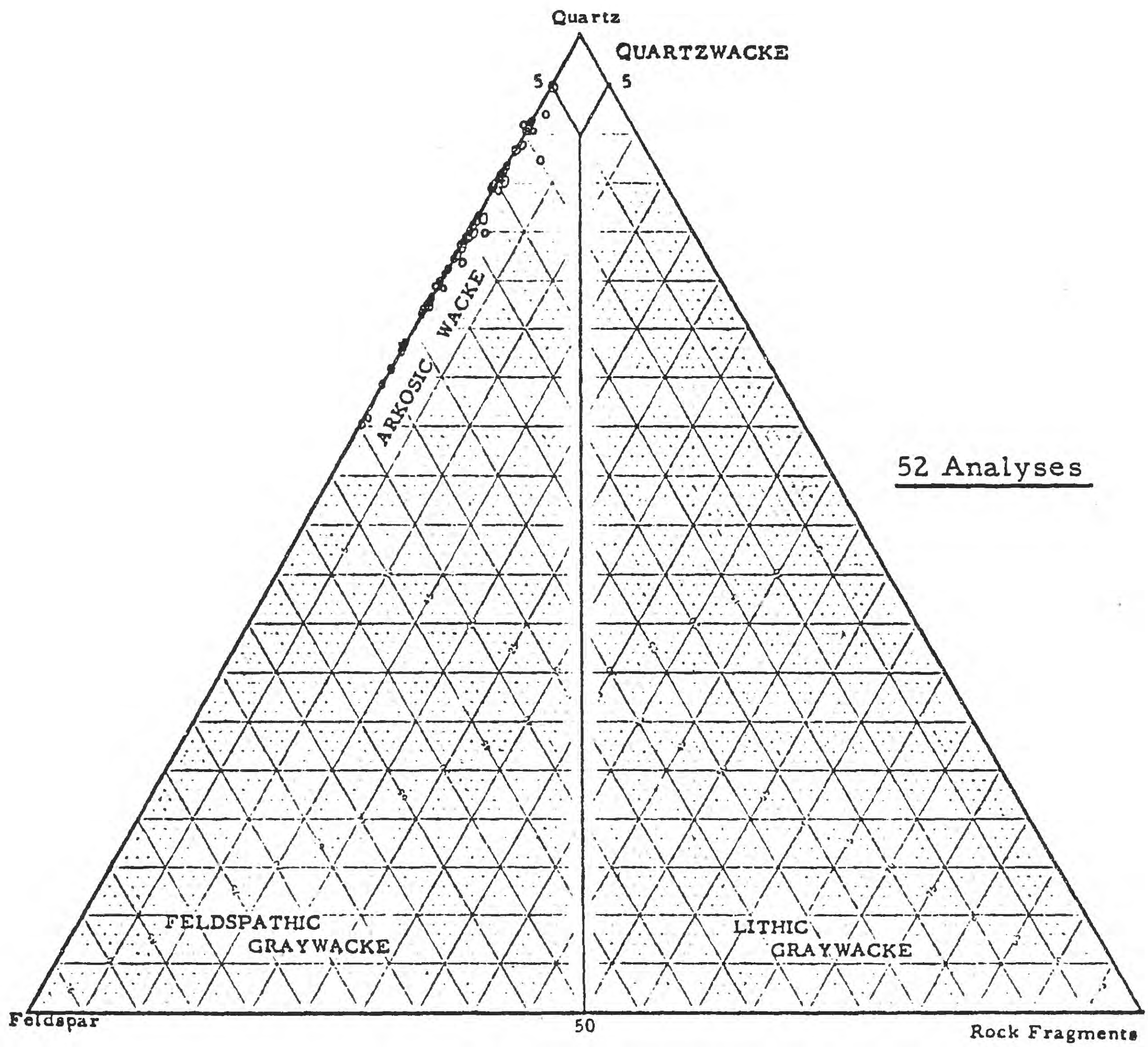



Figure 14.--Composition of rocks, member D, Yellowjacket Formation.

lateral lithologic change observed is the more common occurrence of fine and medium-grained argillaceous quartzite in the North Fork of Iron Creek area.

## Member E

Rocks of member E have limited geographic distribution and were observed at only three localities. They occur in the Deriar Creek--Stormy Peak Road Section about 3 miles north of Salmon; they cap Napoleon Hill and the ridge south of there for a short distance; and they are present along the Iron Lake road beginning about 3 miles south of the Williams Creek Summit (pls. 1 and 2). Only in the Deriar Creek--Stormy Peak Road Section could the thickness be measured; about 225 m are exposed there. On Napoleon Hill member E is thin, forming only a cap on the ridge. Along the Iron Lake Road because exposures are poor the member was not measured, but a thickness of 1,000 m is estimated. In all three areas this member gradationally overlies member D. The top is not exposed; along the Iron Lake Road the member is buried by Tertiary Challis Volcanics. In other areas it is fault-bounded.

Quartzite and slightly argillaceous quartzite are the predominant lithologies (fig. 15). The two lithologies occur together in normally graded beds. Grading is exhibited by an upward increase in the content of argillaceous matrix; thus quartzite occurs at the base and argillaceous quartzite at the top. Graded intervals on the average are thicker than in the other members, about 1 m, and range from about 30 cm to 2 m. Colors in the unit are in general much lighter than in the other members of the Yellowjacket, ranging from light gray to medium dark gray and typically darkening upward within graded beds.

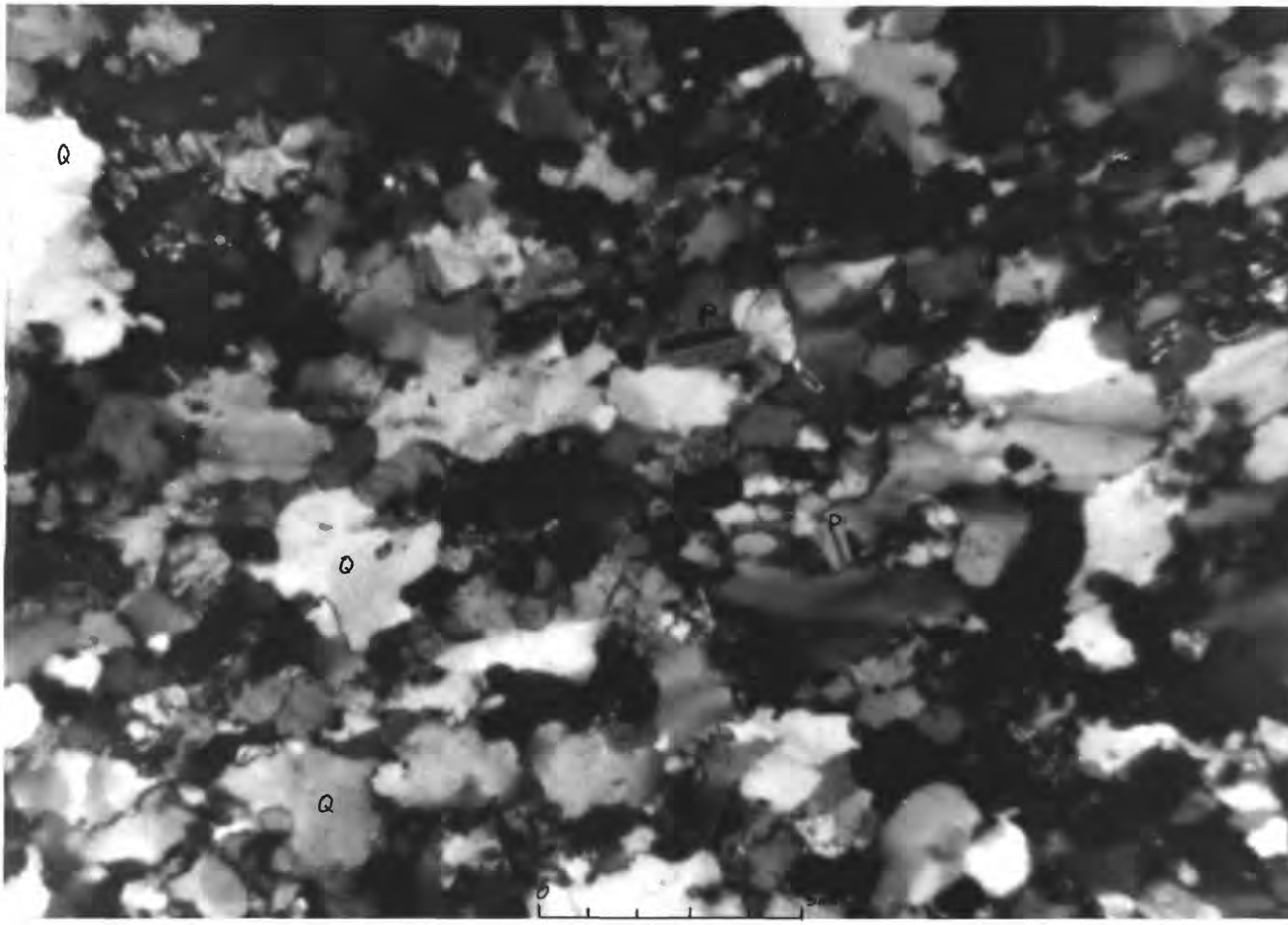



Figure 15.--Photomicrograph of lithology typical of member E. Note grain size is predominantly very fine and fine sand, and the much lower content of clay-size matrix relative to the other members. The rock is composed mainly of grains of quartz with subordinate amounts of feldspar. Note metamorphic suturing of grain boundaries and alignment of grains. Crossed nicols. Q = quartz; P = plagioclase.

Sedimentary structures observed include parallel laminations, ripple cross-laminations, load casts, cut-and-fill structures, ball-and-pillow structures, ripple marks, and, locally, climbing ripples.

Thin-section analysis indicates these rocks are arkosic wacke and subarkose to quartz arenite in composition (fig. 16). The matrix content ranges from about 10 to 30 percent. Quartz makes up 60 to 85 percent of the rock; plagioclase, 3 to 11 percent; orthoclase, 6 to 28 percent; microcline trace amounts to 1 percent; muscovite and sericite, 1 to 15 percent; biotite, 1 to 11 percent. Accessory minerals present include tourmaline, zircon, garnet, chlorite, clinozoisite, and epidote. Quartz, feldspar, tourmaline, zircon, and garnet are present as detrital grains. Biotite, muscovite and sericite, clinozoisite, and epidote are metamorphic in origin.

## Stratigraphic Summary

Although lithologies throughout the Yellowjacket Formation are similar, the members described above can be distinguished on the basis of a combination of features. Compositionally, the members are similar; only member D, which is markedly more feldspathic, can be clearly distinguished from the other members in a combined compositional diagram (fig. 17).

Member A consists of graded beds of the coarsest grained quartzites and argillaceous quartzites in all the formation. Coarse to medium-grained quartzite that is compositionally subarkose and quartz arenite grades upward into fine or very fine grained argillaceous quartzite, compositionally arkosic wacke, which in turn grades into sandy argillite. These graded beds are 10 cm to 1 m thick. High in the section, member A is finer grained, consisting of very fine and fine-grained argillaceous quartzite and sandy argillite. Colors

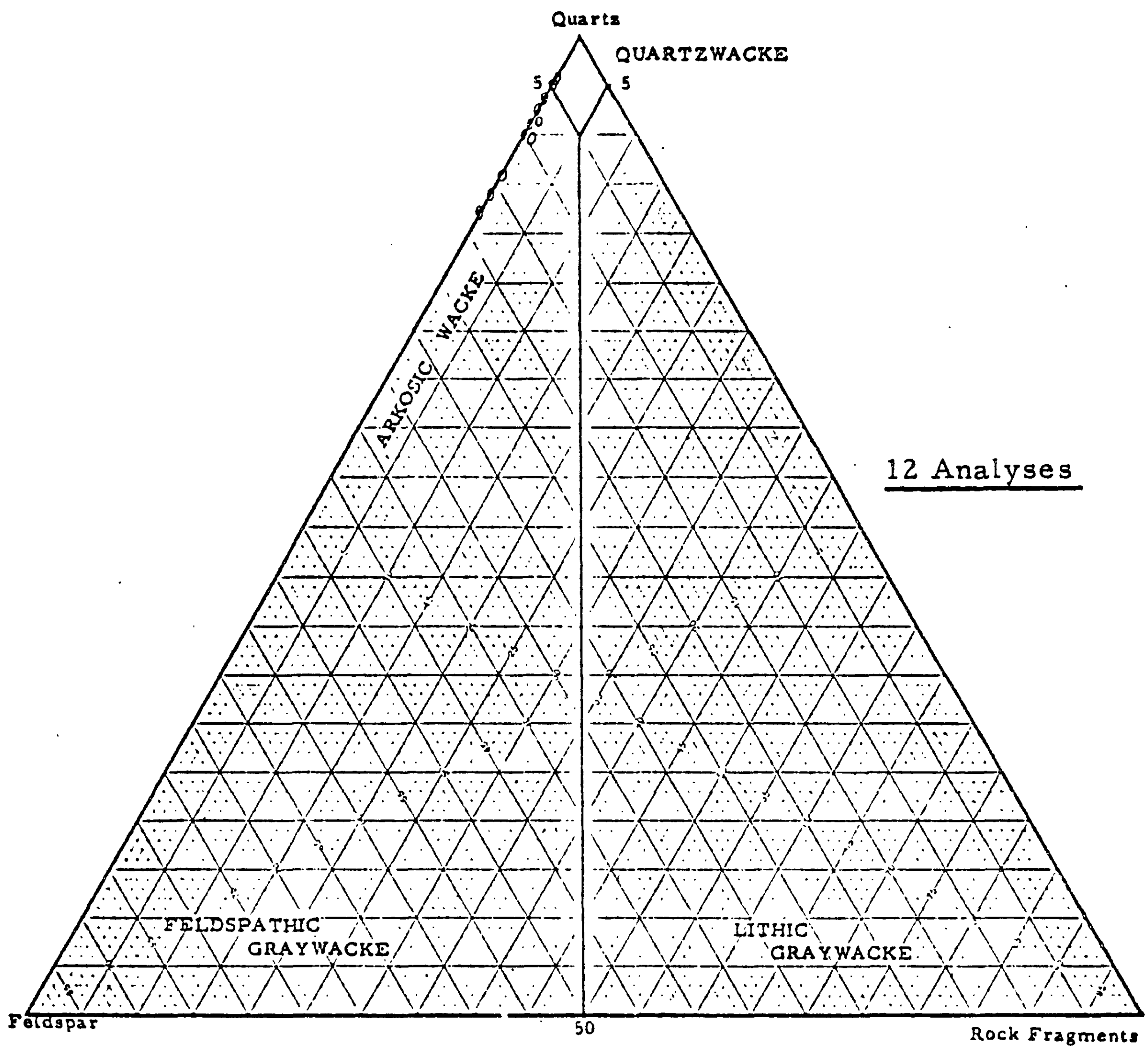



Figure 16.--Composition of rocks, member E, of the Yellowjacket Formation

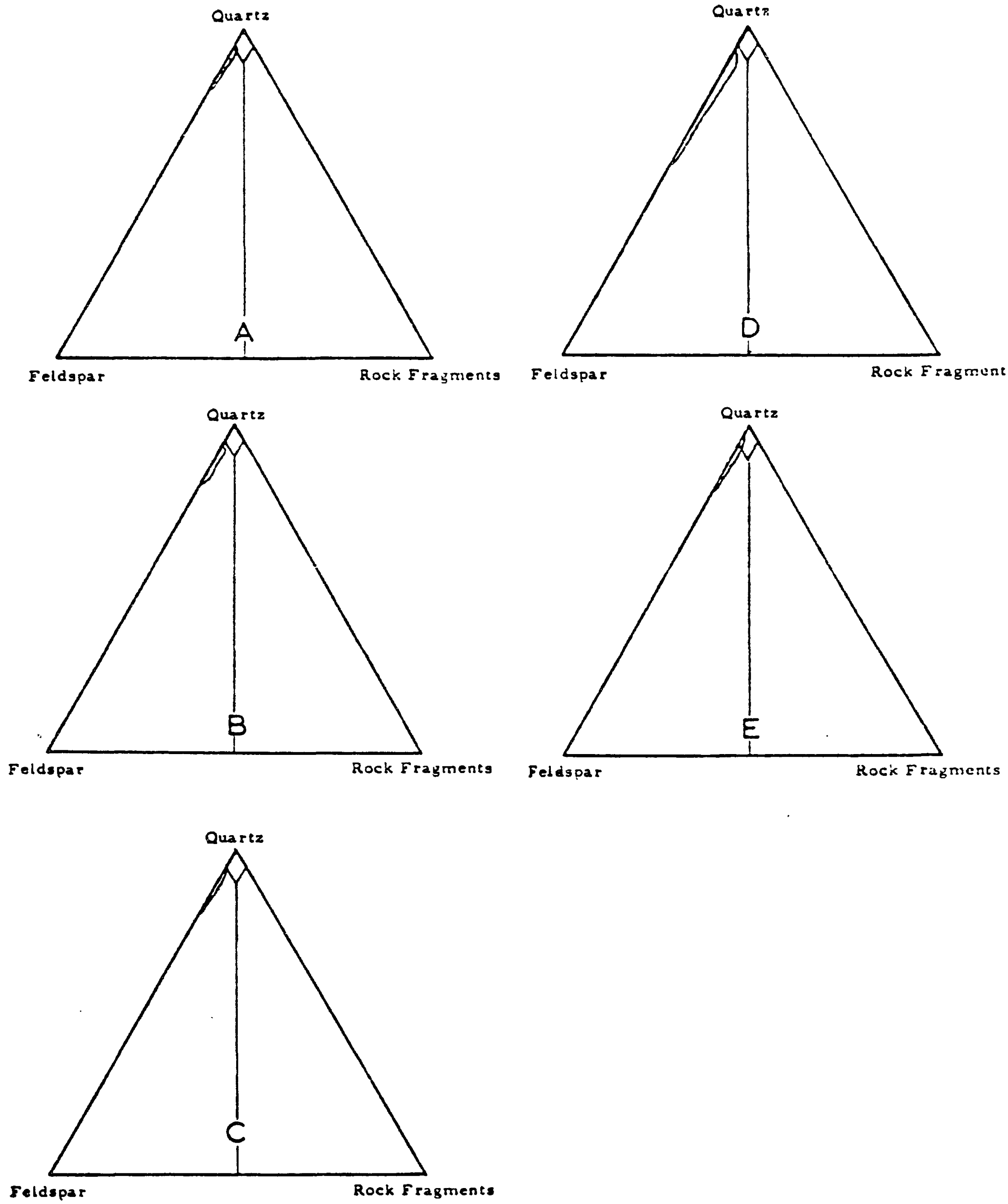



Figure 17.--Compositional summary of the Yellowjacket Formation. Capital letter in bottom center of diagrams is member designation. Fields are the same as those for wackes of figure 2. Note the similarity in composition of all the members; only member D is significantly different in that it tends to be more feldspathic.

in member A range from light gray to dark gray, darkening both upsection and upward within individual graded beds. The exposed thickness of member A is about 700 m.

Member B is predominantly very fine grained, very argillaceous quartzite and siltite. Graded beds are 5 to 50 cm thick. Colors are predominantly medium gray and greenish gray. Characteristic of this member are beds of slightly calcareous argillaceous quartzites and lenticular bodies of banded and mottled highly calcareous quartzite (20 to 35 percent calcite). The thickness of member B is about 1,600 m.

Member C is characterized by couplets of light-colored argillaceous quartzite and/or siltite and dark-colored sandy and silty argillite that occur together in graded genetic units. The quartzite and siltite are arkosic wacke in composition. The graded intervals thicken up-section from couplets a few millimeters thick at the base to beds 5 to 15 cm near the top. Near the base of the member the sand to shale ratio is about 1 and increases to 2 or more at the top. Convolute laminations and "psuedo-mudcracks" are common in this member. Member C is about 1,300 m thick.

Member D is predominantly very fine grained argillaceous quartzite in graded beds 10 cm to about 1 m thick. Grading is exhibited mainly by an increase in the content of clay-size matrix upward, whereas the maximum grain size rarely decreases upward within graded beds. Colors darken upward within graded beds generally from medium gray to dark gray. The thickness of Member D is at least 2,500 m but may reach 3,500 m.

Member E contains the least argillaeous quartzites of all the members of the formation. Quartzite, which is subarkose and quartz arenite in composition, grades upward into argillaceous quartzite, which is compositionally arkosic wacke. Grading is exhibited by the increase of argillaceous matrix content. The graded beds are, in general, thicker than in the other members and range from 30 cm to 2 m thick. Grain sizes are predominantly very fine and fine sand. Colors are light gray to medium dark gray, typically darkening upward within graded beds. The thickness of member E is probably at least 1,000 m.

As mentioned previously, Shockey's (1957) and Bennett's (1977) phyllite members are approximately equivalent and include both members B and C of this study. Their quartzite units correspond to members D and E of this study. The lower and middle units of Cater and others (1973) may correspond to members A and B, respectively, on the basis of the presence of similar lithologies. His upper metavolcanic unit apparently pinches out eastward and is absent in the region of this study. Its position in the section is the same as that of member C but whether it correlates with any of the members described here is not certain.

## REGIONAL CORRELATION AND AGE OF THE YELLOWJACKET FORMATION

On the basis of lithology and stratigraphic position, the Proterozoic or Y-age quartzites of east-central Idaho generally have been correlated with the Belt Supergroup of western Montana and northern Idaho (Umpleby, 1913; Ross, 1934, 1947, 1970; Anderson, 1956, 1957, 1959, 1961; and Ruppel, 1975). Ruppel (1975) made a preliminary correlation of the Yellowjacket Formation with the Prichard Formation of the Belt Supergroup on the bases of lithologic similarity and basal stratigraphic positions of the two units. The Prichard Formation is rich in Sr relative to the other units of the Belt Group; values typically range from 100 to 300 ppm (Harrison and Grimes, 1970; Earle Cressman, oral communication, 1981). Similarly, samples of the Yellowjacket consistently contain 100 to 200 ppm Sr (table 3), which helps to substantiate the correlation of the Yellowjacket and Prichard Formations. The age of the Prichard has been bracketed between 1.4 and 1.76 m.y., based on the age of mafic sill intrusions and the underlying basement.

Precambrian quartzites younger than the Yellowjacket in east-central Idaho are the Lemhi Group, Swauger Formation, and Wilbert Formation. These units have never been seen in depositional contact with the Yellowjacket; the contact is always a fault contact with younger units thrust over it.

A minimum age of 1.4 b.y. for the Yellowjacket is provided by isotopic dates from several large porphyritic quartz monzonite plutons that intrude it (pl. 1) (Armstrong, 1975; Karl Evans, oral communication, 1979). The base of the Yellowjacket has never been observed. No clearly older rocks are present in the study area. Possibly older high-grade metasedimentary rocks along the Salmon River in the area of Panther Creek and west (pl. 1), are in fault contact with Yellowjacket and have not been radiometrically dated. These rocks may in fact be part of the Yellowjacket that have been metamorphosed to a higher grade at a deeper structural level and have since been uplifted along the Hot Springs and Shoup Fault Zones (pl. 1). If the Yellowjacket and Prichard Formations are correlative, then a likely maximum age for the Yellowjacket is 1.76 b.y.

## DEPOSITIONAL ENVIRONMENT

The Yellowjacket Formation is similar to sedimentary rocks of all ages that have been called "flysch" in other parts of the world. The formation is characterized as a thick monotonous sequence of alternating beds of argillaceous quartzite and sandy argillite that together form graded genetic units. Like many other flysch sequences, the deposition of the Yellowjacket can be attributed to turbidity currents in a deep-marine environment, based on the reconstruction of depositional processes from lithology and stratification.

The discussion of this proposed depositional setting will begin with a review of published turbidite and subsea-fan facies models which, in turn, will be followed by a description of sedimentary structures and other features in the Yellowjacket Formation that support this interpretation.

## Review of Turbidity Currents and Turbidite Facies Models

Before the concepts of turbidity currents and turbidites were advanced, flysch sequences of graded sandstone and shales were thought to be the result of repeated uplift and subsidence. Graded bedding, which is nearly ubiquitous in flysch sequences, was first described by Bailey (1930). He attributed graded sands to deep-water deposition where strong currents were absent, primarily in geosynclinal environments. Bailey suggested that earthquakes could have caused the distribution of the sand and mud.

The term turbidity current was proposed by Johnson in 1938 (Reading, 1978). But the existence of density undercurrents, produced in part by sediment suspension, were known from studies in Swiss lakes since the 1880's and in North American reservoirs in the 1930's (Reading, 1978). Daly (1936) hypothesized that submarine canyons were formed by the erosive power of density undercurrents produced by suspended sediment. Kuenen (1937) showed the possibility of sediment laden density undercurrents and some of their properties in a series of important flume experiments (Reading, 1978).

Bramlette and Bradley (1940) in a study of north Atlantic deep-sea cores were first to hypothesize the deposition of graded beds of sand by turbidity currents, although they did not use the term "turbidity current". They stated that the ". . . regular gradation in size of the material, the sharp boundary at the base, the irregular occurrence of clay pellets, and the gradation into material of yet finer grain above suggest that this. . . material was thrown into suspension by a submarine slump carried beyond the slide itself and deposited rapidly. Material thus thrown into suspension would be expected to settle according to the respective settling velocities of the various constituents" (p. 16).

Based on his study of the "Macigno" of Italy, Migliorini postulated in 1944 that when density currents ceased to transport large blocks, the finer material would move down gentle slopes into the lowest depressions and deposit well graded sediment (in Discussion, Kuenen, 1950). Kuenen (1950), in another set of flume experiments, showed that high-density (1.5-2.0) turbidity currents could transport sediment as large as pebbles.

Kuenen and Migliorini (1950) then combined their data and experience to show that graded sands could be deposited by turbidity currents. They reported more flume experiments that showed turbidity currents deposited sands that were graded both vertically and horizontally. As summarized from Kuenen and Migliorini (1950), features observed in the field that support the concept of deposition from turbidity currents include: 1) soft mud present at the time of sand deposition was not disturbed as indicated by preserved worm tracks and sand-grain imprints in the mud; 2) in graded beds the coarsest fraction also contains all sizes present within the bed, which would not be expected for sand deposited from a normal current from which only sizes just above its competence would be deposited; 3) unbroken or rounded flakes of the interbedded shale or mudstone are mixed with the sand and are not concentrated at the base; 4) the large proportion of clay matrix; 5) the great areal extent of even thin graded beds; and 6) the astounding volume of separate beds of uniform composition. The deposits of turbidity currents were first called turbidites by Kuenen (1957).

As a result of a detailed study of the Gres de Peira-Cava in the Maritime Alps, Bouma (1962) developed a turbidite facies model, which has come to be known as the Bouma model or Bouma sequence. In this model, Bouma described a normal turbidite as being divisible vertically into five intervals, a through e, on the basis of the presence of characterisic sedimentary features (fig. 18). Interval a is the graded interval and consists of sand with or without gravel and pebbles. It may be distinctly graded or ungraded. No other features are present. Interval b is the lower interval of parallel lamination. The lamination is due to the alternation of more and less argillaceous sand. Grading may also be evident, although it is usually masked by the lamination. The contact with interval a is gradational. Interval c is an interval of ripple cross-lamination. The cross-laminations are typically less than 5 cm high and are commonly convoluted. Grading is commonly present but is usually indistinct. The contact with interval b is commonly sharp. Interval d is an upper interval of parallel-lamination. The laminations are indistinct and are developed in very fine sandy to silty argillite. Grading may be exhibited by an upward decrease in the sand or silt content. The contact with interval c is typically distinct. The uppermost interval, e, is the pelitic interval, which typically shows no visible sedimentary structures. A very slight upward decrease in grain size and sand content may be present. Interval e gradationally overlies interval d.

Bouma (1962) explained the successive deposition of the five intervals in a turbidite primarily as a response to the decrease in velocity of a turbidity current. If deposition occurs soon after formation of the turbidity current an ungraded interval, a, would result. After a short time, the coarsest

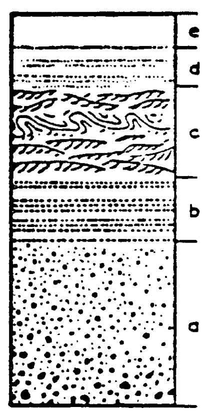



Figure 18.--Complete Bouma sequence (Ta-e) (from Bouma, 1962, fig. 8, p. 49).

material will tend to become concentrated near the base and front of the turbidity current. A small decrease in velocity would cause the current to become overloaded and deposition of graded interval a would result. Further decrease in velocity would cause traction to exert an increasing force on the sediment producing a parallel laminated interval b. A ripple cross-laminated interval would be deposited with a further decrease in velocity into the range in which ripples form.

Finally, with further decrease in velocity, only very fine material would remain in the turbidity current and indistinct laminations of interval d would result. Sediment of interval e settles out of the tail of the turbidity current after flow has ceased.

Similarly, the sedimentation of a turbidite has been related to the concept of flow regimes, which takes into account all variables that affect the flow of a fluid (Harms and Fahnestock, 1965; Walker, 1967; and Bouma, 1972). These variables include velocity, density and viscosity of the fluid, depth, slope, particle size and shape, particle sorting, and specific gravity of particles. The various flow regimes can be distinguished on the basis of the development of characteristic bed forms, which in ancient sedimentary rocks can be deduced from the types of stratification present (fig. 19) (Harms and Fahnestock, 1965). According to Harms and Fahnestock (1965), the lower graded interval of Bouma (1962) was probably deposited in the upper part of the upper-flow regime (standing wave or antidune bed forms); the lower parallel-laminated interval in the lower part of the upper-flow regime (plane bed); the cross-laminated interval in the lower-flow regime (ripple or possibly transitional dune bed forms); and the upper two intervals of Bouma would have been deposited from suspension in a waning current (fig. 19 and fig. 20).

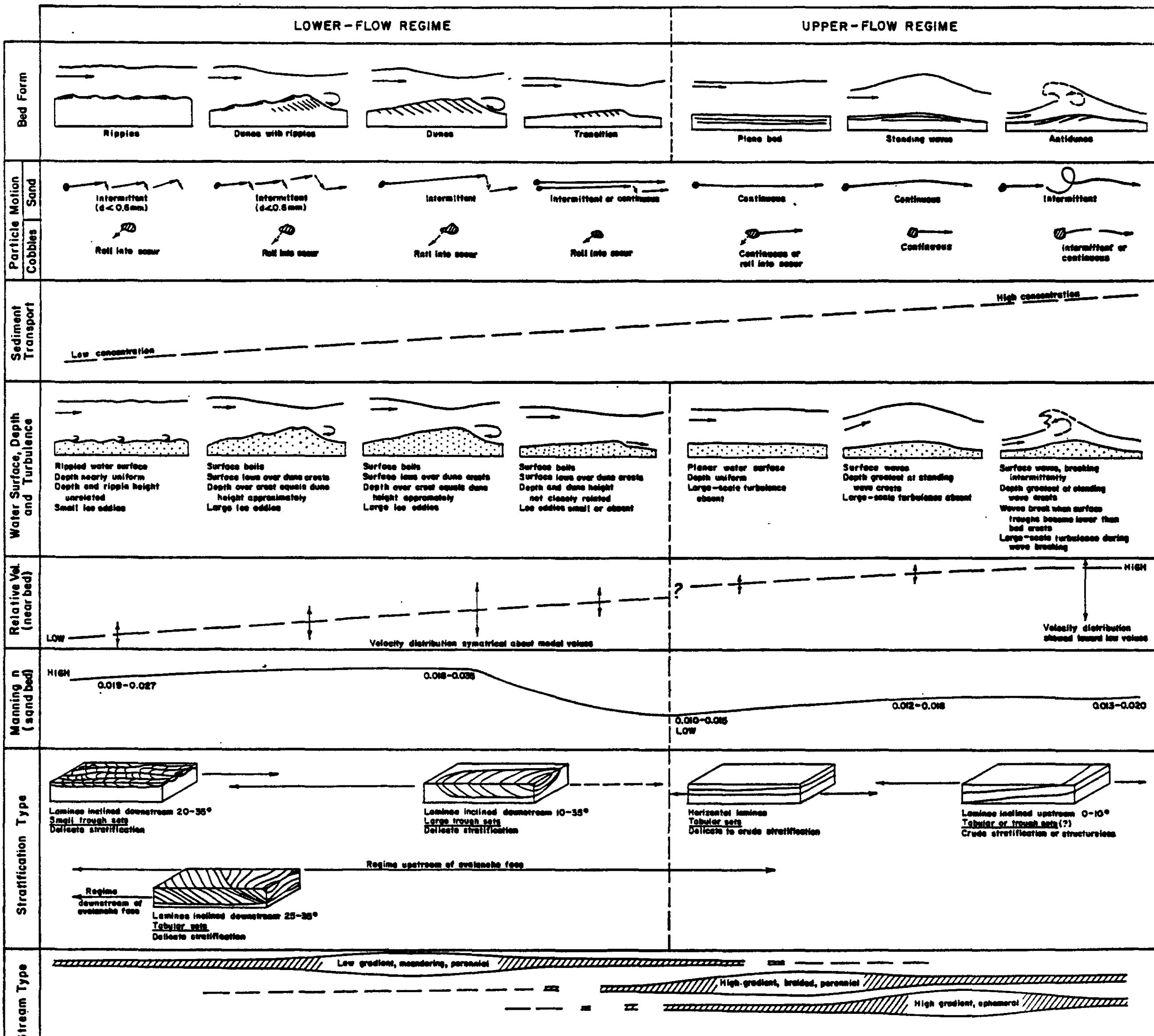



Figure 19.--Relation of bedforms and stratification to flow regimes (from Harms and Fahnestock, 1965, pl. 1).

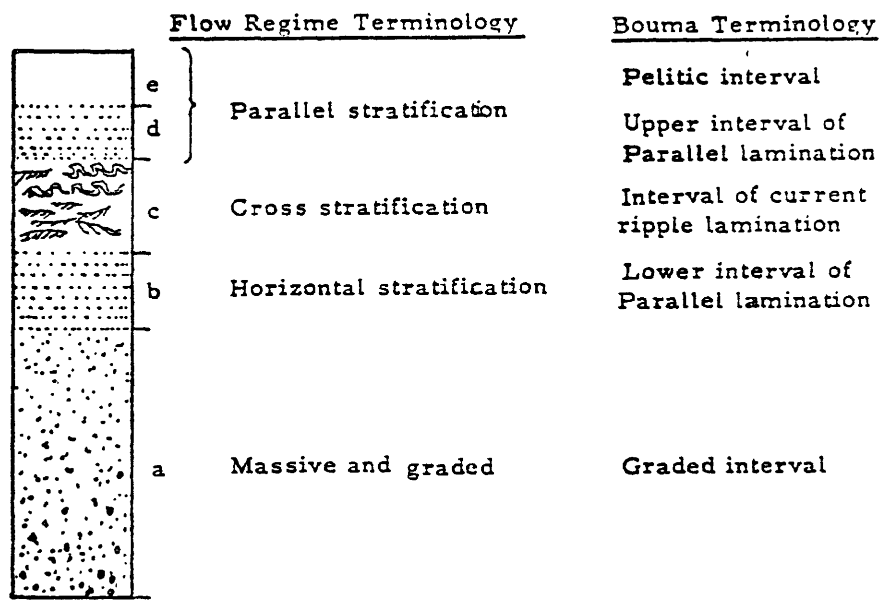



Figure 20.--Succession of stratification types representative of flow regimes in a typical turbidite of Bouma (from Harms and Fahnestock, 1965, fig. 13, p. 109).

Walker (1967) and Bouma (1972) interpreted the Bouma sequence in terms of flow regimes in a manner nearly identical to that of Harms and Fahnestock (1965)(fig. 21). Walker indicated that the flow regimes of turbidite beds are governed mainly by the distance a turbidity current flowed across the basin floor and, to a lesser extent, by the slope of the basin floor and the flow variables of the individual currents.

Complete Bouma sequences are rare; only about 10 percent of beds examined will show a complete sequence of 5 intervals (Walker, 1965). Base cut-out sequences, truncated sequences, and sequences with both the base cut out and the top truncated have been described (Bouma, 1962; Walker, 1965). Base cut-out sequences can be explained in terms of decreasing carrying capacity of a turbidity current, which produces a characteristic depositional cone (fig. 22) (Bouma, 1962, 1972; and Walker, 1967). Because the coarsest material is deposited first, a turbidite decreases in grain size upward and the grain size at the base decreases laterally. In addition, successively higher intervals of the Bouma sequence occur at the base (fig. 22). In figure 22, a complete sequence, Ta-e, occurs only near the source and incomplete sequences Tb-e, Tc-e, Td-e, and Te occur in successive zones farther and farther out from the source.

Truncated sequences exhibiting upper intervals missing may be due to erosion by a later current. A second current formed shortly after the first may overtake and incorporate the tail of the earlier current. Thus, the first current is not allowed to complete its sequence of deposition (Bouma, 1962).

Because a turbidity current tends to flow in the topographically lowest areas in a basin, turbidites deposited from successive turbidity currents will not exactly coincide (fig. 23). In this manner, basin filling occurs by the overlapping of depositional cones deposited from successive turbidity

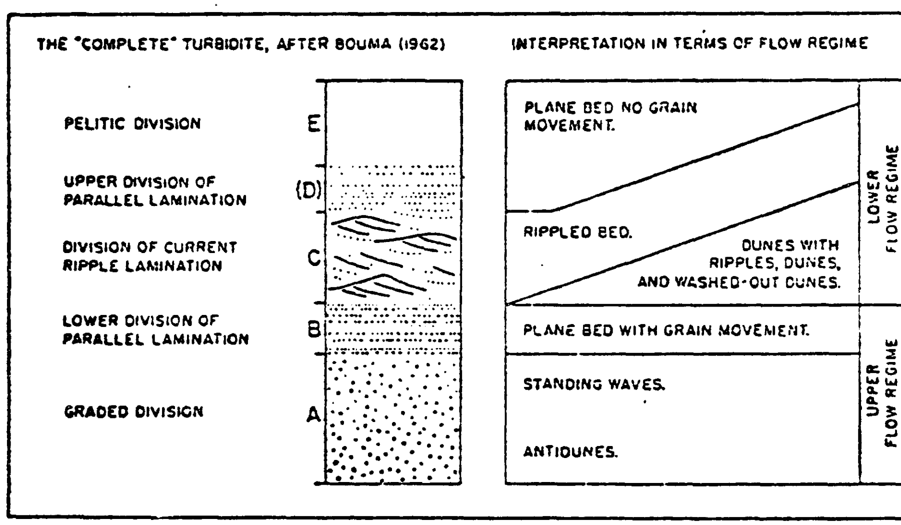



Figure 21.--Bouma's complete turbidite and its interpretation according to flow regimes of Simons and others (1965) (from Walker, 1967).

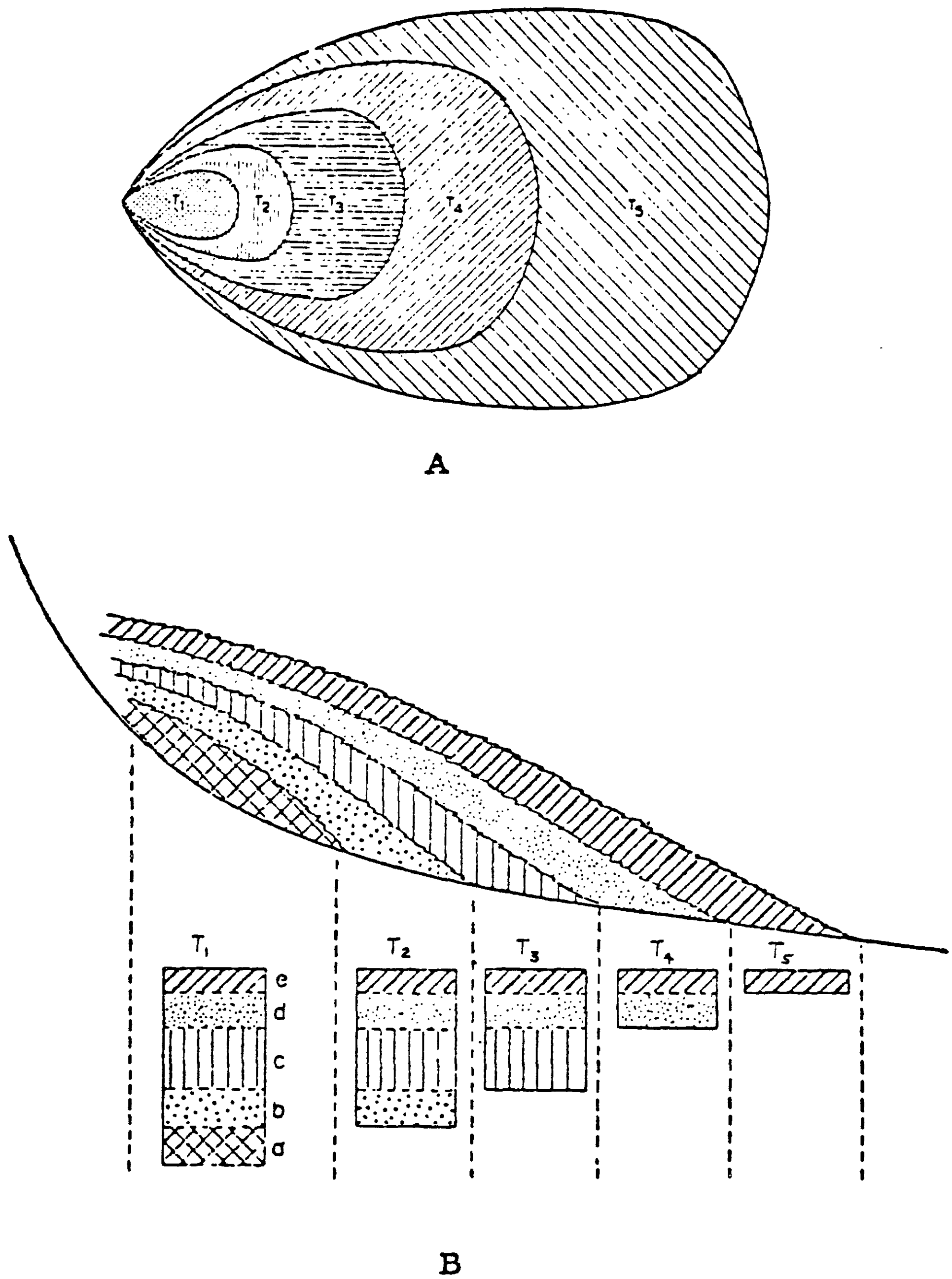



Figure 22.--Hypothetical depositional cone for an ideal turbidite; A is the cone in plan view (Bouma, 1962, fig. 25A). B is the configuration of the cone in cross section (Bouma, 1972, fig. 4) (a-e are intervals of the Bouma sequence).

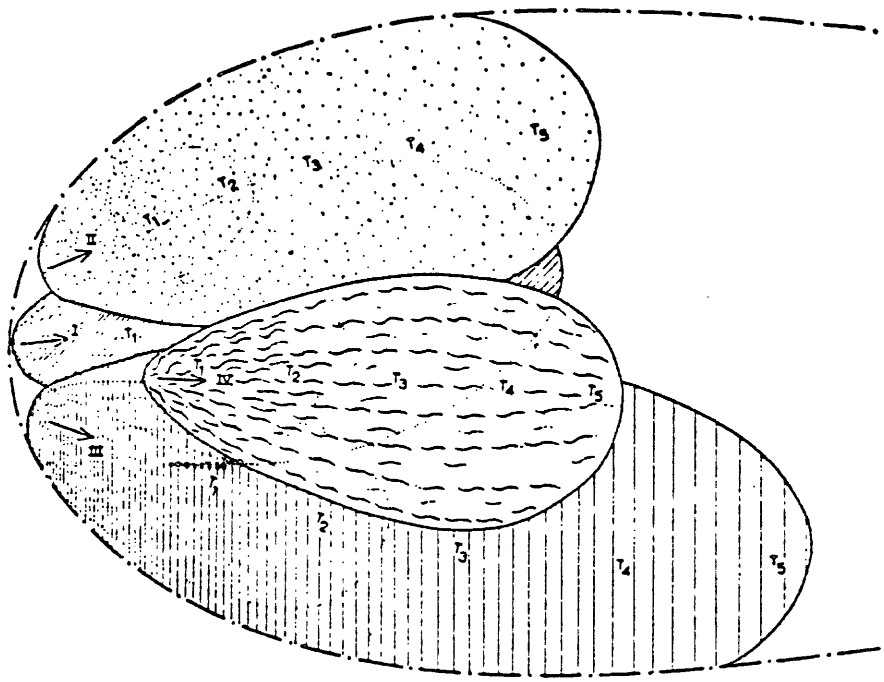



Figure 23.--Hypothetical filling of a basin by turbidites; arrows indicate current direction (Bouma, 1962, fig. 25 B). $T_1$-$T_5$ are the same sequences shown in figure 22.

currents. A consequence of this process is that bottom topography in a basin is smoothed as more and more turbidite beds accumulate (Enos, 1969).

Since the pioneering work of Bouma, more involved and refined facies models have been developed (Mutti and Ricci-Lucchi, 1972; and Walker, 1978, 1979) that incorporate data obtained from the study of modern subsea fan deposits (Haner, 1971; Normark, 1970, 1978).

Mutti and Ricci-Lucchi (1972) provided the first comprehensive facies model for ancient submarine fan sedimentation. They described three major fan-facies associations: inner, middle, and outer fans. The inner fan is characterized by large, coarse-grained sandstone bodies enclosed by hemipelagic deposits that resulted from filling of major fan valleys. The middle-fan association consists of fine-grained, thin-bedded, interchannel deposits enclosing lenticular channel-fill sandstone bodies that display fingering-upward abandonment cycles. Outer fans are characterized by interbedded, fine-grained, thin-bedded, fan-fringe deposits and thicker-bedded nonchannelized outer-fan depositional lobes. Outer-fan lobes consist of progradational sheet-like classical turbidites organized in thickening upward cycles. Development of outer fan lobes occurs at mouths of mid-fan distributary channels. Migration of depositional lobes across the outer fan results from the shifting of mid-fan distributary channels.

A feature described from modern subsea fans not incorporated in the Mutti and Ricci-Lucchi model is that of the suprafan (Normark, 1970). This feature is at the end of the main leveed portion of the mid-fan. It occurs as an upward bulge in radial profile and is characterized by bodies of coarse-grained sediment without levees. The upper reaches of the suprafan may have rapidly shifting, braided, distributary channels. The suprafan is not present in all submarine fans. Normark (1978) believes that the formation of the suprafan is governed by the availability of coarse sediment. If no coarse sediment is available for rapid deposition at the end of a fan valley, no suprafan can develop.

Walker (1978, 1979) has described a facies model for ancient subsea fans in which he incorporates the suprafan concept (fig. 24). The main components of this model are the upper-, middle-, and lower-fan associations. The middle fan is built up from suprafan lobes that are built up by local shifting channels of the inner fan valley. The suprafan lobes have shallow, braided, distributary channels in their upper parts and are smooth in their lower reaches. They grade outward into the lower fan and basin deposits. The outer fan of Mutti and Ricci-Lucchi (1972) corresponds to the outer smooth part of the middle or suprafan of Walker. Proximal classical turbidites would occur in the outer part of the suprafan and would form thickening and coarsening upward cyles as the suprafan progrades outward over the lower fan. Distal classical turbidites occur along the fan fringe and on the basin plain.

Apparently both models are valid; not all subsea fan systems develop suprafan lobes (Mutti and Ricci-Lucchi, 1972; Normark 1978; and Walker, 1978, 1979). A large supply of coarse sediment and rapid deposition at the mouth of a fan valley would cause formation of unstable distributary channels and a suprafan bulge. Delta-fed submarine fans would probably not develop suprafan lobes due to the predominance of fine sediment (Ghibaudo, 1980). In ancient turbidites, the only valid criteria for differentiating mid-fan from outer-fan environments appears to be the presence or absence of important channeling (Ghibaudo, 1980).

Cycles have been recognized and described in turbidite sequences. In classical turbidites, as a basin fills, large-scale thickening and coarsening upward cycles are observed. This occurs as more proximal facies prograde

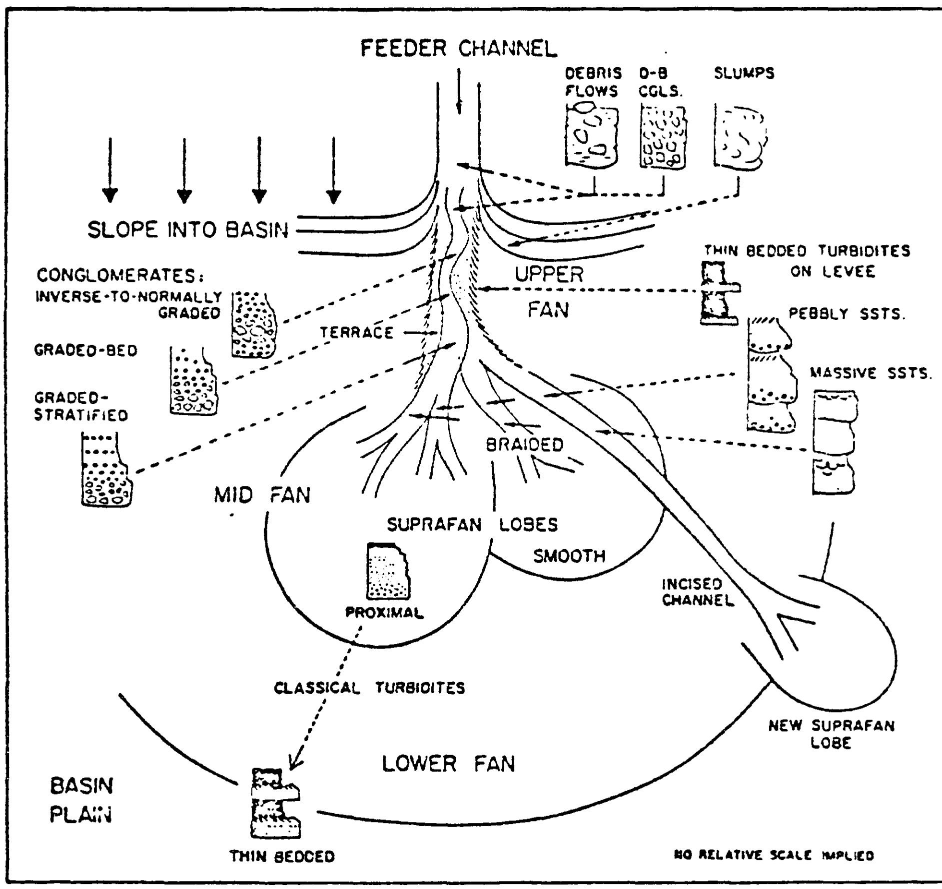



Figure 24.--Submarine fan facies model of Walker (1979, fig. 13).

basinward over more distal facies (Ghibaudo, 1980). Smaller scale thinning-upward or thickening-upward cycles may be caused by changes in the source area or by gradual migration of depositional lobes in a subsea fan system (Sestini, 1970).

In summary, application in detail of a submarine fan facies model to ancient turbidites may not be possible because of erosional or tectonic removal of a large part of the rocks formed in a particular depositional system. Nevertheless, identification of rocks as turbidites is usually possible without much doubt. The Bouma model has been shown in general to be applicable to most turbidite sequences. Identification of turbidites is based on the presence of a significant number of characteristic features organized as described by the Bouma model. In addition, important to the interpretation is the absence of shallow-water features. Kuenen (1964) has provided an inventory of features commonly present in turbidites (table 2).

TABLE 2

INVENTORY OF FEATURES CHARACTERISTIC OF TURBIDITES

(from Kuenen, 1950)

1) Coarsest particles are about medium pebbles.

2) In general, grain size increases with bed thickness.

3) Grading is nearly ubiquitous but may be absent.

4) Increasing admixture of clay tends to darken color upward in a graded bed.

5) Inorganic detritus is predominant.

6) In most beds, fine sand and silt are laminated.

7) Ripple cross-lamination is common.

8) Convoluted laminations and convoluted cross-laminations occur.

9) Mud lumps are common.

10) Beds range in thickness from a few millimeters to 10 m, but most typically are less than 2 m.

11) Lower contacts are abrupt and sharp.

12) Upper contacts may be sharp or gradational into pelagic deposits.

13) Sole markings are common, including flute casts and groove casts.

14) Graded beds are separated by shale or marl.

15) Current directions tend to be subparallel in several beds vertically adjacent to each other.

16) Beds appear to be continuous but of variable thickness.

17) Turbidites form thick extensive formations.

18) Many flysch-like formations of alternating sands and shales are turbidite sequences.

## The Yellowjacket Formation as a Turbidite Sequence

Identification of the Yellowjacket Formation as a turbidite deep-water sequence was made on the basis of the occurrence of a significant number of characteristic features common to turbidites (table 2) and the internal organization of these consistent with the Bouma model. In addition, no shallow-water features have been observed in the Yellowjacket. The huge thickness and monotonous sequence of alternating argillaceous quartzite and sandy argillite of the Yellowjacket are also characteristic of turbidite sequences. Individual beds appear to be continuous; they can be traced across even the largest outcrops, on the order of 50-60 m (fig. 13), without interruption. Graded bedding is nearly ubiquitous, and in most of the formation is of the content type; that is, the maximum grain size remains nearly constant upward within a graded bed, but the content of argillaceous matrix increases dramatically (fig. 25). Visible grading from coarser sand to finer sand and/or silt is rare except in member A where, in at least the lower half, this type of grading is predominant (fig. 26). The thickness of graded beds changes through the section as described in the stratigraphic discussion. Graded beds are thinnest in member C where they are from a few millimeters to 5 cm thick, and typically grade from faintly laminated very fine sand and silt to sandy or silty argillite. Members A and D have graded beds up to 1 m thick; member B typically 2 to 20 cm thick; and member E as thick as 2 m. Parallel laminations are the predominant sedimentary structures observed in the Yellowjacket and are present in all members (fig. 25). Most are of the type in Bouma's lower parallel-laminated division.

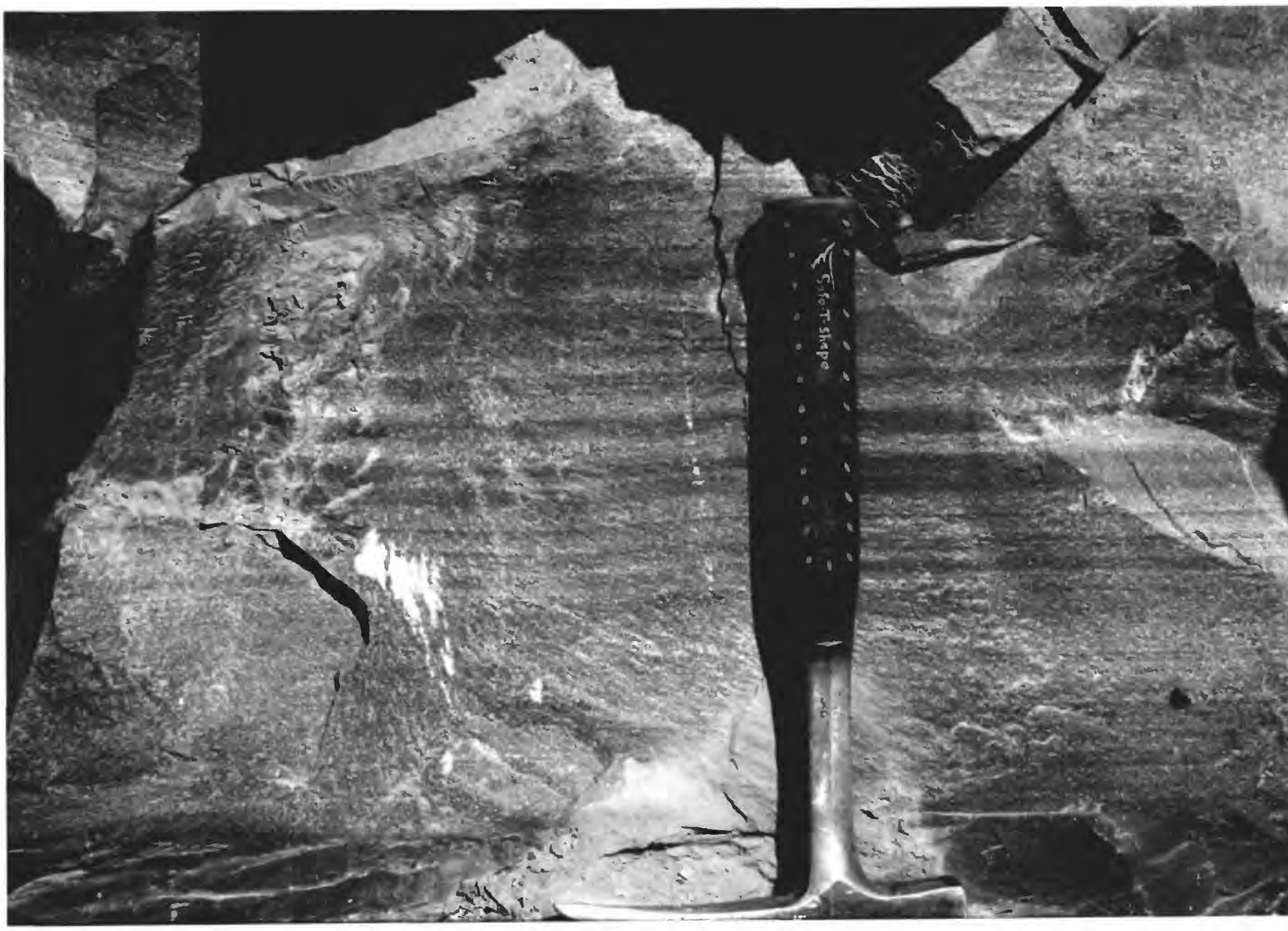


Figure 25.--Photograph showing content graded bedding described in the text. Grading is exhibited as an increase in the proportion of argillaceous matrix upward. From member D near the North Fork Post Office, in the SW1/4, sec. 16, T. 24 N., R. 21 E.

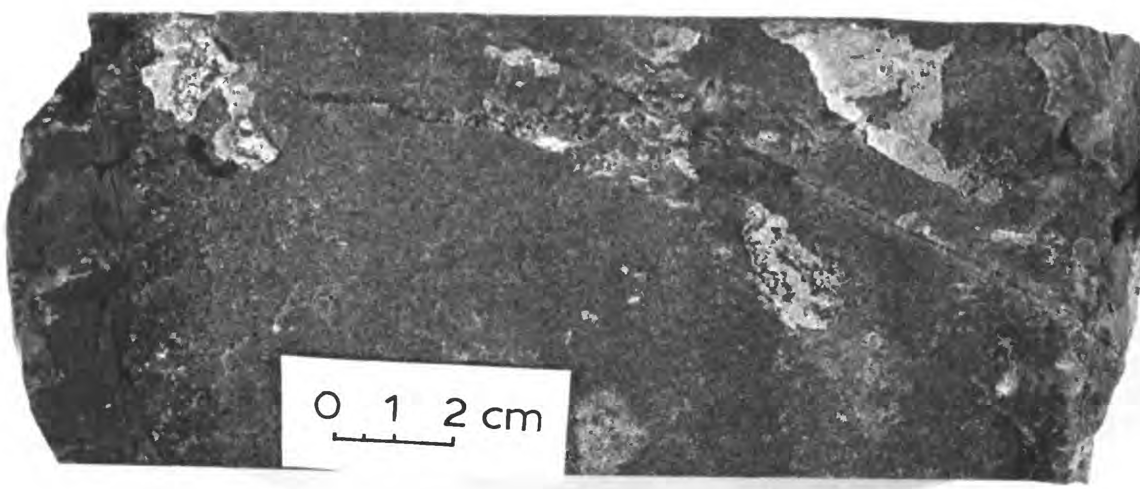



Figure 26.--Photograph showing graded bedding typical of member A; occurs less commonly in other members. Grading is from coarse grained quartzite at the base to very fine argillaceous quartzite at the top (right). From Shovel Creek, just above its junction with Yellowjacket Creek.

Those in member C are indistinct and are sometimes only visible in thin section (fig. 9) and, therefore, correspond to Bouma's upper parallel laminated division. Ripple cross-laminations and ripple marks are present in all members, but are present in only a small percentage of beds observed (fig. 27A and B); the amplitude is small, less than 3 cm. Climbing ripple laminations are present in a few localities; they are common in member A along Shovel Creek and were observed in one exposure on Napoleon Ridge (member D) (fig. 28).

Convolute lamination is common in member C and locally is observed in other members as well (fig. 29). The formation of convolute lamination appears to have been controlled by the sand-shale ratio and the thickness of the sand laminae. Convolutions are most abundant where the sand-shale ratio is 1:1 or less and where the thickness of the sand laminae is less than about 1 cm. In addition, formation of convolute laminations only occurs where the grain size is very fine sand or silt and mixed with clay layers. Other observers have reported the same grain-size restriction (Sanders, 1960).

Load casts and internal load structures like ball-and-pillow structures occur throughout the section, commonly associated with convolute laminations. The scale of the ball-and-pillow structures varies; in member C they are typically on the scale of 1 cm or less (fig. 30a); in member D the pillows may be as large as 50 cm wide and 20 or 30 cm high (fig. 30b).

Few sole markings were observed, but favorable exposures of bottom surfaces of beds are difficult to find. Several were observed in float blocks, but in outcrop only 3 were observed along bedding planes; all were flute casts. Frequent observations were made of possible sole marks in cross-section view.


Figure 27A.--Photograph of ripple cross-lamination typical of the Yellowjacket Formation. This specimen is from member D in the Napoleon Ridge area.

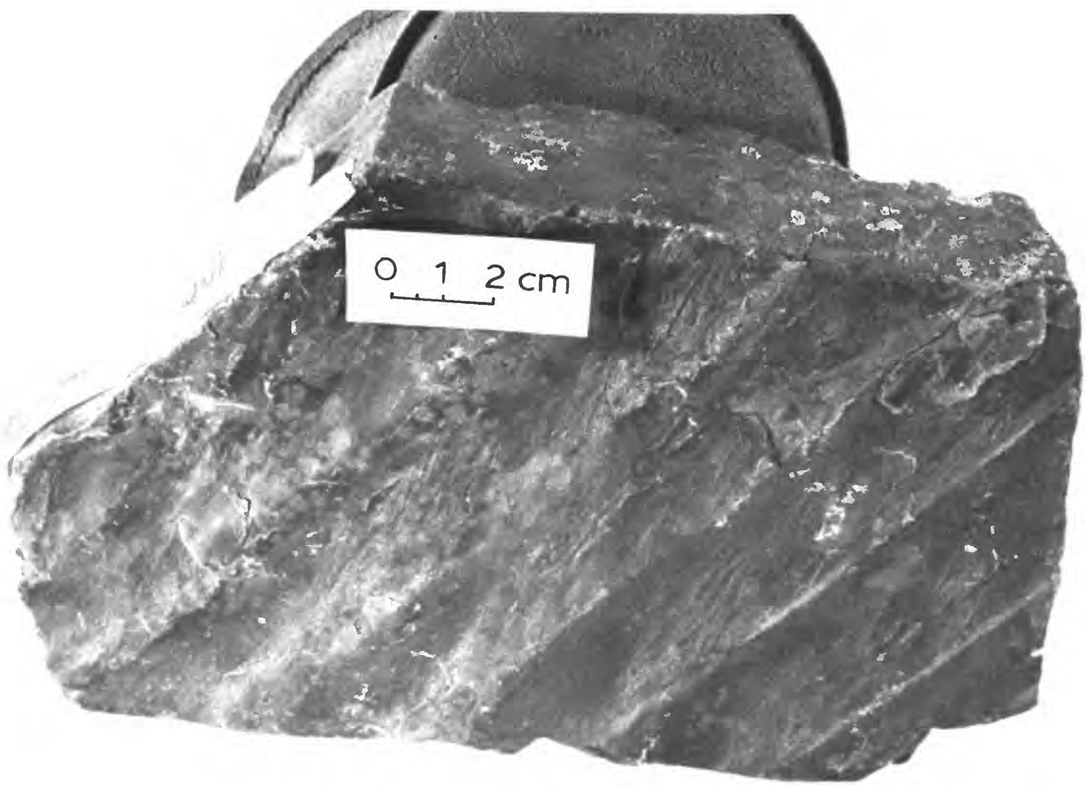



Figure 27B.--Photograph showing ripple marks in the Yellowjacket Formation. This specimen is from high in member C, near the junction of Copper Creek and Panther Creek.

Figure 28.--Photograph showing climbing ripple lamination (just above pick point), from member D in the Napoleon Ridge area.

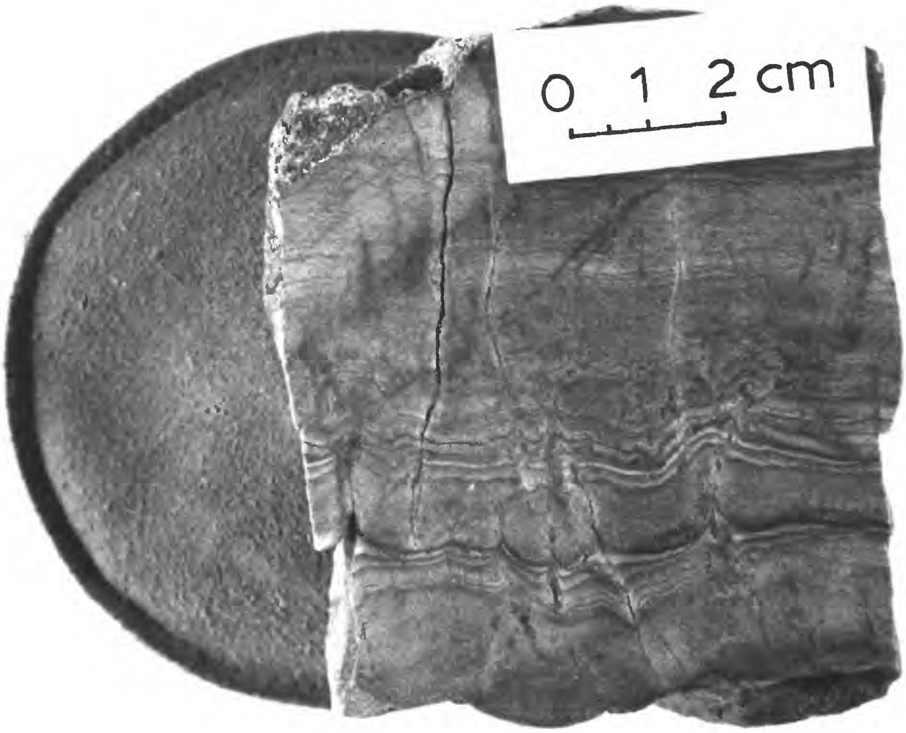
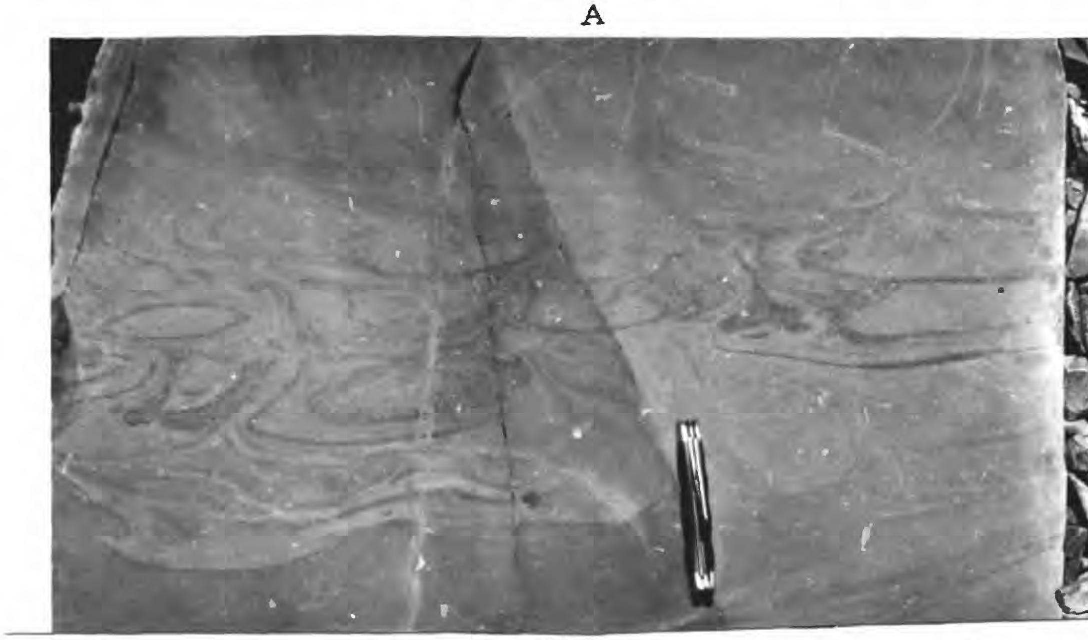



Figure 29.--Photograph showing convolute lamination typical of member C. This specimen is from along the Copper Creek road just west of Swan Peak. Note that flat parallel laminations at the top of the photograph are continuous across the convoluted zone.

A



B

Figure 30.--Photographs showing ball-and-pillow structures associated with convolute laminations. A, small-scale structures typical of member C. Photograph from Copper Creek road. B, larger scale structure from member D in the Iron Creek section.

A variety of soft sediment deformation features are common, especially in members B and C. In member C sand injection structures are common that could probably be called dikelets and contorted dikelets; association with small-scale convolute laminations is common (fig. 31). These are usually less than about 2 mm thick.

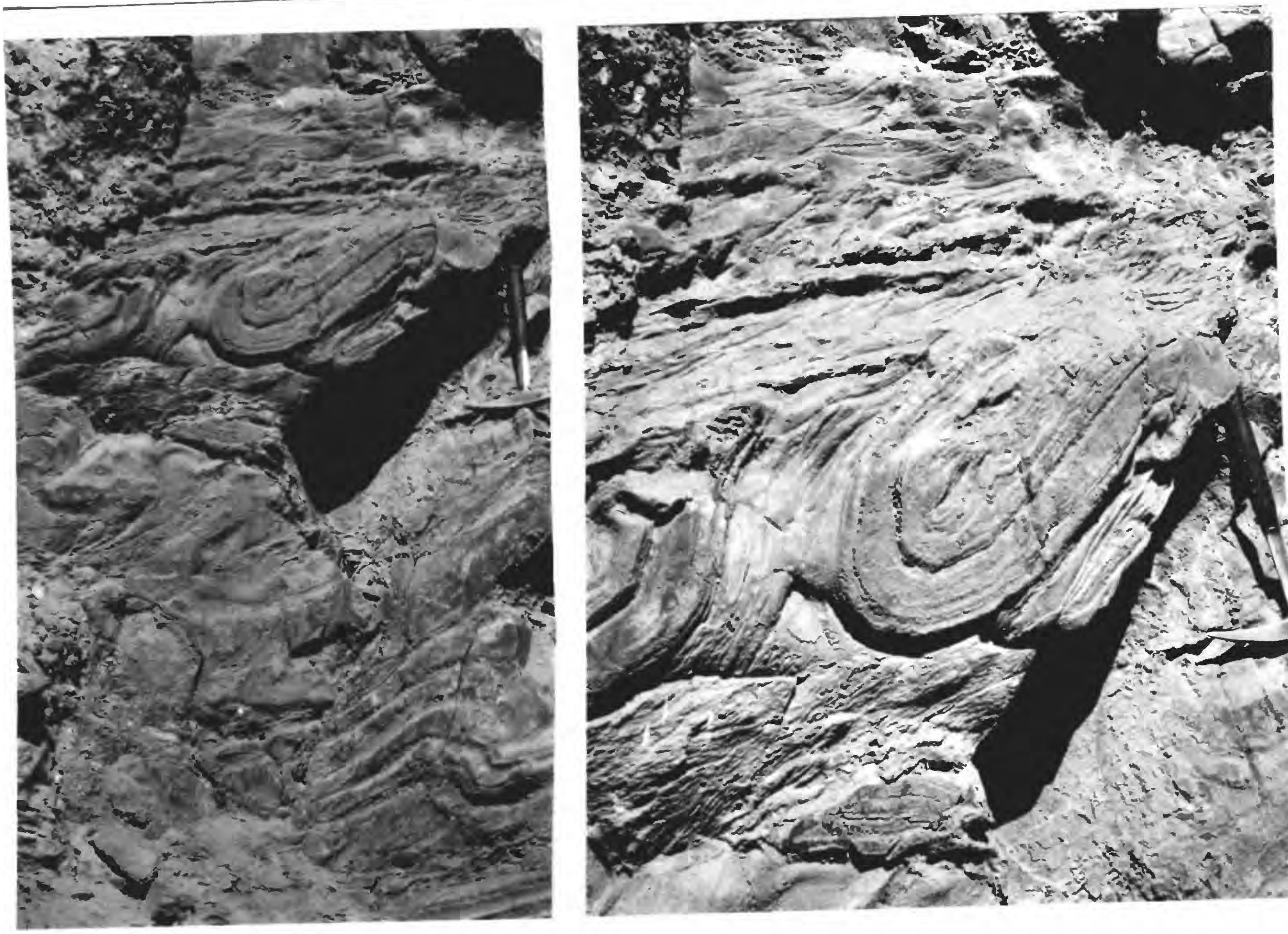
In member B in the Hayden Creek area fluid-escape pipes are commonly associated with faint dish structures (?) (fig. 32) implying deposition from a fluidized flow.

Penecontemporaneous slump structures are common, especially in member D. Examples of small-scale recumbent folds, typically less than 1 m in amplitude, are shown in figure 33. The attitude of axial planes of these folds indicate a local depositional slope consistent with transport directions measured from cross-laminations. Another type of slump feature exhibits dramatic thickening by piling up of sediment down depositional slope and internal disruption and rotation of argillaceous quartzite beds (fig. 34). In a distance of about 60 m, the zone of figure 34a can be traced from interbedded sandy argillite and argillaceous quartzite with load casts to zones where the load casts have progressed to a point at which they completely break the argillaceous quartzite beds into blocks, to a zone of piling up where the blocks of the quartzite have been completely disrupted and rotated in a matrix of sandy argillite. Again this slump indicates a depositional slope consistent with transport directions measured from cross-lamination attitudes. No faulting penecontemporaneous with slumping was observed associated with either type of slump structure.

As mentioned earlier, no evidence of shallow-water deposition has been observed. A variety of features that can be classified as psuedo-mudcracks (Pettijohn and Potter, 1964) occur mainly in members B and C in the Panther Creek area and in the area of the North Fork of Iron Creek. But all these


Figure 31.--Photograph showing sand dikelets and small-scale deformational structures common in member C. Such structures were observed in all areas underlain by member C.

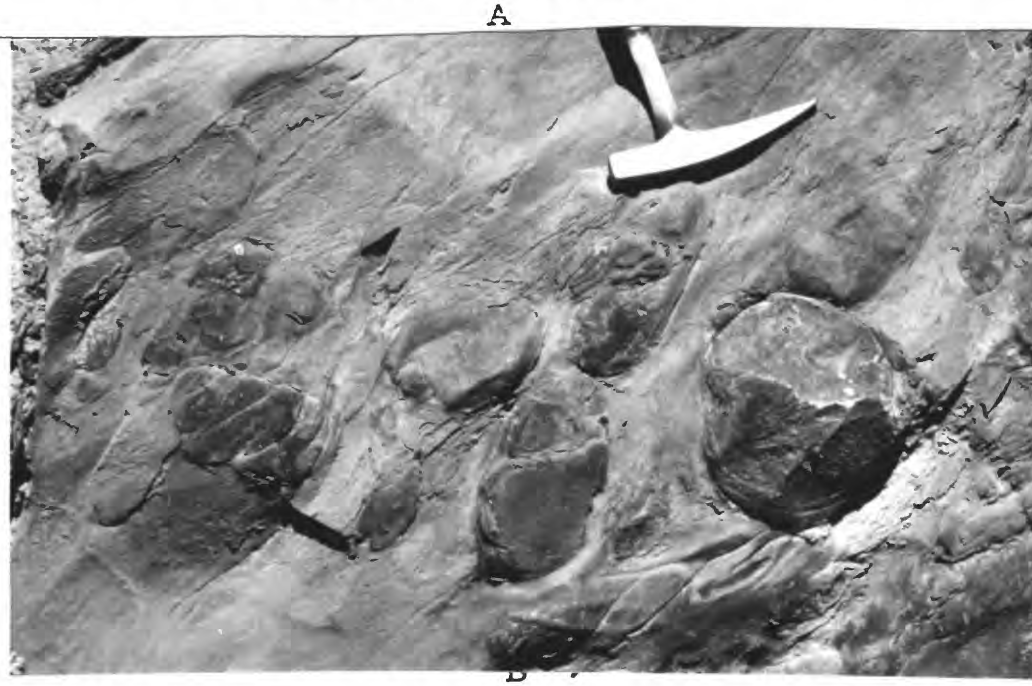
Figure 32.--Photograph showing fluid-escape pipe and indistinct dish structure. From member B, Hayden Creek section, sec. 10, T. 16 N., R. 23 E.



A B

Figure 33.--Photographs showing penecontemporaneous slump fold in an exposure of member D along Highway 93 on the south side of a sharp meander of the Salmon River between Fourth of July Creek and Kriley Creek (NE1/4, sec. 2, T. 23 N., R. 21 E. View is looking north, depositional slope was to the east (right). Photo A is a larger view showing continuous bedding both above and below the folded zone. Photo B is a closer view showing more argillaceous quartzite piercing the hinge of the folded less argillaceous layer.

A



B

Figure 34.--Photographs showing penecontemporaneous slump. View looking north on south side of "Comet", SE1/4, sec. 12, T. 23 N., R. 21 E. As described in the text, the slump can be traced from a bed beginning to be pierced by argillaceous material from below (just below pick point, photo A) to completely ruptured, rotated, and piled up fragments in a more argillaceous matrix (photo B). The distance between photos A and B is about 60 m.

features can be shown not to be mudcracks but to be the bedding-surface expressions of a variety of other sedimentary structures. The most common type is formed by the intersection of a surface that approximates bedding with a convoluted sand laminae or sand dikelets injected from below (fig. 35). Another type are true psuedo-mudcracks as described in Pettijohn and Potter (1964). These occur on surfaces that intersect injections of slightly more sandy material around pulled-apart laminae of silty or sandy argillite (fig. 36). Another type occurs when a surface along which the rock splits is at a slight angle to true bedding, and a bedding plan pattern of thin sandy laminae forms the psuedo-mudcracks.

All the preserved lithologies in the Yellowjacket appear to be distal facies in a turbidite system, probably deposited in fan-fringe and basin-plain environments. Base-cut-out, c-d-e, Bouma sequences are most typical; few a and b intervals were observed (mainly in member A). Mutti (1977) described similar thin-bedded turbidites composed mainly of c-d-e lithologies. He interpreted very thin persistent graded beds and laminae consisting of very fine sandstone, siltstone, and mudstone as basin-plain deposits. Members B and C correspond to this type of deposit. Slightly coarser and thicker bedded (one to tens of meters) turbidites that form thickening and coarsening upward cycles were interpreted as fan-fringe deposits (Mutti, 1977). Members A, D, and E may correspond to these fan-fringe turbidites. Both varieties of thin-bedded turbidites are the result of transport and deposition from dilute and waning turbidity currents.

The lenses of parallel-laminated, indistinctly graded calcareous quartzite of member B probably represent periodic deposition from turbidity currents derived from carbonate source areas with limited geographic distribution.


A


B

Figure 35.--Photographs showing psuedo-mudcracks common in member C. This specimen is from the Panther Creek Section. Photo A shows the sinuous surface view of these features. Photo B shows the cut edge of the specimen in A, and illustrates the origin of the "mud cracks" by convolution of sandy laminae.

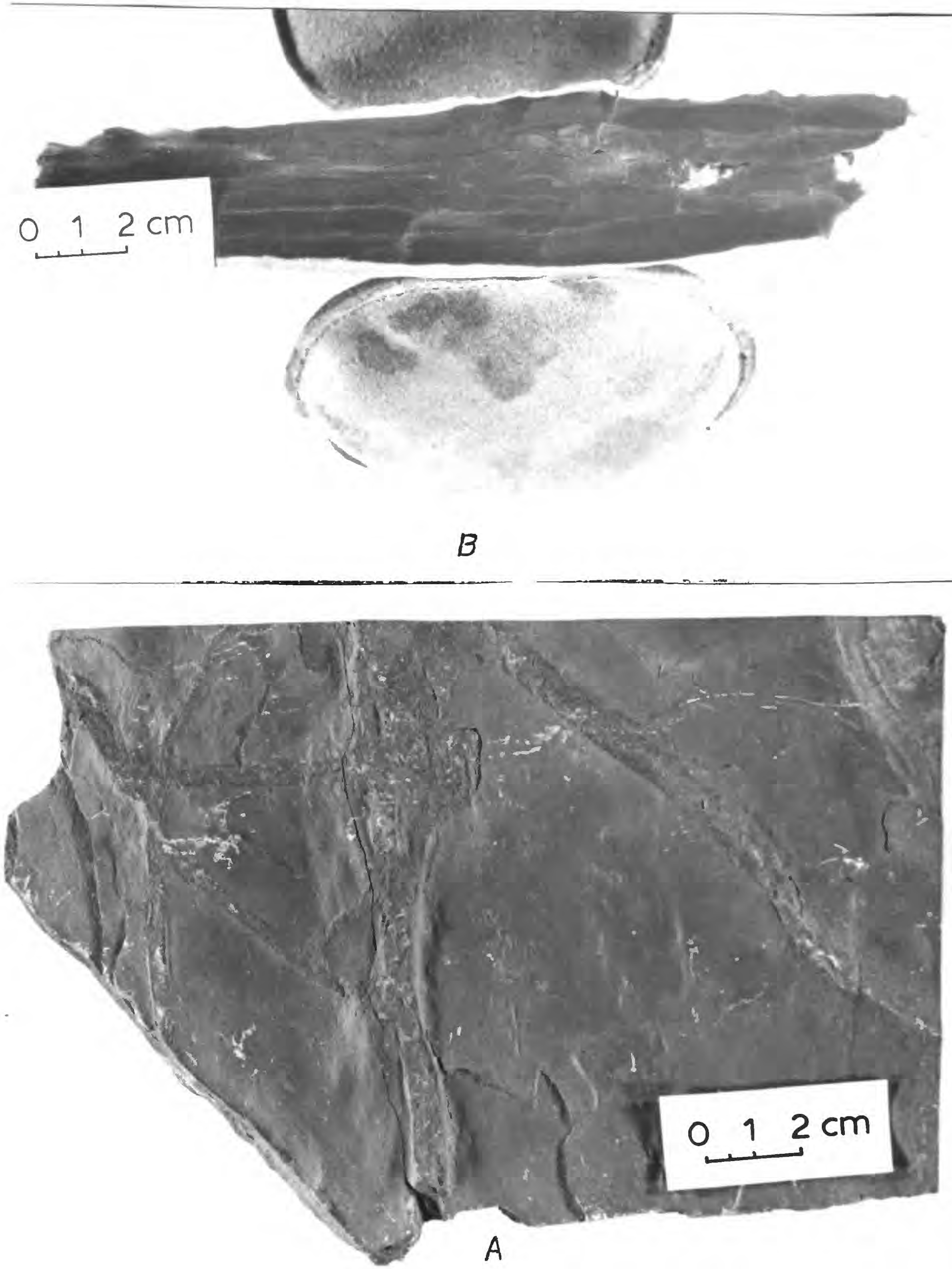



Figure 36.--Photographs showing psuedo-mudcracks common in member C. Photo A shows the bedding surface expression of these features. Photo B shows a cut edge of the specimen in A, showing the origin of these features is by pull-apart and break up of lighter colored silty laminae and injection of more argillaceous material around them.

Two large scale cycles are present in the Yellowjacket. Member A through C form an upward-fining and thinning cycle about 3500 m thick in which graded beds thin from several meters thick to several millimeters and grain size decreases from coarse sand to very fine sand and silt. Members C through E represent an upward-coarsening and thickening cycle 3000 to 4000 m thick in which graded beds thicken from several millimeters to 1 or 2 m. The lower thinning and and fining-upward cycle may have been caused by changes in the source area which governed the type and amount of sediment available to the basin. Or it may reflect the early widening and possibly deepening of the basin. Fluctuations in sea level, possibly caused by glaciation, may also have caused these vertical changes, but it is uncertain that glaciation occurred during Yellowjacket time. The upper cycle of coarsening and thickening upward would be expected as basin filling progressed (Ghibaudo, 1980). As the basin filled, areas in which initially basinal deposition occurred would be covered by less distal facies as a subsea fan depositional system prograded basinward.

## The Yellowjacket Depositional Basin

The paleogeography during Yellowjacket time is difficult to describe precisely, due to the lack of detailed facies data and also because only a part of the original distribution of the Yellowjacket is preserved. Walker (1979) believes that submarine fan-facies models are difficult to apply to thin-bedded (distal) facies in large basins, because current-direction data and lithologies often show no significant variations. This is often due to deflection of currents down the axis of the basins.

Based on a limited number of transport-direction data and knowledge of the distribution of the formation some general statements can be made. Plate 4 illustrates transport directions now available and the known distribution of the Yellowjacket. At first glance, transport-direction data seems inconsistent, but data per individual member are consistent. Directional structures in member A in the Shovel Creek area all indicate northeastward and east-northeastward transport. The only data available from member B is from the Hayden Creek area and indicate northwest and north-northwest transport. Structures in member C in the North Fork of Iron Creek give mainly westward transport. Member D has mainly eastward and southeastward transport directions in all areas; North Fork, Iron Creek, Deep Creek, and Panther Creek. Exceptions are one southwest transport direction in Panther Creek, a northward direction in Deriar Creek and a west-northwest direction in the Lemhi Pass area. The westward transport directions are expected because crystalline basement rocks older than the Yellowjacket are present in southwest Montana and in Wyoming and would provide a suitable source for the Yellowjacket. The eastward transport directions require that a large landmass was present west of the Yellowjacket depositional basin. Such a landmass is also indicated by recent work in the Prichard Formation of the Belt Supergroup which also indicates eastward transport directions (Earle Cressman, oral communication, 1981).

Rifting of a large continental mass away from North America could provide the necessary western source region for Yellowjacket sediment. Such rifting has been suggested to have produced the Cordilleran geocline (Stewart, 1972; Monger and others, 1972; Gabrielse 1972; Burke and Dewey, 1973; Burchfiel and Davis, 1975; Sears and Price, 1978; and Young and others, 1979). The Siberian Craton has been proposed to be the continental fragment rifted away from North

America and that the rifting occurred about 1.5 b.y. ago (fig. 37) (Sears and Price, 1978; Khain and Seslavinsky, 1979; Sears and Price, 1979; and Churkin and Trexler, 1979). Recent work of the I.U.G.S. Working Group on the Precambrian for the U. S. and Mexico and by Ray Price indicates three distinct phases of rifting occurred; one beginning between 1.7 b.y. and 1.5 b.y. ago; one about 850 m.y. ago; and one in early Paleozoic (Jack E. Harrison, oral communication, 1981). During these phases of rifting, eastward-thinning miogeoclinal wedges of sediment were deposited on oceanic crust or attenuated and tectonically thinned continental crust. Rifting would not necessarily have formed a primary ocean basin during Yellowjacket deposition. Limited data available indicate that rifting may have only progressed far enough to attenuate and tectonically thin the continental crust sufficiently to allow subsidence and deep water sedimentation (see page 101).

Another possible mechanism for thinning the crust to initiate subsidence is by attenuation associated with movement along major transcurrent shear zones in a manner similar to that proposed for the origin of Tertiary basins in southern California (Crowell, 1974, and Blake and others, 1978).

In southwest Montana and in northern Idaho, several major northwest-trending faults and fault zones exist that are known to have had Precambrian strike-slip displacements. The Lewis and Clark line (fig. 38), one of these northwest-trending zones, has been described as a "long-lived fundamental crustal discontinuity" (Reynolds, 1977), as a "major long-lived intraplate tectonic boundary" (Reynolds and Kleinkopf, 1977), and as a "mega-shear" (Smith, 1965) that has had a history of recurrent movement from early Precambrian to Holocene time (Wallace and others, 1960, Smith, 1965, Reynolds, 1977). The zone is marked by a nearly continuous gravity gradient of 15 mgal and separates a block on the north with northwest-trending gravity anomalies from a southern block with northeast trends. In addition, north of the line,

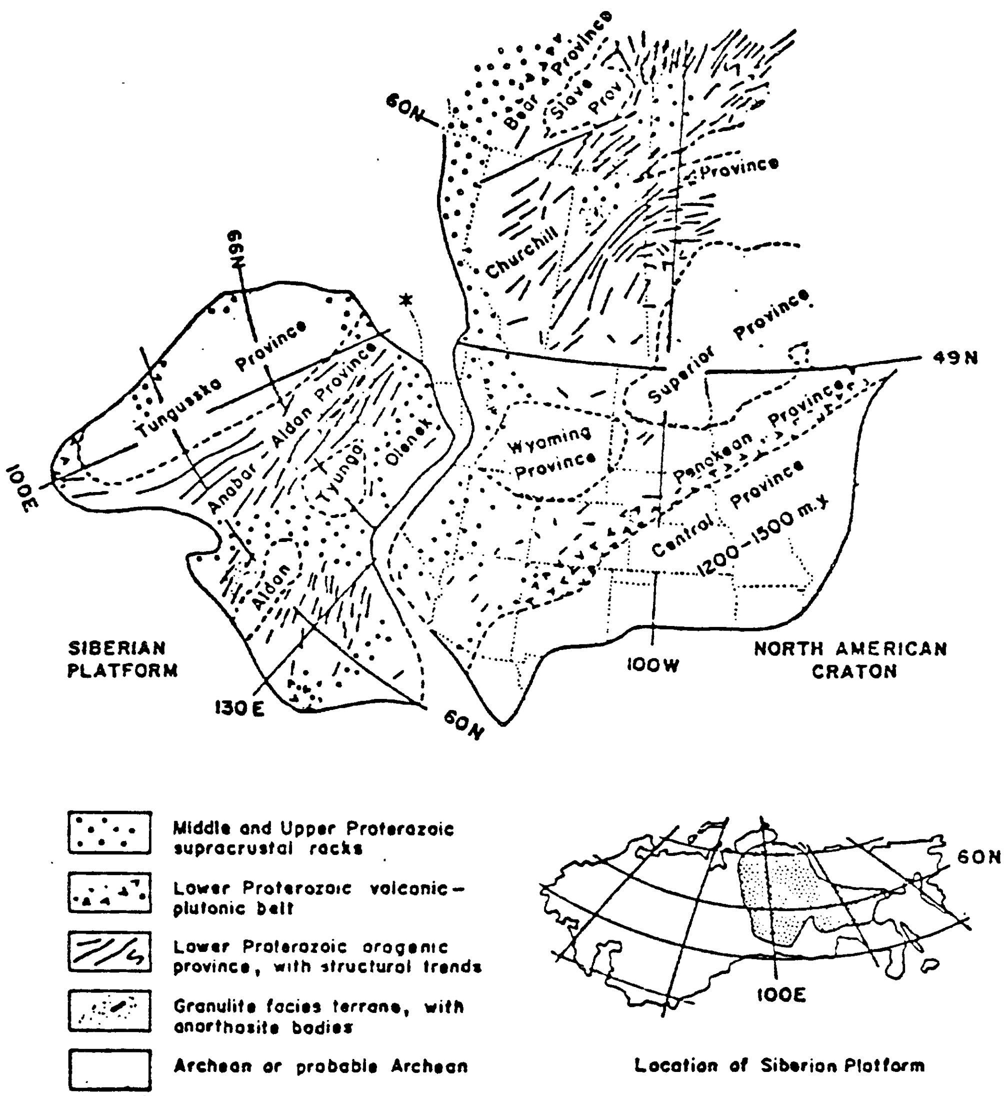



Figure 37.--Map showing the hypothesized reconstruction of the Siberian and North American Precambrian Cratons (from Sears and Price, 1978, fig. 1).

gravity and magnetic fields show regionally higher values (Reynolds and Kleinkopf, 1977).

In southwest Montana, many faults subparallel to the Lewis and Clark line exhibit strike-slip displacements that occurred in Precambrian time (Reid, 1957, and J. M. O'Neil, personal communication, 1981)(fig. 38). Many of these faults have been intruded by diabase dikes dated at 1.1 to 1.45 b.y. old (James and Hedge, 1980), which indicates the faults are older than those dates. One of these faults, the Spanish Peaks Fault (fig. 38), can be traced from the Madison Range into the Tobacco Root Mountains and its projection farther northwest is marked by a distinct topographic and geologic lineament (Ruppel and others, in press, and Edward T. Ruppel, oral communication, 1981).

The Miner Lake--Beaverhead Divide Fault Zone another northwest trending fault zone, forms the northeastern limit of Yellowjacket occurrences and appears to have had a Precambrian ancestry (Ruppel and others, in press).

If this system of northwest-trending faults, which show strike-slip displacements in Precambrian time, were in existence before Yellowjacket time they could have caused enough attenuation of the crust to allow subsidence and to initiate Yellowjacket deposition.

Whatever its origin, the Yellowjacket depositional basin must have originally extended much farther eastward than the present edge of exposure, the Miner Lake-Beaverhead Divide Fault Zone. No lithologic or facies trends are present that indicate approach of a basin edge; in fact, all the Yellowjacket observed indicates that deposition occurred in deep water and in the very distal portions of a turbidite depositional system. To the east only a short distance (100 to 120 km), Archean basement is encountered and in the Highland Mountains rocks of the LaHood Formation of the Belt Supergroup occur

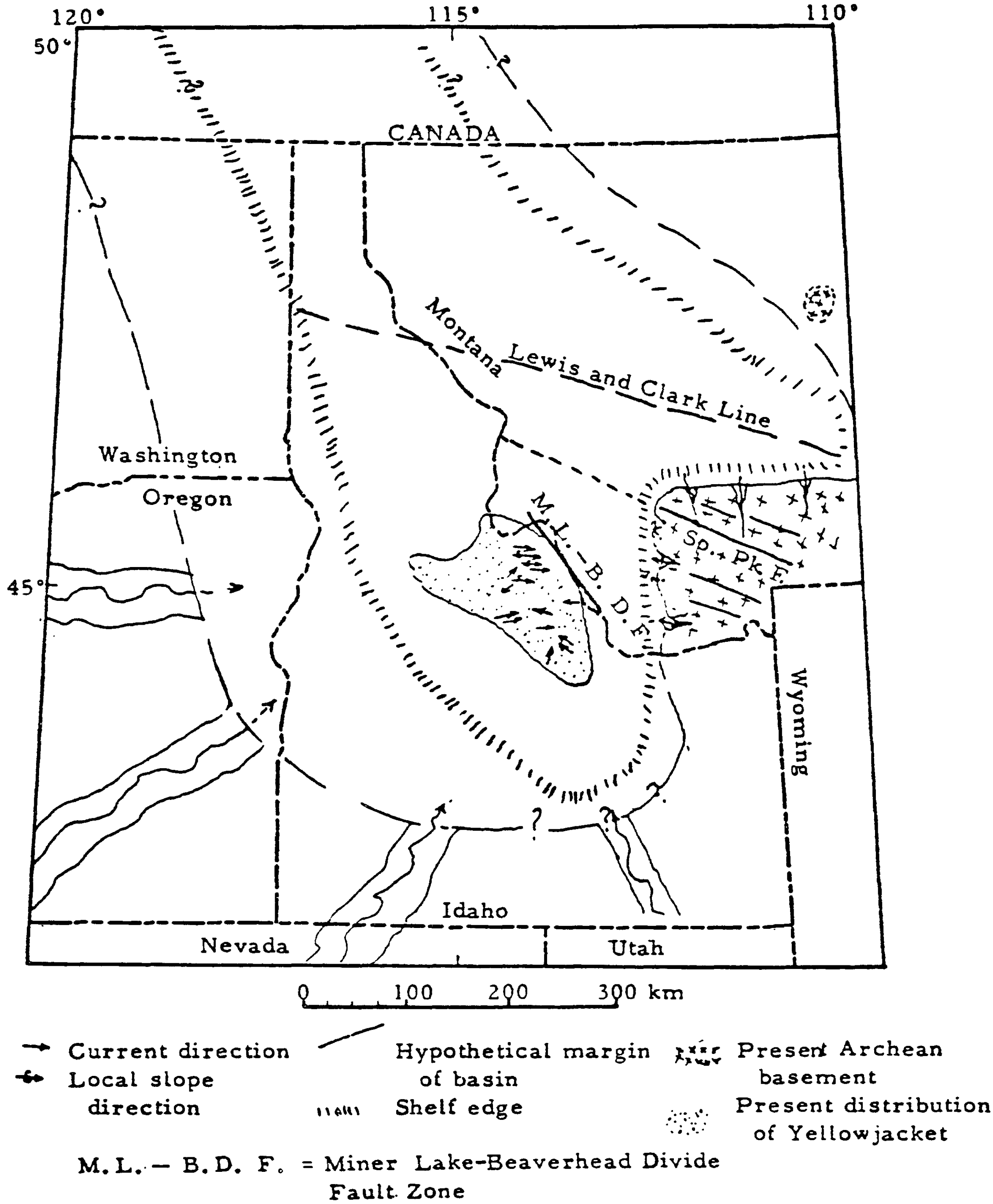



Figure 38.--Speculative Paleogeographic Map of the Yellowjacket--Prichard Depositional Basin.

in contact with the basement. The LaHood is a coarse facies of Belt rocks and is the time-equivalent of rocks of lower Prichard equivalents and younger Belt rocks as well (McMannis, 1963). McMannis interpreted the LaHood as a deep-water deposit formed along a steep, fault-controlled shore line. As has been discussed earlier, the Yellowjacket and the Prichard Formations are probably time-equivalent. These relations indicate that the Yellowjacket, Prichard, and LaHood Formations were probably all deposited in different parts of the same basin. The reversals of transport directions for the Yellowjacket indicate it occupies the axial portion of the basin. Because the LaHood appears to be in depositional contact with older rocks, it provides an excellent control of the location of the shoreline at that time. A speculative paleogeographic map (fig. 38) shows a possible interpretation of the Yellowjacket and Prichard-LaHood depositional basin based on the discussion above, the distribution of Archean rocks, and transport direction data and depositional setting of the preserved portion of the Yellowjacket Formation. The required western landmass would necessarily have been composed of plutonic and metamorphic rocks, much like the Archean basement of southwest Montana, as indicated by the mineralogy of the Yellowjacket (pl. 4, 6, 8-14). In addition, the Yellowjacket's large volume of fine sediment of nearly homogenous composition would best be supplied by large river systems feeding deltas, which in turn supplied sediment to the turbidite system. These major river systems were probably along the western and southern margins of the basin as shown in figure 38 because the eastern margin was probably steep and fault-controlled, as suggested by McMannis for the LaHood Formation, and probably fed mainly coarse material to the depositional basin via numerous short steep streams. McMannis (1963) described rapid facies changes from coarse LaHood sediment to fine-grained sediment of the Prichard and its equivalents. Therefore, a narrow shelf is shown in figure 38 on the east side of the speculative Yellowjacket depositional basin. The coincidence of the sharp eastward embayment of the depositional basin with the location of the Lewis and Clark line suggests that it may have been controlled by tectonics along the line, although it appears not to have effected Prichard facies patterns (Earle Cressman, personal communication, 1981).

As will be discussed in the section on structural geology below, the Yellowjacket is interpreted as an autochthonous block beneath thrust plates of younger rocks; but the possibility does exist that the Yellowjacket is also in a transported thrust plate that has been cut off by the Miner Lake-Beaverhead Divide Fault Zone. Figure 38 was drawn based on the assumption that the Yellowjacket is not involved in thrusting. If thrusting of the Yellowjacket did occur, the whole depositional system would have to be translated an unknown distance westward.

The large amount of missing Yellowjacket Formation raises the question of where all the eroded material was deposited. To the north and northeast of the present region of Yellowjacket occurrences, much of the argillite and siltite of the Belt Supergroup could have originated as detritus eroded from rocks like the preserved part of the Yellowjacket. The Lemhi Group and Swauger Formation in east-central Idaho are composed of predominantly more quartz-rich and much coarser grained quartzites than the preserved Yellowjacket; but east of the Miner Lake--Beaverhead Divide Fault Zone much coarser grained facies of the Yellowjacket must have existed and detritus eroded from this area could have been deposited as the Lemhi Group and Swauger Formation.

# STRUCTURAL GEOLOGY

The Yellowjacket Formation crops out in an area of east-central Idaho that was an up-arched area during late Proterozoic and Paleozoic time. Sloss (1954) recognized thinning patterns of Paleozoic sedimentary rocks and theorized the presence in Paleozoic time of an island in south-central Idaho that he named the Lemhi Arch.

Ruppel (1978) redefined the name "as an intermittently emergent major landmass that separated the Cordilleran miogeocline in western Idaho from a shelf embayment or seaway in southwestern Montana during Precambrian [post-Yellowjacket] and Paleozoic time" (p. 12) (fig. 39). Armstrong (1975) described a nearly identical arch but gave it a new name, the Salmon River Arch.

The area in which the Yellowjacket occurs is also the area of Belt island (fig. 39), a postulated source area for some of the units of the Belt Supergroup (Harrison and others, 1974). Note that the area of the Lemhi Arch (fig. 39) coincides approximately with the preserved distribution of the Yellowjacket (fig. 38). Therefore, the Lemhi Arch appears to represent a structural inversion of a previously low area in which the thick prism of Yellowjacket sediment was deposited.

The basement on which the Yellowjacket lies may be like the Archean crystalline basement of southwest Montana, because in the central Lemhi Range a Tertiary granodiorite stock contains very large (several meters) inclusions of schist that are similar to rocks of the basement in southwest Montana (Ruppel, in press). Armstrong and others (1977) have positioned the western edge of Precambrian basement in western Idaho on the basis of initial

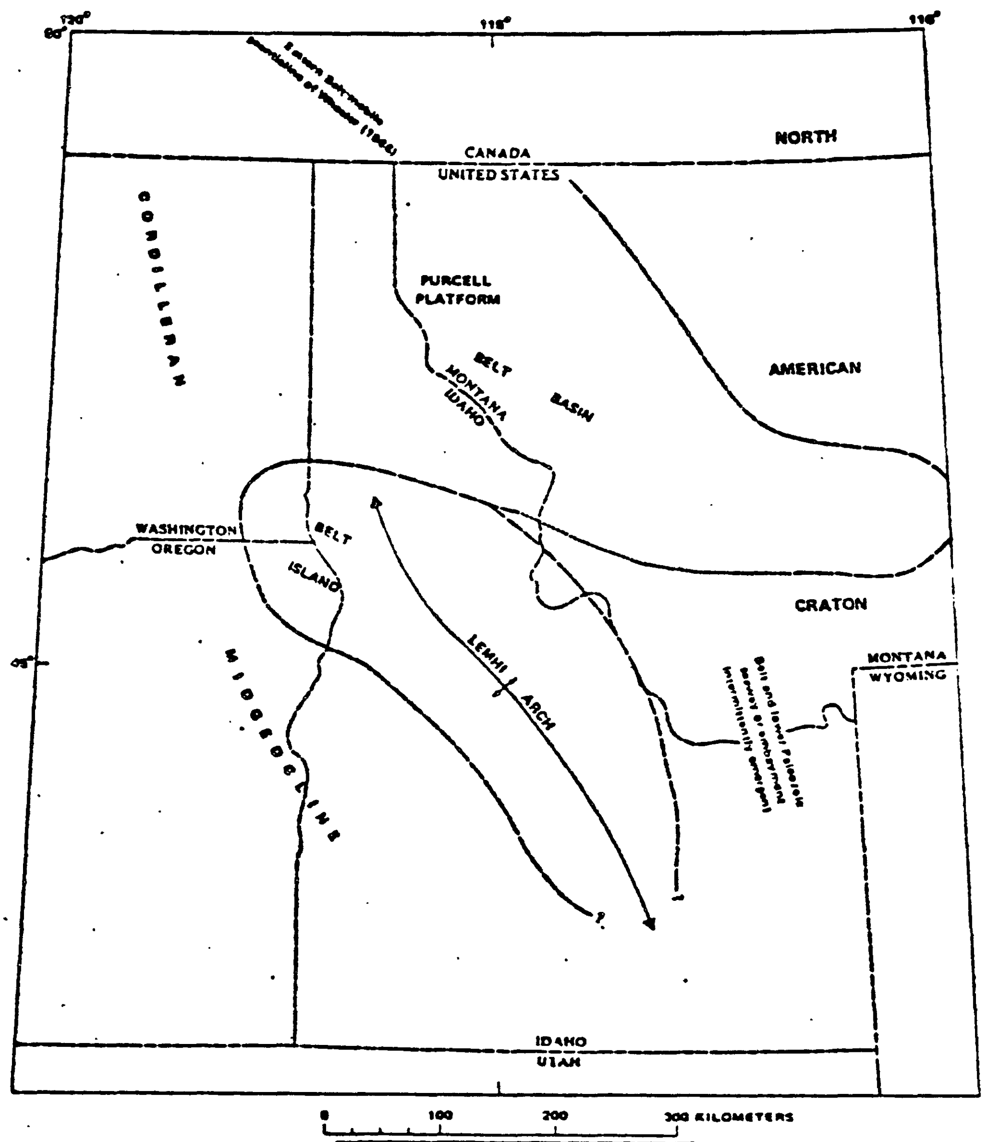



Figure 39.--Map showing the approximate location of the Lemhi Arch in east-central Idaho and southwest Montana and its relation to Belt Island (from Ruppel, 1978, fig. 4).

$^{87}Sr/^{86}Sr$ ratios of Mesozoic and Cenozoic granitic rocks. The initial ratios in east-central Idaho are similar to those in southwest Montana (fig. 40).

In general, the Yellowjacket is metamorphosed to the lower green schist facies and sedimentary features are well preserved. Typical metamorphic minerals are biotite, muscovite, and chlorite, and locally epidote and clinozoisite. Higher grade metamorphism, indicated by the presence of garnet, hornblende, and actinolite have been reported (Cater and others, 1973; and Bennett, 1977). In addition, along margins of quartz monzonite plutons the Yellowjacket is contact metamorphosed to gneiss and schist to distances as much as 0.5 km from the contact. In these zones, foliation in the gneiss and schist is parallel to bedding in the Yellowjacket, and normal Yellowjacket grades into schist and gneiss toward the contact.

## Folding in the Yellowjacket Formation

Structure within the Yellowjacket is distinctly different from that exhibited in all the younger rocks in the region. In general, the Yellowjacket in the area of the study strikes west-northwest and dips northward, although this trend is interrupted by numerous faults and folds that repeat restricted intervals of the stratigraphic section. Large tight to isoclinal, commonly overturned folds are typical of the Yellowjacket. These are much different from the much smaller tight, overturned, thrust-related folds that occur in younger Precambrian and Paleozoic rocks. Commonly, only one limb of a fold occurs in separate fault blocks, but where axial plane cleavage is present its attitude indicates that the limb faulted off was overturned. In the Panther Creek area where folds can be traced from the

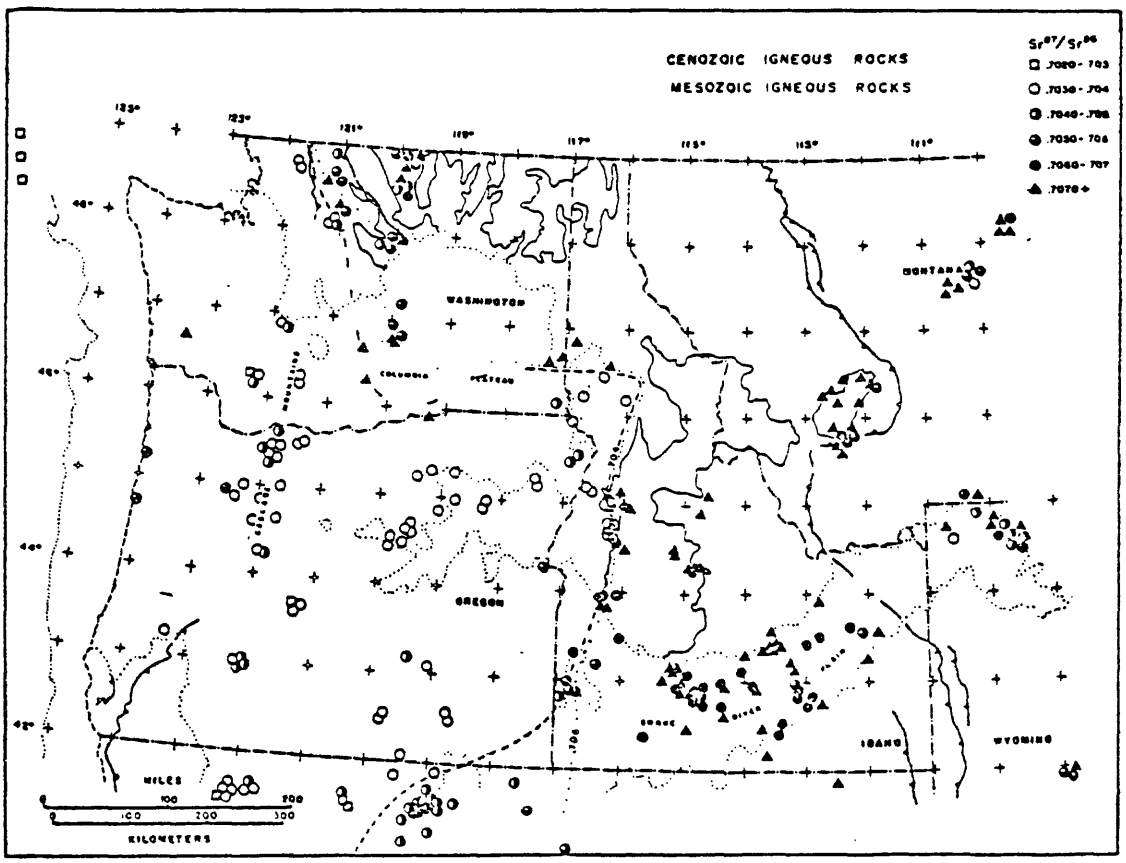



Figure 40.--Map of northwestern United States showing initial Sr isotope ratio determinations for Mesozoic and Cenozoic granitic rocks. The 0.704 contour is interpreted as the western edge of Precambrian basement (from Armstrong and others, 1977, fig. 10).

upright limb to the overturned limb, it can be observed that the wavelength of the folds ranges from 0.5 to 1.5 km (pl. 5). These folds are steeply plunging to the northwest and are overturned to the southwest. Axial plane cleavage is best developed near the hinges of folds as along Panther Creek south of Copper Creek. Elsewhere, cleavage is only weakly developed except in the North Fork of Iron Creek (fig. 41) where the entire section of Yellowjacket is in the upright limb of a fold, whose axial plane cleavage strikes about N. 30$^{\circ}$ W. and dips 65$^{\circ}$ NE; bedding strikes approximately N 45$^{\circ}$ W and dips about 45$^{\circ}$NE. Thus, the axial plane of this fold has an attitude similar to those along Panther Creek and the direction of overturning is the same, to the southwest. In fact, all the cleavage planes measured had strikes between N. 30$^{\circ}$ W. and N. 60$^{\circ}$ W. and dips between 45$^{\circ}$ and 75$^{\circ}$ to the northeast. Directions of overturning in rocks of the Medicine Lodge Plate, in contrast, are mainly to the east with axial planes that strike northward and dip westward (Brown and Beutner, 1975; Ruppel, 1978; and Ruppel and others, in press).

Both the metamorphism and the folding appear to have occurred before intrusion of the 1.4-b.y.-old quartz monzonite plutons because the intrusive rocks cut across all the fold structure in the Yellowjacket, and the plutons south of the Hot Springs Fault are not metamorphosed like the Yellowjacket.

## Major Fault Zones

### Miner Lake-Beaverhead Divide Fault Zone

Several major high-angle faults in the region appear to have moved in Precambrian time. The Miner Lake-Beaverhead Divide fault zone (Mackenzie, 1949; Ruppel, in press; and Ruppel and others, in press) forms the eastern

Figure 41.--Photograph showing cleavage developed in the Yellowjacket Formation in the North Fork of Iron Creek. Note the incipient formation of foliation and distruption of bedding in the left-central part of the photograph.

edge of Yellowjacket occurrences. It is thought to be older than 1.4 b.y. on the basis of radiometric dates of dike rocks that have intruded fault zones with the similar trends in the Archean basment of southwest Montana (Ruppel, in press). Movement was pre-Missoula Group because east of the fault Missoula Group rocks are present in the Pioneer Mountains and the Yellowjacket is absent beneath them (Ruppel and others, in press). Elsewhere to the east of the fault, Cambrian Flathead Sandstone is in depositional contact with Archean crystalline rocks.

The Miner Lake-Beaverhead Divide fault zone has had repeated movement; Precambrian movement was normal with the west side down, after which all the Yellowjacket on the eastern block was removed. Post-thrusting (Late Cretaceous) displacement was reverse with the east side down, because east of the fault zone, Lemhi Group rocks make up the Beaverhead Mountains and the Medicine Lodge thrust is deeply buried. But west of the fault zone the Medicine Lodge thrust containing rocks of the Lemhi Group is exposed above the Yellowjacket near the crest of the Beaverhead Mountains. In the Yellowjacket Formation, the fault zone is marked by a steeply dipping thick zone of shearing and mylonitization, but in the overlying Medicine Lodge thrust plate the mylonitization is absent (E. T. Ruppel, oral communication, 1981; and Mackenzie, 1949), which further substantiates the recurrence of movement along the fault zone. Movement has probably continued into the Quaternary as indicated by the dramatic physiographic differences across the Montana--Idaho border in this area.

## Panther Creek Fault Zone

The Panther Creek Fault (pl. 1) is marked by a distinct northeast-trending lineament along upper Panther Creek, Napias Creek, and Moose Creek.

Ross and Forrester (1940) also showed a fault in this position, and Bennett (1977) briefly described a similar lineament but did not map a fault zone. This fault offsets the contact between the Yellowjacket and the quartz monzonite plutons in the Moose Creek-Dump Creek area and near the mouth of Napias Creek. The northern end of the fault zone is in the Dump Creek area where displacement appears to be taken up by north-trending faults. At the southern end, structures on opposite sides of the Panther Creek fault are offset and many can not be matched. The fault follows the drainages of Panther Creek and Napias Creek for much of its length, but where it leaves the present drainages the fault is marked by zones of poor exposure and breccia (pls. 1 and 5). South of the Yellowjacket outcrop area, the fault is marked by a complex zone of horsts and grabens in the Tertiary Challis Volcanics (E. B. Ekren, oral communication, 1980), which appears to have disrupted the Silver Creek drainage (pl. 1). The Panther Creek fault is associated with the zone of tight overturned folds in the Yellowjacket described above. In both directions away from the fault, the severity of deformation in the Yellowjacket decreases and cleavage is only rarely detectable. The nature and orientation of these folds indicate that at least the initial movement was strike-slip. That this movement was pre-1.4 b.y. ago is indicated by the truncation of the folds associated with the fault by the 1.4-b.y.-old intrusive rocks, and also by the apparent control of the intrusive in the Panther Creek-Napias Creek area by the fault zone where the intrusive contact is parallel to the fault zone but fault breccia is wholly within the Yellowjacket (Karl Evans, oral communication, 1979). Later movement has been recurrent along the same fault zone as indicated by post-Challis faulting along the southward extension of the fault zone. Recent movement on the fault zone is indicated by the presence of fresh unvegetated landslides and fault scarps(?) at the mouth of Porphyry Creek and the common occurrence of earthquakes with epicenters in that same vicinty (U.S.G.S. National Earthquake Information Service, written communication, 1980). Several earthquakes occurred in that area during field work related to this report.

## Big Deer Creek, Hot Springs, and Shoup Fault Zones

Three other major faults subparallel to the Panther Creek fault, the Big Deer Creek fault, the Hot Springs fault, and the Shoup fault, are probably also Precambrian structures. The Big Deer Creek fault forms the contact between the Yellowjacket Formation on the south and higher grade metasedimentary rocks on the north (pl. 1). This fault has had at least two periods of recurrent movement: 1) pre-thrusting, because a thrust plate of Lemhi Group rocks overlies Yellowjacket on the south but overlies gneiss and schist on the north; and 2) post-thrusting and post-Crags pluton (44.2-47.5 m.y. old (Cater and others, 1973,1975), because both the thrust plate and the Yellowjacket-Crags pluton contact are offset (pl. 1). The Hot Springs fault and the Shoup fault are two major fault zones that merge to the northeast and separate 1.4-b.y.-old quartz monzonite plutons and Yellowjacket Formation on the south from augen gneiss and metasedimentary gneiss and schist on the north (pl. 1). Maley (1974) first used the name Hot Springs fault for that segment along Hot Springs Creek from Panther Creek northeast to Pine Creek. The fault is here extended southwestward into the Clear Creek drainage and northeastward to where it is apparently cut off by a north-trending fault near Hughes Creek. The Shoup fault parallels the Hot Springs fault on the northwest and is marked by a lineament along Bear Gulch, Pretty Gulch, and a straight segment of the Salmon River. It merges with the Hot Springs fault in the Hull

Creek drainage just northeast of Ulysses Mountain (pl. 1). Both these faults are marked by wide zones of gouge and breccia locally to as much as 0.5 km wide. The Hot Springs fault, as the name indicates, is also marked by several hot springs in Hot Springs Creek. The water issuing from these springs has a temperature of 93°C and aquifer temperature as high as 175°C has been calculated (Idaho Department of Water Resources, 1980). According to Bennett (1977) this fault is also marked by a silver anomaly in stream-sediment samples. No direct evidence is available to indicate an age of these faults, but on the basis of trend and structural relations similar to the previously described faults, they are probably also Precambrian in age, and they have had recurrent movement as indicated by the control of hot spring activity. The Hot Springs-Shoup fault zone and the Big Deer Creek fault are significant in that they clearly separate two distinctly different rocks assemblages. On the north, high-grade metasediments and augen gneiss and associated rocks occur; on the south only slightly metamorphosed Yellowjacket Formation and porphyritic quartz monzonite plutons dated at approximately 1.4 b.y. (Armstrong, 1975; and Karl Evans, oral communication, 1980) are observed. The augen gneisses of the Salmon River and the porphyritic quartz monzonites previously have all been considered to be phases of one augen-gneiss complex (Maley, 1974; Armstrong, 1975; and Bennett, 1977). All radiometrically dated samples are from the porphyritic quartz monzonite south of these fault zones (Armstrong, 1975; and written communication, 1978; and Karl Evans, oral communication, 1981). Therefore, whether the augen-gneiss complex north of these faults is older than or the same age as the dated rocks has not yet been determined. But, as will be discussed below, structural evidence indicates that the augen gneiss-complex can be interpreted as being older than the 1.4-b.y.-old porphyritic quartz monzonites. Structural relations between the augen gneiss complex and metasedimentary rocks north of these faults zones were not determined.

Another similar fault outside the area studied, but shown on plate 1, is the Bargamin Creek Fault, a major fault thought to have had strike-slip movement (Cater and others, 1975; and Weis and others, 1972).

Ruppel (1981 in press) has described a series of major blocks in east-central Idaho and southwest Montana bounded by northeast-trending lineaments approximately parallel to the faults just described. These blocks contain rocks that are successively older and/or from deeper structural levels toward the northwest. His northernmost lineament apparently coincides with the Hot Springs-Shoup Fault zone, which extends northeastward through northeast-trending faults near Gibbonsville, Idaho, and along the northwest side of the Big Hole Basin. The block north of this lineament contains predominantly batholithic rocks (Ruppel, 1981 in press) but also contains Precambrian high-grade metmorphic rocks.

## Brushy Gulch Fault

The Brushy Gulch fault, a northwest-trending fault just north of Indianola, separates biotite schist and rocks of the Yellowjacket Formation from a complex of augen gneiss, amphibolites, and associated metamorphic rocks north of the Hot Springs fault (pl.1). The fault appears to extend southeastward beyond the Hot Springs fault at the quartz monzonite-Yellowjacket contact; in fact, Kaiser (1956) mapped a similar fault along that contact. But south of the Hot Springs fault the apparent extension of the Brushy Gulch fault is clearly an intrusive contact of quartz monzonite into the Yellowjacket Formation. These relations suggest that this intrusive contact was controlled by the former extension of the Brushy Gulch fault. If this is true, then a logical conclusion is that the augen-gneiss complex is older than the 1.4-b.y.-old quartz monzonite plutons.

## Medicine Lodge Thrust System

Superimposed on all this structure of pre-1.4 b.y. ancestry is the Medicine Lodge thrust system of Ruppel (1978) and Ruppel and others (in press). In the region of this study, rocks of the Proterozoic Y age, Lemhi Group and Swauger Formation, and Paleozoic sedimentary rocks occur in thrust plates that overrode the Yellowjacket from the west. The Yellowjacket is interpreted as autochthonous. Nowhere has the Yellowjacket been observed or reported to be involved in thrusting. The eastern margin of the Yellowjacket outcrop area, the Miner Lake-Beaverhead Divide Fault Zone, cannot be interpreted as a frontal zone of a major thrust zone because none of the features described in zones of frontal buttressing (Raleigh and Griggs, 1963; Crosby 1973), such as tight overturned folds with directions of yielding consistent with the direction of thrusting and complex zones of imbricate thrust faults, are present.

Several klippe of the Medicine Lodge thrust system not previously described were identified during reconnaissance mapping for this report. A large area in the Taylor Mountain-Iron Lake area is underlain by a thrust plate containing rocks of the Apple Creek Formation and of the Big Creek or Swauger Formations. North-trending faults have broken the thrust plate and form the contacts with Yellowjacket on both the east and west (pl. 1). On the south end of the block, the contact is a northwest-trending normal fault (pl. 1) (E. B. Ekren, oral commun., 1980). At the north end of the block, about 9 km north of Iron Lake, the thrust plate containing rocks of the Apple Creek Formation can be observed overriding rocks of member C of the Yellowjacket Formation (pl. 1). The thrust plate is marked by a change in slope, and the Yellowjacket is intensely fractured and thus poorly exposed near the fault. The Apple Creek is also intensely fractured to brecciated just above the thrust. The internal structure within this thrust plate is not yet known, but is not as simple as is shown in plate 1. Apparently, a steep northwest-trending fault just north of Iron Lake marks the boundary between the Apple Creek and light-colored fine- to medium-grained quartz-rich quartzites that may be of the Big Creek or Swauger Formations. Another small klippe of Apple Creek on Swan Peak north of the plate just described is an erosional remnant of that same thrust plate.

Quartzite Mountain, just north of the Porphyry Creek-Shovel Creek divide, is also a small Medicine Lodge klippe of intensely brecciated quartzite of the Swauger Formation.

A broken thrust sheet of similar quartzite also occurs in the Big Deer Creek drainage. As has already been mentioned, the Big Deer Creek fault cuts the plate, and the same rocks in a thrust plate overrode the Yellowjacket Formation on the south and gneiss and schist on the north.

Farther west, Ross (1934) mapped rocks of the Hoodoo Quartzite in a thrust plate above the Yellowjacket. Where examined in that area, the rocks are quartzite of the Swauger Formation.

Another strip of clean quartzites from Phelan Mountain northwest to the Arnett Creek area represent a thrust plate that has been broken by later steep faults (Karl Evans, oral communication, 1979; and Larry Hillesland, oral communication, 1980). These have been mapped as Hoodoo Quartzite (Shockey, 1957; and Bennett, 1977), but are probably part of the Big Creek Formation.

## Tertiary Faulting

The latest structures are a complex system of mainly north-trending and northwest-trending high-angle faults that have outlined the present basins and ranges. Ruppel (1981, in press) has described this system of faults in detail. Many of these faults have had recent movement (Ruppel 1968, 1980; and Ruppel and Lopez, in press) and are thought to be minor but many have vertical relative displacements of as much as 1,000 m, and Ruppel (1964) has reported relative horizontal displacements of as much as to 2.5 km. Many veins that have been prospected in the Panther Creek area were observed to be controlled by north-trending fault zones; many of the zones of cobalt mineralization of the Blackbird mine appear to be controlled by some of these fault zones. The straight north-trending eastern boundary of the Crags Pluton is probably controlled by a fault of this system (pl. 1).

## Summary of Structural Geology

Much of the structure in the region and within the Yellowjacket Formation was developed before 1.4 b.y. ago, and these structures have strongly influenced structural development in the area up to the present. The present outcrop distribution of the members of the Yellowjacket is in part the result of the development of the Lemhi arch as redefined by Ruppel (1978) from the original feature described by Sloss (1954). This feature is nearly identical to the Salmon River arch described by Armstrong (1975). Near the axis of the Lemhi arch, units low in the section (members A, B, and C) are present, whereas near the flanks stratigraphically higher rocks occur. The Lemhi arch developed as a structural inversion of the thick Yellowjacket prism of sediment. The arch formed in pre-Missoula Group time, because it appears to have controlled the position of Belt seaway (fig. 39) in which the Missoula Group was deposited, and also provided a sediment source for post-Prichard rocks in the Belt Basin (Harrison and others, 1974). In addition, the Lemhi arch controlled depositional patterns of sedimentary rocks through the Paleozoic (Sloss, 1954; Armstrong, 1975; Ruppel, 1978).

Geologic relations preserved in the Yellowjacket region put definite constraints on the order and timing of events in the geologic history. The Precambrian structural development of the region can be summarized in the following sequence of events for which there is geologic evidence preserved in the region of this study: 1) Attenuation of the continental crust and development of the Yellowjacket depositional basin, probably after 1.76 b. y. ago, followed by deposition of about 8,000 m of Yellowjacket sediment in a deep-marine setting, 2) Metamorphism of the Yellowjacket, strike-slip movement along the Panther Creek Fault zone, and probably the other major northeast-trending fault zones as well, occurred during this event. Metamorphism of the Yellowjacket was not the result solely of deep burial because there is no stratigraphic variation in metamorphic grade within the Yellowjacket Formation, but it may represent the 1.6-b.y.-old metamorphic event reported for the basement of southwest Montana (James and Hedge, 1980), 3) Normal faulting about 1.4-b.y.-ago along the Miner Lake-Beaverhead Divide Fault Zone (fig. 38 and pl. 1) with the west side down. Intrusion of the porphyritic quartz monzonite plutons into the Yellowjacket also occurred at about this time (p€qm on pl. 1), 4) Erosion of all the Yellowjacket that had been deposited on the uplifted block east of the Miner Lake-Beaverhead Divide Fault Zone, 5) Formation of the Lemhi Arch by structural inversion of the thick preserved prism of Yellowjacket rocks and deposition of Missoula Group sediments in the Belt Seaway (fig. 39). Reverse movement along the Miner Lake-Beaverhead Divide Fault Zone may have occurred at this time.

# ECONOMIC GEOLOGY

Economic interest in the Yellowjacket Formation is because of the cobalt and copper-cobalt mineralization within the unit. This mineralization appears to be restricted to the Yellowjacket except for the reported occurrence of cobalt in the ore of the Salmon Canyon Copper Company mine, which occurs in high-grade metasediments in the Salmon River Canyon (p€gs on plate 1). As has been mentioned earlier, these rocks, in fact, may be high-grade metamorphic equivalents of the Yellowjacket.

## Known Occurrences of Cobalt Mineralization

### Blackbird Deposit

The most noteworthy cobalt mineralization is at the Blackbird Property, which includes a number of mines and claims in the Blackbird Creek drainage about 9 km west of Panther Creek. The property is now under development and exploration by Noranda Mining Incorporated and present plans are to start production in 1984 (The Mining Record, Jan. 28, 1981). The history of the Blackbird deposits and the Blackbird District are discussed in several reports (Umpleby, 1913; Anderson, 1943; Purdue, 1975; and Bennett, 1977). Total production from these properties has been about 5,495,000 lbs of cobalt concentrate averaging 17.74 percent cobalt, and 3,320 tons of copper concentrate of unspecified copper content (Bennett, 1977). Descriptions of these deposits are available in several published reports (Umpleby, 1913; Anderson, 1943, 1947; Vhay, 1948; Canney and others, 1953; Purdue, 1975; and Bennett, 1977). The mineralization is in a fault block called the Blackbird Block (Vhay, 1948), which is bounded by north-trending faults on both the east and west, by quartz monzonite plutonic rocks on the north, and an indefinite boundary on the south near the West Fork of Blackbird Creek (Vhay, in Canney and others, 1953). Rocks are more intensely deformed within the Blackbird Block than outside the block. The mineralization is in sheared and fractured zones 3-10 m wide, the most important of which strike northwest and dip moderately northeast or are steep and strike north and northeast (Vhay, 1948; Anderson, 1943, 1947; Purdue, 1957; and Bennett, 1977). Mafic dikes are commonly associated with the mineralization, which may occur along the contacts of the dikes but not within them (Umpleby, 1913). However the mineralization is not always associated with the dikes (Vhay, 1948). Typically, high-grade ore occurs in plunging pods within broader zones of low-grade material. The ore consists of chalcopyrite, cobaltite, pyrite, and pyrrhotite in a gangue of quartz, biotite, siderite, tourmaline, and locally muscovite (Vhay, in Canney and others, 1953). Cobaltite grains are all less than 0.3 mm in diameter and most commonly are less than 0.02 mm in diameter (Purdue, 1975). Tourmalinization in the ore zones occurs in two stages: 1) early fine crystalline aggregates, and 2) veinlets of crystalline tourmaline that cut the earlier fine tourmaline (Purdue, 1975). Tourmalinization was found widely distributed in the Yellowjacket, but whether it can be used as a guide to mineralization was not ascertained during this study. The most common occurrence was as filling between clasts of fault breccias in the Yellowjacket; this type of tourmalinization was observed in nearly all areas underlain by the Yellowjacket Formation. Another type occurs as laminae, lenses, and veins and veinlets of finely crystalline tourmaline that contain only fractions of a percent of quartz and clay minerals. In addition, detrital grains of tourmaline were observed in nearly all thin sections of Yellowjacket rocks.

The stratigraphic interval in which the Blackbird deposit occurs is approximately in the lower part of member D. Due to the reconnaissance nature of this study and the deformation of the rocks in the Blackbird area, the stratigraphic position of the deposit cannot be identified more precisely as yet.

## Blackpine Mine

Cobalt mineralization associated with copper, as in the Blackbird deposit, also occurs at the Blackpine mine near the head of the north branch of Copper Creek east of Panther Creek. Production from this mine has been limited to about 24,200 lbs of copper (Shockey, 1957). The mineralization is along northwest-trending fault zones that dip $45^{o}$ to $70^{o}$ northeasterly (Shockey, 1957).

Chalcopyrite is the principle ore mineral. Cobalt occurs as cobaltiferous arsenopyrite (glaucodot) (Shockey, 1957). Other minerals present are pyrite, bornite, limonite, malachite, azurite, sericite, chlorite, and quartz (Shockey, 1957).

Examination of limited exposures in the area and float indicate that this deposit occurs approximately in the interval of the transition from member B to member C of the Yellowjacket Formation. Shockey's (1957) brief description is consitent with this conclusion.

## Little Deer Creek Occurrences

A different type of cobalt mineralization occurs on a number of claims along Panther Creek across from Little Deer Creek. These claims are owned by E. F. Waterman of Salmon, Idaho. An exploration tunnel driven on the Sweet Repose Claim, which is typical of these occurrences, was mapped to determine the manner of occurrence of the cobalt. The location of the Sweet Repose prospect is shown in figure 42, and a map of the exploration adit is shown in figure 43. The mineralization is in the Yellowjacket Formation and is in a block bounded on the north and east by intrusive quartz monzonite and by faults on the south and west (fig. 42). The mineralization on the Sweet Repose was briefly described from surface exposures by Anderson (1943). As seen in figure 43, the mineralization is associated with a steeply dipping fault zone trending N. 80° W., clearly discordant to bedding. The mineralized zone is about 10.6 m wide, and consists of a central coarsely brecciated zone bounded by mylonitized zones on each side. The brecciated zone contains angular differentially rotated blocks as much as 1 m across of the Yellowjacket Formation, member D, that have not been notably altered. The mylonitized zones are nearly black coarse biotite schist with quartz and feldspar. Locally the biotite schist is coarsely tourmalinized and commonly exhibits lath-shaped chalky white spots as much as 0.5 cm long that apparently represent incipient formation of feldspar porphyroplasts. The cobalt occurs as disseminated cobaltite, and, unlike the mineralization at the Blackbird Deposit, the cobaltite is very coarse grained; grains as much as 1 cm in diameter have been observed. In addition, chalcopyrite and other sulfide minerals are present in relatively minor amounts. Erytherite is commonly present in oxidized surface exposures of the vein. Cobalt content in the vein is highest in the biotite schist at the margins (as much as 15 percent Co) and

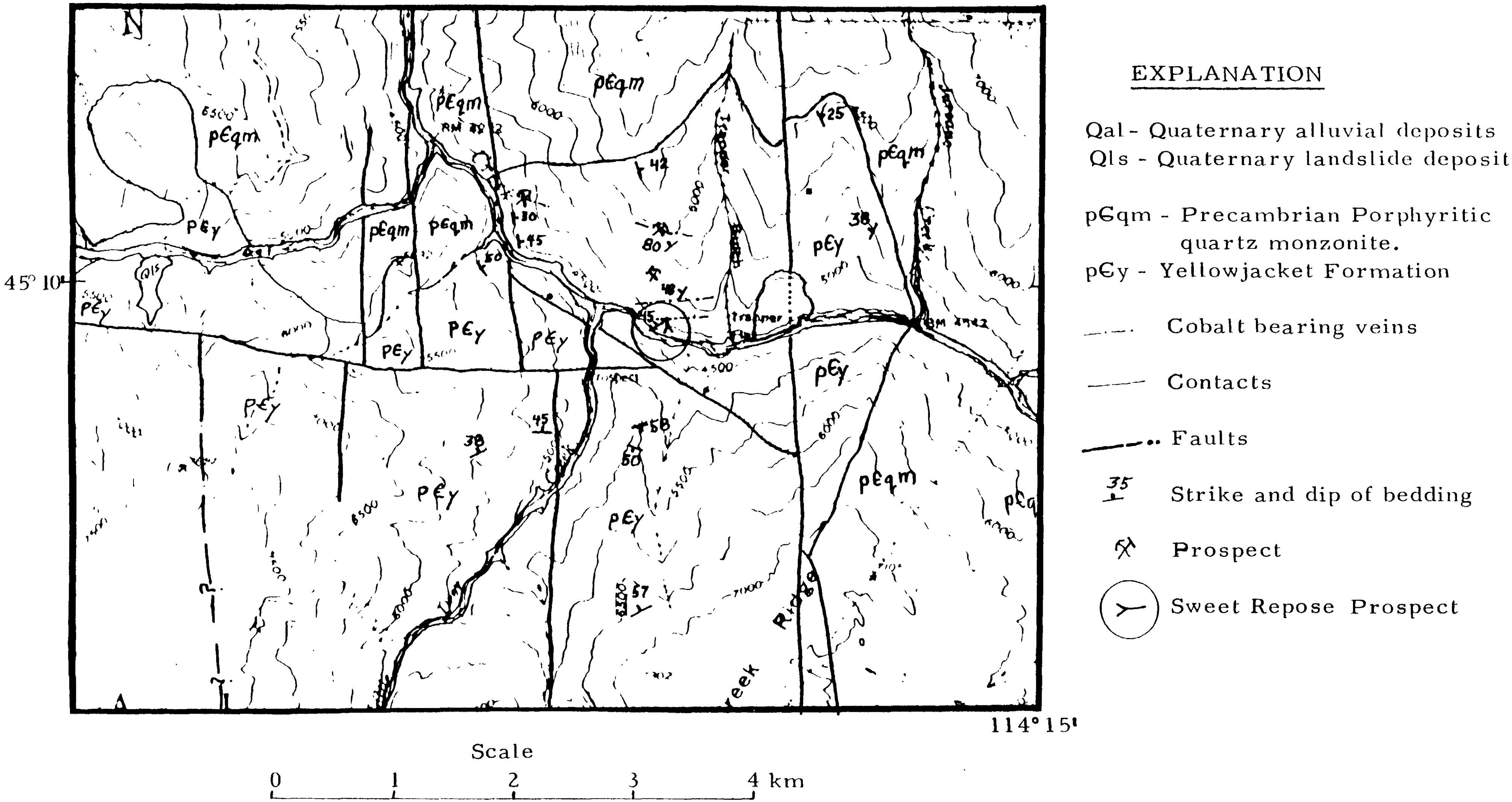



Figure 42. Geologic map of the area of the Sweet Repose Prospect, Blackbird Mountain Quadrangle, Idaho.

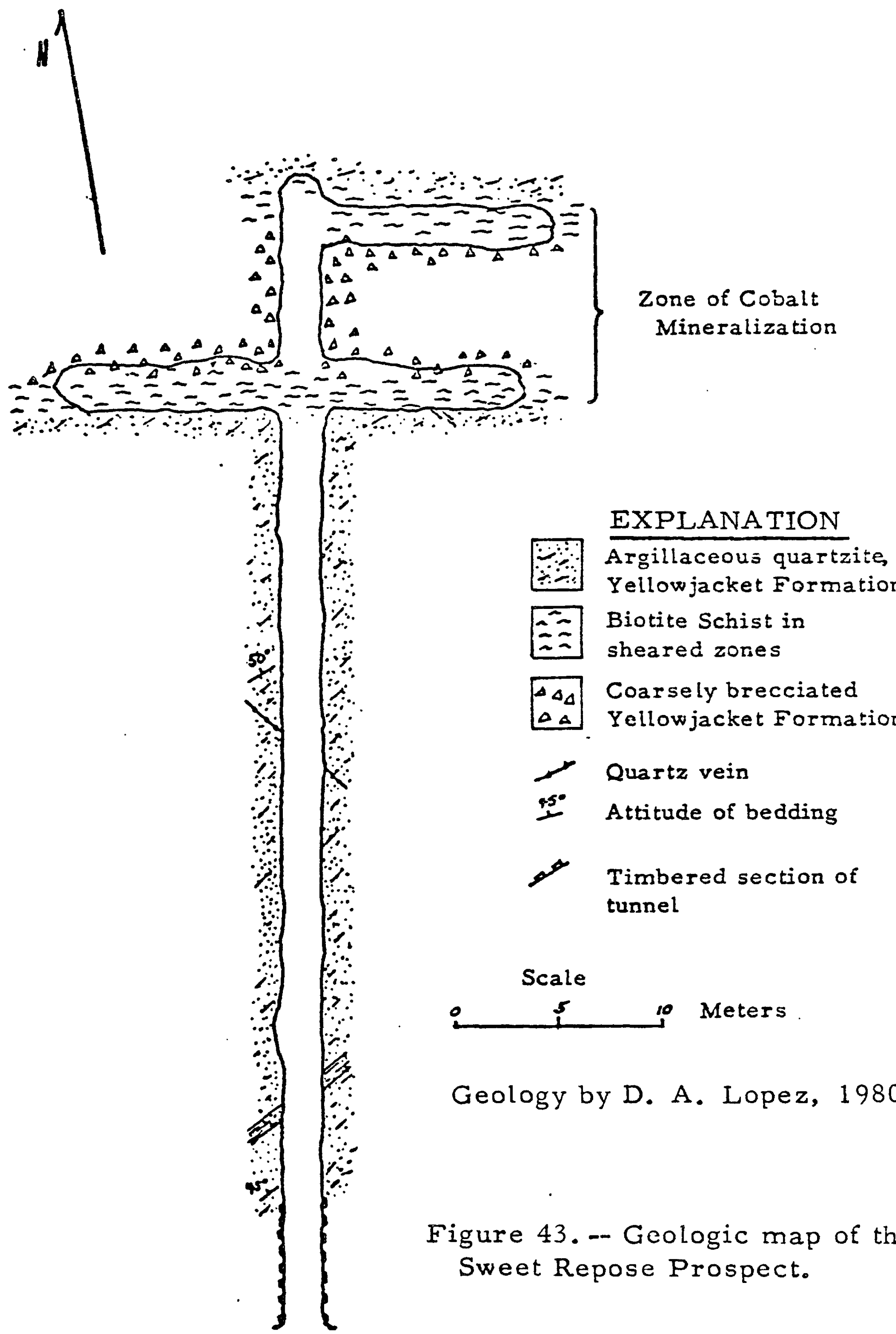



Figure 43. -- Geologic map of the Sweet Repose Prospect.

decreases toward the center of the brecciated zone (about 0.5 percent Co) (E. F. Waterman, oral communication, 1980). There has been no production from the property except for 300-500 lbs of high-grade ore sold as mineral specimens. There are several other similar veins scattered around the hillside surrounding this prospect, as well as across Panther Creek in the Little Deer Creek drainage, all of which appear to be discontinuous zones, pinching out within 25-100 m (fig. 42).

The Yellowjacket in the area of these claims is within member D, but is relatively much higher, stratigraphically, than the Blackbird deposits.

Claims on similar small deposits have been located in the Deep Creek drainage north of the town of Cobalt by local prospectors but assessment work has probably not been kept current (E. F. Waterman, oral communication, 1980).

## Iron Creek Occurrences

Two known zones of mineralization that contain copper and cobalt (D. Peters, U.S. Forest Service, Salmon, Idaho, oral communication, 1979) occur in the Iron Creek drainage (pl. 7). One is a vein controlled by a shear zone and is exposed in a road cut about 1.7 km due west of Degan Mountain. This vein is in member D of the Yellowjacket Formation. Pink cobalt-bloom (erythrite), pyrite, chalcopyrite, bornite and limonite can be observed in the exposure.

In the North Fork of Iron Creek, the Little No Name Mine deposit is also said to contain cobalt. No production has been reported, and mining has been done mainly for exploration purposes. Chalcopyrite and pyrite were the common sulfide minerals observed. This deposit is apparently stratiform. The mineralized zone exposed in the roadcut along the creek is a complex of interlaminated sulfides and argillaceous quartzite. The beds and laminae preserved in the mineralized zone have the same attitude as beds above and below the zone. As the mineralized zone is approached, both from stratigraphically above and below, increasing amounts of disseminated sulfides can be observed along bedding planes in the argillaceous quartzite of the Yellowjacket. The mineralized zone is about 30 m thick and exhibits intense argillic hydrothermal alteration. The stratigraphic position of this deposit appears to be in member D, near the transition from member C to member D.

## Other Occurrences

Copper-cobalt mineralization occurs in the Salmon Canyon Copper Company mine located on the north canyon wall of the Salmon river between Colson Creek and Long Tom Creek, about 3 km east of the mouth of the Middle Fork (pl. 1). The deposit was not investigated during this study, and apparently no published information on the cobalt occurrence is available.

Cobalt is also reportedly present in small discontinuous veins in the East Fork Claims on Indian Creek, Indian Creek District, Lemhi County (Vhay <u>in</u> U.S. Geological Survey, 1964). The exact location of these veins is not known and no other information was available.

Many other mines occur within the Yellowjacket Formation in the study area, most of which produced copper and/or gold, and in which the presence of cobalt has not been reported. At the Yellowjacket Mine, a fault-controlled vein of gold-pyrite ore was mined. Member B of the Yellowjacket Formation is the country rock for this deposit. Ross (1934) has described the Yellowjacket Mine, as well as the other mines in the Yellowjacket District. Other predominantly copper mines and prospects in the Salmon, Idaho area are described in Ross (1925). These deposits could not be evaluated in enough detail during this study to add to the already published descriptions.

## Trace-Element Geochemistry of the Yellowjacket Formation

Rock samples for trace-element geochemical analysis were collected from the Yellowjacket along measured sections at intervals from 500 to 1000 m to attempt to discriminate stratigraphic intervals most favorable for the location of cobalt mineralization. Samples were also collected in the area around a mineralized Tertiary-age stock about 8 km south of North Fork, Idaho (Ti on pl. 1). Sample localities are plotted on plate 2. Samples were taken of all lithologies present at a sample locality and combined so that it would be representative of the Yellowjacket at that locality. This was done because most commonly lithologies were interbedded or interlaminated in thickness of several millimeters to a few centimeters.

Each sample was analyzed semiquantitatively for 31 elements using a six-step, D.C.-arc optical emission spectrographic method (Grimes and Marranzino, 1968). An atomic absorption spectrometric technique was used to analyze for zinc (Ward and others, 1969).

The semiquantitative spectrographic values are reported as six steps per order of magnitude (1, 0.7, 0.5, 0.3, 0.2, 0.15, and multiples of 10 of these members) and are approximate geometric midpoints of the concentration ranges. The precision is shown to be within one adjoining reporting interval on each side of the reported values 83 percent of the time, and within two adjoining intervals on each side of the reported value 96 percent of the time (Motooka and Grimes, 1976).

The visual lower limit of determinations for the 31 elements that were determined spectrographically and are included in this report are as follows:

| For those given in percent | |
|---|---|
| Calcium | 0.05 |
| Iron | 0.05 |
| Magnesium | 0.02 |
| Titanium | 0.002 |

| For those given in parts per million | | | |
|---|---|---|---|
| Antimony | 100 | Molybdenum | 5 |
| Arsenic | 200 | Nickel | 5 |
| Barium | 20 | Niobium | 20 |
| Beryllium | 1 | Scandium | 5 |
| Bismuth | 10 | Silver | 0.5 |
| Boron | 10 | Strontium | 100 |
| Cadmium | 20 | Thorium | 100 |
| Chromium | 10 | Tin | 10 |
| Cobalt | 5 | Tungsten | 50 |
| Copper | 5 | Vanadium | 10 |
| Gold | 10 | Yttrium | 10 |
| Lanthanum | 20 | Zinc | 200 |
| Lead | 10 | Zirconium | 10 |
| Manganese | 10 | | |

The lower limit for zinc determinations by atomic absorption is 5 ppm.

The data obtained are summarized in table 3 and are presented in total in Appendix 4.

Table 3.--Summary of B, Co, Cu, Pb, and Sr content (parts per million) of the Yellowjacket Formation

| B | | Co | | Cu | | Pb | | Sr | |
|---|---|---|---|---|---|---|---|---|---|
| R | A | R | A | R | A | R | A | R | A |
| Member E; 2 analyses: | | | | | | | | | |
| 10 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 100-150 | 125 |
| Member D; 54 analyses: | | | | | | | | | |
| 10-300 | 37 | 0-30 | 13 | 0-700 | 19 | 0-70 | 9 | 0-300 | 110 |
| Member C; 6 analyses: | | | | | | | | | |
| 20-300 | 100 | 5-15 | 10 | 0-20 | 6 | 0-15 | 8 | 100 | 100 |
| Member B; 6 analyses: | | | | | | | | | |
| 15-70 | 39 | 7-20 | 13 | 0-30 | 9 | 0-50 | 15 | 0-100 | 67 |

R = range of values. A = arithmetic mean.

The upper part of member B, member C, and member D show similar cobalt contents, generally ranging from 5 to 20 ppm except near the Little No Name Mine in the North Fork of Iron Creek where values increase to 30 ppm. No data are available for member A and the lower part of member B. No cobalt was detected in member E (pls. 6, 8, 9, 11, 12, and 13, and table 3).

The upper part of member B, member, C, and member D are probably all equally favorable for locating cobalt mineralization, as is indicated by the above chemical data and because all known cobalt mineralization occurs from about the stratigraphic level of the transition from member B to C upward, stratigraphically, through much of member D.

To test whether tourmaline content could be used as a guide to locating favorable stratigraphic intervals, boron was also analyzed. Boron content, in general, correlates with the cobalt content; it is relatively high (20-300 ppm) in members B, C, and D and much lower in member E. But near the Little No Name Mine, where cobalt content is high, the boron content does not show a significant increase or decrease. Copper values do not show any significant trends. Pb, Zn, and Ag were analyzed because of the lithologic similarity of the Yellowjacket with the Aldridge Formation of Canada in which the Sullivan mine occurs that produces these metals. Ag was not detected in any of the samples of the Yellowjacket. Lead and zinc both show relatively high values in the upper part of member B in the North Fork of Iron Creek (pl.8), and in Panther Creek lead values in that same interval are also relatively high (pl. 6). Extremely high zinc contents were detected in member D between about 2,750 m and 3,100 m of the North Fork of Iron Creek section (pl. 8) where zinc ranges from 150 ppm to 540 ppm. No lithologic explanation was detected in the field for this anomaly.

Regional reconnaissance stream-sediment geochemical data (Broxton, 1979, Broxton and Beyth, 1980) indicate a clear correlation between high values of Co, Bi, Cu, and As, and the distribution of the Yellowjacket Formation (B. R. Berger, unpublished maps and data). These data are all total metal values determined by neutron activation and X-ray florescence methods. A most interesting feature of these data is that a high correlation of these same four elements exists with the distribution of high-grade metasedimentary rocks in which the Salmon Canyon Copper Company deposit occurs (p€gs and p€g on pl. 1). These relations thus appear to substantiate the idea that these metasedimentary rocks may in fact be Yellowjacket Formation metamorphosed to a higher grade. Islands of presumably similar metamorphic rocks farther west along the Salmon River also exhibit the same chemical correlations, and, therefore, also may be part of the Yellowjacket Formation. The importance of these inferences is obvious; the extent of rocks favorable for the occurrence of cobalt mineralization is approximately doubled.

## Origin of the Mineralization

The source of cobalt in all these deposits is yet a problem. Bennett (1977) believes nearby quartz monzonite intrusive rocks ("augen gneiss") could be the source. But Anderson states that these rocks "apparently.... had nothing to do with the mineralization...." (1947 p. 25). Cobalt mineralization occurs in areas far from known intrusive bodies of that kind, as in the Iron Creek drainage.

Mining company geologists working in the area believe that the cobalt in the Yellowjacket is syngenetic in origin. Bennett (1977) also mentioned this possibility. The apparent restriction of cobalt mineralization to rocks of the Yellowjacket Formation and ròcks that are probably higher grade metamorphic equivalents of the Yellowjacket supports this interpretation. Known occurrences of cobalt mineralization, except the North Fork of Iron Creek locality, all exhibit clear structural control of vein-like deposits. The best interpretation based on present knowledge available is that the cobalt was initially deposited as syngenetic mineralization of extremely low grade in the Yellowjacket, but economic deposits occur only where the cobalt was remobilized and concentrated in favorable structurally prepared rock, typically in fault zones.

Because of the nature and time frame of this study, speculation on syngenetic models for the deposition of the metals in the Yellowjacket is difficult.

From discussions with industry geologists, it became apparent that a possible model being considered was one similar to that proposed for the Zambian Copperbelt, presumably because of the association of cobalt with copper.

> "It is considered that [in the Zambian deposits] the various metals were transported into marine waters and eventually concentrated through chemico-bacterial processes in favourably confined basinsat river mouths or gulfs under anaerobic conditions" (Fleischer and others, 1976, p. 241).

Carbon occurs in varying amounts in all the Zambian deposits, indicating a possible biogenic origin. In addition, the association with gypsum and anhydrite indicates that the waters were probably near chemical saturation (Fleischer and others, 1976). The depositional setting, therefore, appears to be nearshore in shallow water, apparently with restricted circulation. A syngenetic model like that proposed for Zambian deposits is not possible for cobalt deposits in the Yellowjacket because of its deep-water depositional setting. A syngenetic model incorporating deep-water sedimentation is possible because reducing environments for the precipitation of the metals would be present. A biogenic influence on the deposition of the metals is unlikely because carbonaceous matter was not detected anywhere in the Yellowjacket. Further work is necessary to understand possible sources of, or feeders for, the mineralizing fluids and to determine within narrower limits favorable zones for mineralization.

## CONCLUSION

The Yellowjacket Formation of east-central Idaho is a 6,500- m to 8,000-m-thick sequence of predominantly medium-gray to dark-gray argillaceous quartzite and sandy or silty argillite. In general, regional metamorphism is in the low greenschist range, and primary sedimentary features are generally easily identifiable.

Neither the base nor the top of the Yellowjacket have ever been observed or reported. The Yellowjacket is in fault contact with older looking, high-grade metasedimentary rocks that occur in the area of the mouth of Panther Creek and farther west along the Salmon River. These rocks may be older than the Yellowjacket or may be metamorphosed Yellowjacket Formation. Younger rocks, the Lemhi Group, Swauger Formation, and Paleozoic formations, always occur in thrust plates above the Yellowjacket in all the region covered during this study.

Five members, A through E, have been distinguished on the basis of a combination of features including, grain size, range in grain size, thickness of graded beds, sedimentary structures, paleocurrent directions, and the proportions of quartzite and argillite within individual graded genetic units.

Member A contains the coarsest grain sizes in all the formation. The rocks are coarse- to medium-grained quartzite that grades upward into fine or very fine grained relatively argillaceous quartzite and locally sandy argillite. These graded beds are 10 cm to 1 m thick. High in the section, member A becomes overall finer grained; very fine and fine-grained argillaceous quartzite becomes predominant and sandy argillite becomes more common. Colors in member A range from light gray to dark gray, darkening both upsection and upward within individual graded beds. The exposed thickness of member A is about 700 m.

Member B is predominantly very fine sand- and silt-size very argillaceous quartzite and siltite. Graded beds are 5 to 50 cm thick. Colors are predominantly medium gray and greenish gray. Characteristic of this unit are beds and laminae of slightly calcareous quartzite and discontinuous lenses, typically less than 15 m thick and 60 m wide, of highly calcareous quartzite (as much as 35 percent calcite). The thickness of member B is about 1,600 m.

Member C is characterized by couplets of light-colored argillaceous quartzite and/or siltstone and dark-colored sandy argillite that occur together in single graded intervals. The quartzite and siltite are arkosic wacke in composition. The graded intervals thicken up-section from a few millimeters at the base to 5-15 cm near the top. Near the base, the ratio of quartzite and siltite to argillite is about 1 and increases to 2 or more at the top. Convolute laminations and "psuedo-mudcracks" are common in this member. Member C is about 1,300 m thick.

Member D is predominantly very fine grained argillaceous quartzite in graded beds 10 cm to about 1 m thick. Grading is exhibited mainly by an increase in the content of clay-size matrix upward, whereas the maximum grain size rarely decreases upward within graded beds. Colors darken upward within graded beds generally from medium gray to dark gray. The thickness of member D is at least 2,500 m and may reach 3,500 m.

Member E contains the least argillaceous rocks. It consists of quartzites that are compositionally subarkose and quartz arenites that grade upward into argillaceos quartzite, compositionally arkosic wacke. Grading is exhibited by an increasing content of argillaceous matrix. The graded beds are, in general, thicker than in the other members and range from 30 cm to 2 m in thickness. Grain sizes are predominantly very fine and fine sand. Colors are light gray to medium dark gray, typically darkening upward within graded beds. The thickness of member E is probably at least 1,000 m.

A minimum age of 1.4 b.y. for the Yellowjacket Formation is provided by radiometric dates from several large porphyritic quartz monzonite plutons that intrude it. No data is available for its maximum age, except that by comparison with the Prichard Formation of the Belt Supergroup, it should be younger than about 1.76 b.y.

The Yellowjacket Formation is interpreted as a deep-marine turbidite sequence on the basis of the presence of a significant number of features characteristic of turbidites and their internal organization, in general, consistent with the Bouma model. In addition, no shallow-water features were observed within the Yellowjacket. The formation's great thickness and monotonous sequence of alternating argillaceous quartzite and sandy argillite are also consistent with this interpretation. The original extent of the Yellowjacket depositional basin must have been much greater than its present preserved distribution because all the preserved lithologies indicate deposition in the distal parts of subsea-fan depositional systems, and no facies trends indicate approach of a depositional edge. The Beaverhead Divide-Miner Lake Fault zone now forms the eastern limit of Yellowjacket outcrop and the Yellowjacket was eroded from the eastern uplifted block in pre-Missoula Group time, because the Yellowjacket is not present beneath the Missoula Group in southwest Montana. Where the Missoula Group is absent, Cambrian Flathead Sandstone was deposited directly on Archean crystalline basement.

The Yellowjacket Formation occurs within a tectonic feature called the Lemhi Arch (Salmon River Arch of Armstrong, 1975; and Belt Island of Harrison and others, 1974). This arch formed as a structural inversion of the thick prism of Yellowjacket sediment and has controlled depositional patterns of all post-Yellowjacket Precambrian and Paleozoic sedimentary rocks.

Noteworthy of the structure of the region are many old faults that have moved recurrently and have influenced the structural development of the region, in many cases, into Holocene time. The most important fault trends are northeast, northwest, and north. Many of these faults have controlled intrusive contacts, vein-type mineral deposits, and the development of modern drainages. Many of these faults, especially the northeast trending ones, are marked by pronounced topographic lineaments.

The Beaverhead Divide-Miner Lake fault zone, the northeast boundary of Yellowjacket distribution, had normal movement in pre-Missoula Group time and has had post-Medicine Lodge thrust reverse movement, which probably has continued into the Quaternary as indicated by the dramatic physiographic differences across the Montana-Idaho border in this area. The Big Deer Creek and Shoup-Hot Springs Fault zones separate distinctly different packages of rocks; south of these faults are the Yellowjacket Formation and nearly unmetamorphosed 1.4-b.y.-old porphyritic quartz monzonite intrusive rocks; north of these faults are distinctly higher grade metasedimentary rocks and augen gneisses and associated rocks that have apparently been faulted up from a much deeper structural level.

Recent economic interest in the Yellowjacket Formation is a result of the occurrence of cobalt and copper-cobalt mineralization. Chemical and stratigraphic data indicate that members B, C, and D are probably all equally favorable units for cobalt mineralization. Stream-sediment samples from drainage areas of metasedimentary rocks northwest of the Big Deer Creek and Shoup-Hot Springs Fault zones exhibit anomalies in Cu, Co, As, and Bi similar to those present in areas underlain by rocks that clearly are part of the Yellowjacket Formation. Therefore, these rocks also appear to be favorable areas for discovery of cobalt mineralization, and, in fact, may be higher grade metamorphic equivalents of the Yellowjacket. Known deposits, like the Blackbird deposit, clearly are vein deposits controlled by fractured and sheared zones along faults, but the cobalt, and possibly the copper as well, was probably derived from syngenetic low-grade mineralization distributed through much of the Yellowjacket. The syngenetic origin is suggested by the restricted occurrence of cobalt in rocks of the Yellowjacket and the widespread cobalt content of Yellowjacket rock samples ranging from 10 to 30 ppm. But clearly, ore deposits will be found only where the cobalt has been remobilized and concentrated in favorable structurally prepared rock, as along fault zones.

## RECOMMENDATIONS FOR FUTURE WORK

Because of the economic importance of the Yellowjacket Formation, the most important further work to be done is geochemical evaluation aimed at the identification of stratigraphic intervals favorable for cobalt mineralization within narrower limits than are presented here. Sampling should be done at closer stratigraphic intervals than was done in this study. In addition, an attempt should be made to differentiate between lithologic variations present in the Yellowjacket. That is, argillite, argillaceous quartzite, and quartzite should be sampled and analyzed separately. But sampling will be difficult because of gradational relationships of these three predominant lithologies. Perhaps correlations between trace-element content and content of argillaceous material in the rock samples can be utilized instead.

Reconnaissance rock geochemistry of the metasedimentary rocks present along the Salmon River is needed to test the suggestion in this report that they may also be favorable host rocks for cobalt mineralization.

As is obvious from the present status of geologic mapping, much detailed geologic mapping is needed to further refine the stratigraphy of the Yellowjacket Formation presented here and to more completely understand the structural geology of the region.

References Cited


Anderson, A. L., 1943, A preliminary report on the cobalt deposits in the Blackbird District, Lemhi County, Idaho: Idaho Bureau of Mines and Geology Pamphlet 61, 34 p.

_____1947, Cobalt mineralization in the Blackbird District, Lemhi County, Idaho: Economic Geology v. 42, p. 22-46.

_____1956, Geology and mineral resources of the Salmon quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines Geology Pamphlet 106, 102 p.

_____1957, Geology and mineral resources of the Baker quadrangle, Lemhi County Idaho: Idaho Bureau of Mines Geology Pamphlet 112, 71 p.

_____1959, Geology and mineral resources of the North Fork quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines Geology Pamphlet 118, 92 p.

_____1961, Geology and mineral resources of the Lemhi quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines Geology Pamphlet 124, 111 p.

Armstrong, R. L., 1975, Precambrian (1500 m.y. old) rocks of central Idaho--The Salmon River Arch and its role in Cordilleran sedimentation and tectonics: American Journal of Science, v. 275-A. p. 437-467.

Armstrong, R. L., Taubeneck, W. H., and Hales, P. O., 1977, Rb-Sr geochronology of Mesozoic granitic rocks and their Sr-isotope composition, Oregon, Washington, and Idaho: Geological Society of America Bulletin, v. 88, p. 397-411.

Bailey, E. B., 1930, New light on sedimentation and tectonics: Geology Magazine v. 67, p. 77-92.

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

Blake, M. C., Jr., Campbell, R. H., Dibblee, T. W., Jr., Howell, D. G., Nilsen, T. H., Normark, W. R., Vedder, J. C., and Silver, E. A., 1978, Neogene basin formation in relation to plate-tectonic evolution of San Andreas Fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, p. 344-372.

Bouma, A. H., 1962, Sedimentology of some flysch deposits; A graphic approach to facies interpretation: Amsterdam, Elsevier Publishing Co., 159 p.

_____ 1972, Recent and ancient turbidites and contourites: Gulf Coast Association Geological Society Transactions, v. 22, p. 205-221.

Bramlette, M. N., and Bradley, W. H., 1940, Geology and biology of North Atlantic deep-sea cores between New Foundland and Ireland, Part 1; Lithology and geologic interpretations: U.S. Geological Survey Professional Paper 196-A, p. 1-34.

Brown, D. C., and Beutner, E. C., 1973, Fold geometry in the Salmon, Idaho area: Geological Society of America Abstracts with Programs, v. 5, no. 2, p. 468.

Broxton, D. E., 1979, Uranium hydrogeochemical and stream sediment reconnaissance of the Dillon NTMS quadrangle, Montana/Idaho, including concentrations of forty five additional elements: U.S. Department of Energy, Grand Junction, Colo., GJBX--38(79), 228 p.

Broxton, D. E., and Beyth, Michael, 1980, Uranium hydrogeochemical and stream sediment reconnaissance data release for the Elk City NTMS quadrangle, Idaho/Montana, including concentrations of forty five additional elements: U.S. Department of Energy, Grand Junction, Colo., GJBX-176(80), 212 p.

Burchfiel, B. C., and Davis, G. A., 1975, Nature and controls of Cordilleran orogenies, western United States: Extensions of an earlier synthesis: American Journal of Science, v. 275A, p. 363-396.

Burke, K., and Dewey, J. F., 1973, Plume generated triple junctions; Key indicators in applying plate tectonics to old rocks: Journal of Geology, v. 81, p. 406-433.

Canney, F. C., Hawkes, H. E., Richmond, G. M., and Vhay, J. S., 1953, A preliminary report of geochemical investigations in the Blackbird District: U.S. Geological Survey Open-file report, 20 p.

Cater, F. W., Pinckney, D. M., Hamilton, W, S., Parker, R. L., Weldin, R. D., Close, T. J., Zilka, N. T., Leonard, B. E., and Davis, W. E., 1973, Mineral resources of the Idaho Primitive Area and vicinity: U.S. Geological Survey Bulletin 1304, 431 p.

Cater, F. W., Pinckney, D. M., and Stotemeyer, R. B., 1975, Mineral resources of the Clear Creek-Upper Big Deer Creek study area, contiguous to the Idaho Primitive Area, Lemhi County, Idaho: U.S. Geological Survey Bulletin 1391-C, 41 p.

Churkin, Michael, Jr., and Trexler, J. H., 1979, Comment on "The Siberian connection; A case for Precambrian separation of the North American and Siberian cratons": Geology, v. 7, p. 467-469.

Crosby, G. W., 1973, The mechanical significance of deformation within overthrust plates: Brigham Young University Geological Studies, v. 20, pt. 4, p. 117-136.

Crowell, J. C., 1974, Origin of Late Cenozoic basins in southern California, in Dickinson, W. R. , ed., Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22, p. 190-204.

Enos, Paul, 1969, Anatomy of a flysch: Journal of Sedimentary Petrology, v. 39, p. 680-723.

Fleischer, V. D., Garlick, W. G., and Haldane, R., 1976, Geology of the Zambian Copperbelt: in Wolf, K. H., ed., Handbook of strata-bound and stratiform ore deposits, v. 6, p. 223-352.

Friedman, G. M., 1958, Determination of sieve-size distribution from thin-section data for sedimentary petrological studies: Journal of Geology, v. 66, p. 394-416.

Gabrielse, Hubert, 1972, Younger Precambrian of the Canadian Cordillera: American Journal of Science, v. 272, p. 521-536.

Ghibaudo, Guido, 1980, Deep-sea fan deposits in the Macigno Formation (Middle-Upper Oligocene) of the Gordana Valley, Northern Appennines, Italy: Journal of Sedimentary Petrology, v. 50, p. 723-742.

Grimes, D. J., and Marranzino, A. P., 1968, Direct current arc and alternating current spark emission spectrographic field methods for the semiquantitative analysis of geologic materials: U.S. Geological Survey Circular 59, 6 p.

Haner, B. E., 1971, Morphology and sediments of Redondo submarine fan, southern California: Geological Society of America Bulletin, v. 82, p. 2413-2432.

Harms, J. C., and Fahnestock, R. K., 1965, Stratification, bed forms, and flow phenomena (with an example from the Rio Grande): Society of Econonic Paleontologists and Mineralogists Special Publication 12, p. 84-115.

Harrison, J. E., Griggs, A. B., and Wells, J. D., 1974, Tectonic features of Precambrian Belt Basin and their influence on post-Belt structures: U.S. Geological Survey Professional Paper 866, 15 p.

Harrison, J. E., and Grimes, D. J., 1970, Mineralogy and geochemistry of some belt rocks, Montana and Idaho: U.S. Geological Survey Bulletin 1312-O, 49 p.

Idaho Department of Water Resources, 1980, Geothermal Resources of Idaho.

James, H. L., and Hedge, C. E., 1980, Age of the basement rocks of southwest Montana: Geological Society of America Bulletin, pt. 1, v. 91, p. 11-15.

Kaiser, E. P., 1956, Preliminary report on the geology and deposits of monazite, thorite, and niobium-bearing rutile of the Mineral Hill District, Lemhi County, Idaho: U.S. Geological Survey Open-file report, 43 p.

Khain, V. E., and Seslavinsky, K. B., 1979, Comment on "The Siberian connection; A case for Precambrian separation of the North American and Siberian cratons": Geology, v. 7, p. 466-467.

Kuenen, Ph. H., 1937, Experiments in connection with Daly's hypothesis on the formation of submarine canyons: Leidse Geol. Mededel., v. 8,p. 327-335.

_____ 1950, Turbidity currents of high density: International Geologic Congress 18th London, 1948 Report., v. 8, p. 44-52.

_____1957, Sole markings of graded graywacke beds: Journal of Geology, v. 65, p. 231-258.

_____ 1964, Deep-sea sands and ancient turbidites, in Bouma, A. H., and Brouwer, Aart, Turbidites, Developments in sedimentology no. 3: Amsterdam, Elsevier Publishing Co., p. 3-33.

Kuenen, Ph. H., and Migliorini, C. I., 1950, Turbidity currents as a cause of graded bedding: Journal of Geology, v. 58, p. 91-127.

Mackenzie, W. O., 1949, Geology and ore deposits of a section of the Beaverhead Range east of Salmon, Idaho: University of Idaho, Moscow, unpub. M.S. thesis, 65 p.

Maley, T. S., 1974, Structure and petrology of the lower Panther Creek area, Lemhi County, Idaho: University of Idaho, Moscow, Ph. D. thesis, 175 p.

McMannis, W. J., 1963, LaHood Formation--A coarse facies of the Belt Series in southwestern Montana: Geological Society of America Bulletin, v. 74, p. 407-436.

The Mining Record, 1981, Noranda considers site for cobalt recovery: Denver, Colorado, The Mining Record, Jan. 28, 1981, v. 93, p. 1.

Monger, J. W. H., Souther, J. G., and Gabrielse, Hubert, 1972, Evolution of the Canadian Cordillera; A plate tectonic model: American Journal of Science, v. 272, p. 577-602.

Motooka, J. M., and Grimes, D. J., 1976, Analytical precision of one-sixth order semiquantitative spectrographic analyses: U.S. Geological Survey Circular 738, 25 p.

Mutti, Emiliano, 1977, Distinctive thin-bedded turbidite facies and related depositional environments in the Eocene Hecho Group (South-central Pyrenees, Spain): Sedimentology, v. 24, p. 107-131.

Mutti, Emiliano, and Ricci-Lucchi, F., 1972, Le Torbiditi dell′ Appennino settentrionale: Introduzione all′ analisi di facies: Mem. Soc. Geol. Italia, v. 11, p. 161-199.

Normark, W. R., 1970, Growth patterns of deep-sea fans: American Association of Petroleum Geologists Bulletin, v. 54, p. 2170-2195.

_____ 1978, Fan valleys, channels, and depositional lobes on modern submarine fans; Characters for recognition of sandy turbidite environments: American Association of Petroleum Geologists Bulletin, v. 62, p. 912-931.

Pettijohn, F. J., and Potter, P. E., 1964, Atlas and glossary of primary sedimentary structures: New York, Springer-Verlag, 370 p.

Pettijohn, F. J., Potter, P. E., and Sevier, Raymond, 1972, Sand and sandstone: New York, Springer-Verlag, 618 p.

Purdue, G. L., 1975, Geology and ore deposits of the Blackbird District, Lemhi County, Idaho: Univ. New Mexico, Albuquerque, M.S. thesis, 49 p.

Raleigh, C. B., and Griggs, D. T., 1963, Effect of the toe in the mechanics of overthrust faulting: Geological Society of America Bulletin, v. 74, p. 819-830.

Reading, H. G., 1978, Sedimentary environments and facies: Oxford, Blackwell Press, 557p.

Reid, R. R., 1957, Bedrock geology of the north end of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines Geology Memoir 36, 27p.

Reynolds, M. W., 1977, Character and significance of deformation at the east end of the Lewis and Clark Line, Montana: Geological Society of America Abstracts with Programs, v. 9, p. 758-759.

Reynolds, M. W., and Kleinkopf, M. D., 1977, The Lewis and Clark Line, Montana-Idaho; A major intraplate tectonic boundary: Geological Society of America Abstracts with Programs, v. 9, p. 1140-1141.

Ross, C. P., 1925, The copper deposits near Salmon, Idaho: U.S. Geological Survey Bulletin 774, 44 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 Geology Pamphlet 125, 125 p.

Ross, C. P., and Forrester, J. R., 1946, Geologic map of the state of Idaho: U.S. Geological Survey and Idaho Bureau of Mines and Geology.

Ruppel, E. T., 1964, Strike-slip faulting and broken basin-ranges in east-central Idaho and adjacent Montana: U.S. Geological Survey Professional Paper 501-C, p. C14-C18.

_____ 1968, Geologic map of the Leadore quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-733.

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

_____ 1978, Medicine Lodge thrust system, east-central Idaho and southwest Montana: U.S. Geological Survey Professional Paper 1031, 23 p.

_____ 1980, Geologic map of the Patterson Quadrangle, Lemhi County, Idaho: U. S. Geological Survey Geologic Quadrangle Map GQ-1529.

_____ 1981 (in press), Cenozoic block uplifts in southwest Montana and east-central Idaho: U.S. Geological Survey Professional Paper 1224.

Ruppel, E. T., and Lopez, D. A., 1981 (in press), Geologic map of the Gilmore Quadrangle, Lemhi and Custer Counties, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1543.

Ruppel, E. T., Lopez, D. A., and Meyers, W. B., 1981 (in press), The thrust belt in southwest Montana and east-central Idaho: U.S. Geological Survey Professional Paper.

Sanders, J. E , 1960, Origin of convoluted laminae: Geology Magazine, v. 97, p. 409-421.

Shockey, P. N., 1957, Reconnaissance geology of the Leesburg quadrangle, Lemhi County, Idaho: Idaho Bureau of Mines Geology Pamphlet 113, 42 p.

Sears, J. W., and Price, R. A., 1978, The Siberian connection; A case for Precambrian separation of the North American and Siberian cratons: Geology, v. 6, p. 267-270.

_____ 1979, Reply on "The Siberian connection; A case for Precambrian separation of the North American and Siberian cratons": Geology, v. 7, p. 467.

Sestini, G., 1970, Vertical variation in flysch turbidite sequences; a review: Journal of Earth Science, v. 8, p. 15-30.

Simons, D. B., Richardson, E. V., and Nordin, C. F., 1965, Sedimentary structures generated by flow in alluvial channels: Society of Economic Paleontologists Mineralogists Special Publication 12, p. 34-52.

Sloss, L. L., 1954, Lemhi arch, a mid-Paleozoic positive elment in south-central Idaho: Geological Society of America Bulletin, v. 65, p. 365-368.

Smith, J. G., 1965, Fundamental transcurrent faulting in the northern Rocky Mountains: American Association of Petroleum Geologists Bulletin, v. 49, p. 1398-1409.

Staatz, M. H., 1972, Geology and description of the thorium-bearing veins, Lemhi Pass Quadrangle, Idaho and Montana: U.S. Geological Survey Bulletin 1351, 94 p.

_____ 1973, Geologic map of the Goat Mountain Quadrangle, Lemhi County, Idaho and Beaverhead County, Montana: U.S. Geological Survey Quadrangle Map GQ-1097.

_____ 1979, Geology and mineral resources of the Lemhi Pass thorium district, Idaho and Montana: U.S. Geological Survey Professional Paper 1049-A, 90 p.

Stewart, J. H., 1972, Inital deposits in the Cordilleran geosyncline: Evidence of a late Precambrian (<850 m.y.) continental separation: Geological Society of America Bulletin, v. 83, p. 1345-1360.

Umpleby, J. B., 1913, Geology and ore deposits of Lemhi County, Idaho: U.S. Geological Survey Bulletin 528, 182p.

U.S. Geological Survey, 1964, Mineral and water resources of Idaho: Washington D. C., U.S. Government Printing Office.

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, 26p.

Walker, R. G., 1965, The origin and significance of the internal sedimentary structures of turbidites: Proceedings Yorkshire Geological Society, v. 35, pt. 1, no. 1, p. 1-32.

_____ 1967, Turbidite sedimentary structures and their relationship to proximal and distal depostional environments: Journal of Sedimentary Petrology, v. 37, p. 25-43.

_____ 1978, Deep-water sandstone facies and ancient submarine fans; Models for exploration for stratigraphic traps: American Association of Petroleum Geologists Bulletin, v. 62, p. 932-966.

_____ 1979, Facies models: Turbidites and associated coarse clastic deposits, in Walker, R. G., ed., Facies models: Geoscience Canada Reprint Series 1, p. 91-103.

Wallace, R. E., Griggs, A. B., Campbell, A. B., and Hobbs, S. W., 1960, Tectonic setting of the Coeur d'Alene district, Idaho: U.S. Geological Survey Professional Paper 400-B, p. 25-27.

Ward, F. N., Nakagawa, H. M., Harm, T. F., and Van Sickle, G. H., 1969, Atomic absorption methods of analysis useful in geochemical exploration: U.S. Geological Survey Bulletin 1289, p. 20-22.

Weis, P. L., Schmitt, L. J., Jr., Tuchek, E. T., and Davis, W. E., 1972, Mineral resources of the Salmon River Breaks Primitive Area, Idaho: U.S. Geological Survey Bulletin 1353-C, 91 p.

Young, G. M., Jefferson, C. W., Delaney, G. D., and Yeo, G. M., 1979, Middle and Late Proterozoic evolution of the northern Canadian Cordillera and shield: Geology, v. 7, p. 125-128.

APPENDIX I

# DESCRIPTIONS OF THE YELLOWJACKET BY AREA AND MEASURED SECTION

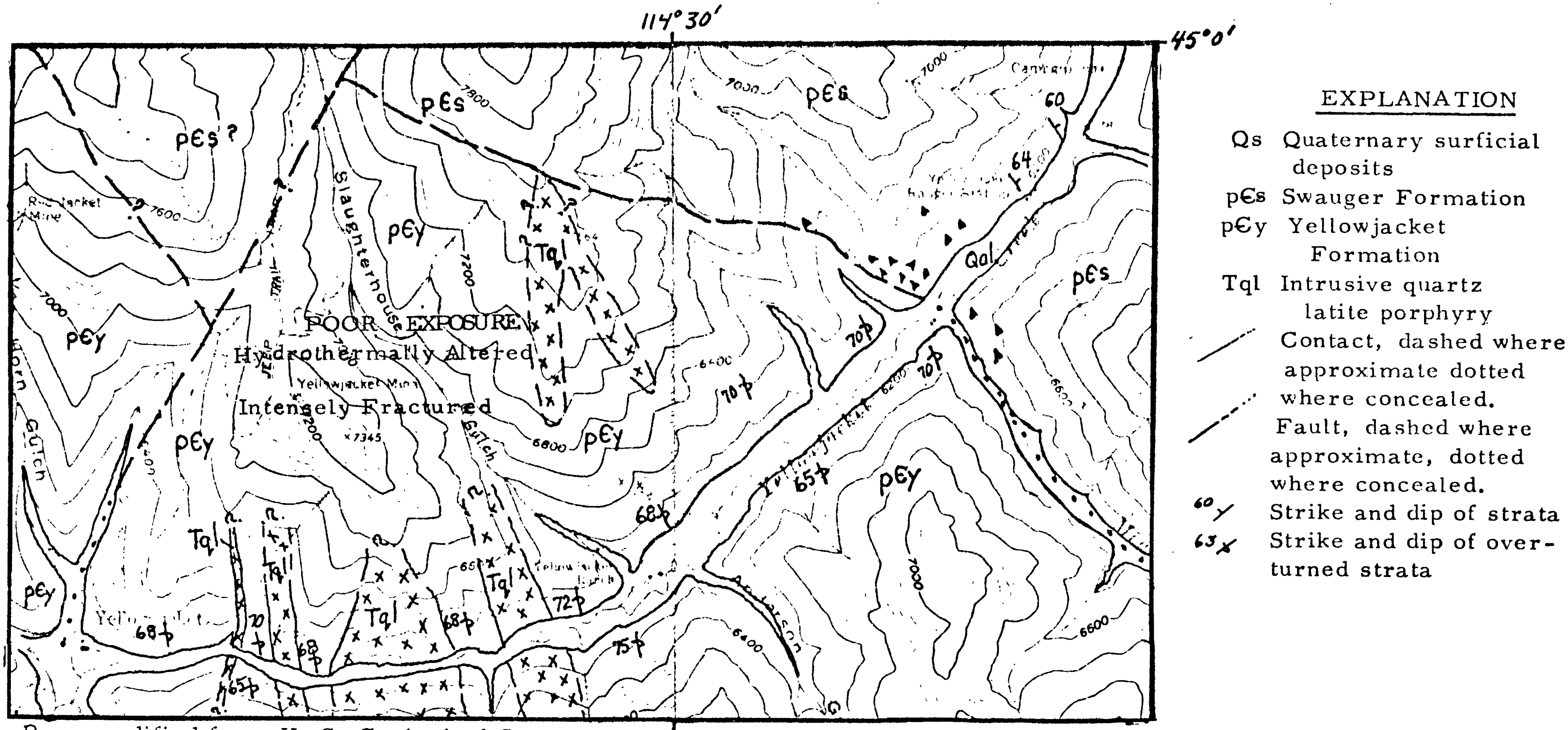
## Yellowjacket Area

Ross named the Yellowjacket Formation after the town and mining district of Yellowjacket (1934). He measured a reference section along Yellowjacket Creek extending upstream from the Yellowjacket mill a distance of about 7.5 km (table 1, p. 9). The area of Ross' measured section is not a favorable location for stratigraphic study; exposures are poor, several thick dikes intrude the Yellowjacket, and two major faults cut the section (fig. 44). For about 4 km Ross' section is in Yellowjacket rocks, but for approximately the next 2 km his section is in rocks of the Swauger Formation (Ross called these Hoodoo Quartzite). At about 6 km from the Yellowjacket Mill rocks of the Yellowjacket Formation are again found (Ross' distinctly banded gray, somewhat calcareous quartzite).

I measured and described the lower part of Ross' section along Yellowjacket Creek between the Yellowjacket Mill and the first fault present upstream (fig. 44 and measured section 1). The entire section is overturned, but strikes and dips are reasonably uniform. Therefore, the section does not appear to be significantly disrupted by folding or faulting, although exposures are too poor to be certain. Due to the inadequacy of exposure the detail of this section is not comparable to that of other measured sections. Rocks in this section are part of member B.

As described by Ross, this section contains numerous calcareous lenses interbedded with argillaceous quartzite and argillite. The calcareous lenses are usually thinner than 15 m and pinch out laterally within 60 to 70 m.

The calcareous lenses are calcareous quartzite with interlaminae of dark gray (N4) argillite. Ross' description of the three main variations is accurate: 1) banded rocks with closely spaced irregular dark-green, black and




Base modified from U. S. Geological Survey 1:24,000 Yellowjacket (1963) and Duck Creek Point (1963), Idaho

Geology by D.A. Lopez, 1979 and from Ross (1934)

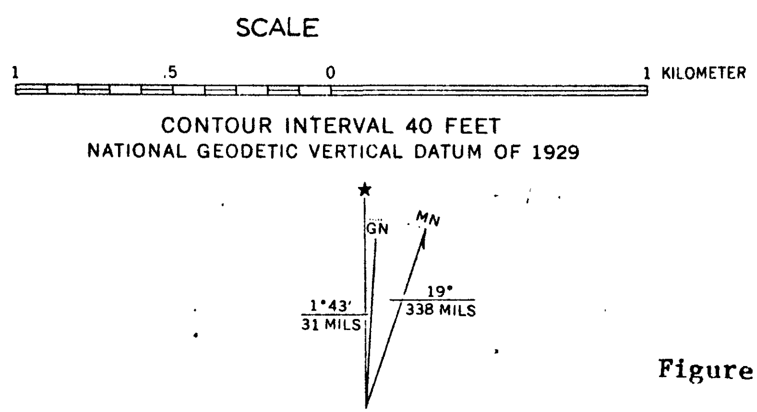



Figure 44.--Geologic map of the Yellowjacket area.

gray laminae, 2) nearly white rocks mottled with dark clusters of metamorphic minerals, and 3) quartzite typical of the Yellowjacket elsewhere but with varying amounts of calcareous material. The dominant constituent of all these variations is quartz (Ross, 1934, p. 17-18). Some of the most calcareous rocks have a pisolitic-like texture that is interpreted as incipient formation of porphyroblasts. These porphyroblasts are large crystals of scapolite choked with inclusions of quartz and feldspar. The dark-colored laminae and clusters of metamorphic minerals spoken of above are recrystallized and metamorphosed argillite laminae.

The stratigraphically lowest rocks exposed in this section are medium gray (N5) to dark-gray (N3) quartzites that range in grain size from silt to very fine sand. These quaratzites are in graded beds 3-35 cm thick. Ripple cross-laminations and parallel laminations are the most common sedimentary structures. The thickness and number of calcareous beds increase upward as these rocks grade upward into the most calcareous beds (measured section 1).

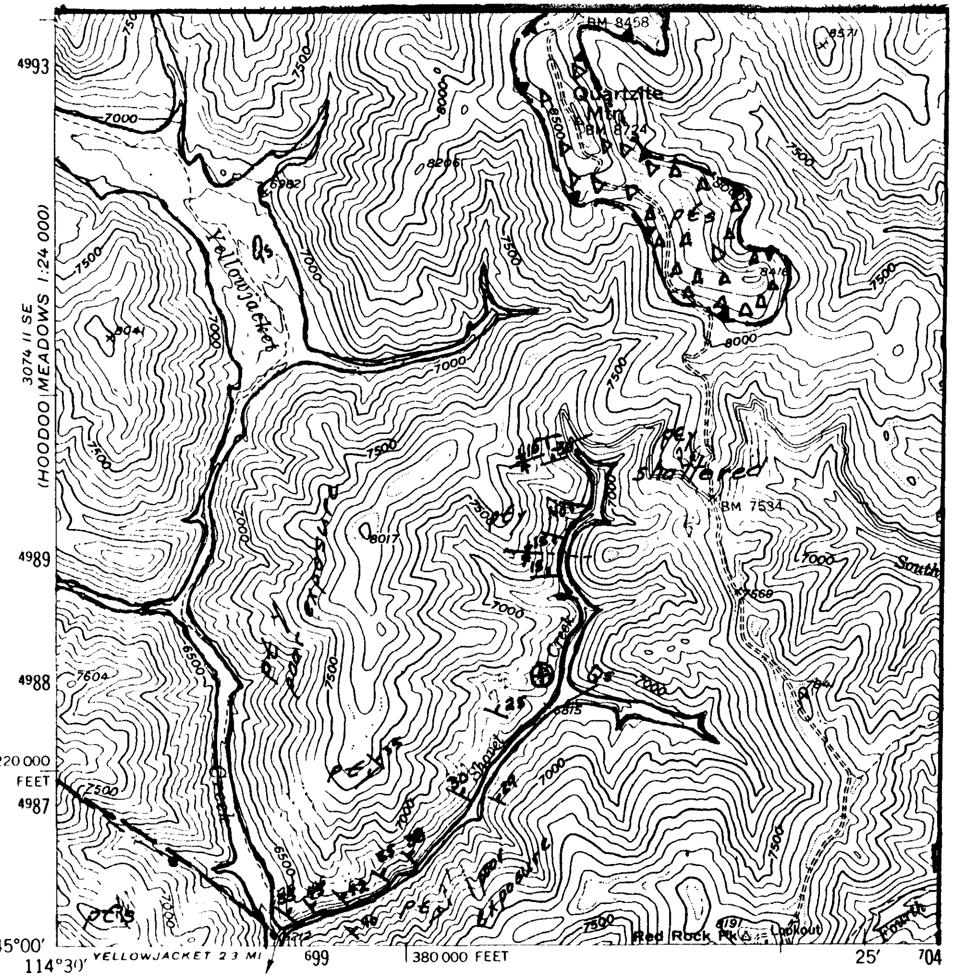
Several quartz latite porphyry dikes intrude the section, the cumulative thickness of which is about 880 m.

## Shovel Creek Section

The rocks exposed in this section are the stratigraphically lowest observed in the Yellowjacket to date. The lower contact is a fault contact against the Precambrian Swauger Formation (fig. 45). Ross′ measured section along Yellowjacket Creek reached these rocks, which he called "distinctly banded gray, somewhat calcareous quartzite" (1934, p. 16). He apparently did not consider these rocks to be part of the Yellowjacket Formation. The coarsest grained sands observed in the Yellowjacket are in the stratigraphically lowest beds of this section. All this section is within member A of the composite Yellowjacket section.

The section was measured from the junction of Shovel and Yellowjacket Creeks up Shovel Creek, a distance of about 3 km. At this point the attitude of the strata changes dramatically and the Yellowjacket is folded into a series of several open folds of low amplitude (fig. 45). Exposures are scattered in this zone, but the stratigraphic level of the rocks exposed along the road appears to change little as one travels toward the Shovel Creek-Porphyry Creek divide. Near that summit, the Yellowjacket becomes intensely shattered due to the proximity of a thrust plate of Swauger Formation in the Quartzite Mountain area (fig. 45).

The measured thickness of the Shovel Creek section is about 668 m (measured section 2). The coarsest and some of the least argillaceous quartzites in the Yellowjacket are in the lowest strata of this section (pl. 4). Colors are typically from light gray (N7) to medium gray (N5). These rocks from graded beds 5 cm to 1 m thick; grading is from coarse to medium sand at the base to fine sand and rarely very fine sand at the top of the graded bed. The coarsest, least argillaceous quartzites are arenites plotting in the subarkose field of figure 2 (fig. 5). The matrix content in these quartzites is from 10 to 13 percent. The tops of the graded units are more argillaceous quartzites and are compositionally arkosic wackes. Up section the rocks become overall finer, and all can be classified as arkosic wacke (fig. 5). Also up-section, colors become darker, reaching dark gray (N3), and sandy argillite laminae become increasingly abundant at the tops of graded intervals. The matrix content of these dirtier rocks ranges from 15 to 56 percent. As elsewhere in the Yellowjacket, lithic fragments are rare.




Base from U. S. Geol. Survey
1:62500 Blackbird Mtn., Idaho, 1950

Geology by D. Lopez, 1979

## EXPLANATION

Qs Quaternary surficial deposits

pЄs Swauger Formation

pЄy Yellowjacket Formation

Contact, dashed where approximate

Fault, dashed where approximate, dotted where concealed

Thrust Fault, dashed where approximate teeth on upper plate

Breccia

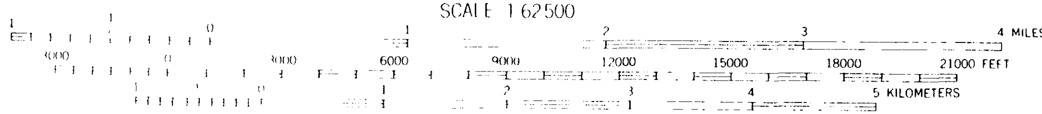
Strike and dip of inclined bedding

Horizontal bedding

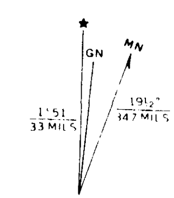
Trace of axial surface of syncline

Figure 45. Geologic Map of the Shovel Creek Area

SCALE 1:62500




CONTOUR INTERVAL 100 FEET
DOTTED LINES REPRESENT HALF-INTERVAL CONTOURS
DATUM IS MEAN SEA LEVEL




UTM GRID AND 1950 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

Quartz makes up 50 to 80 percent of the quartzites; feldspar ranges from 5 to 15 percent; muscovite and sericite from 4 to 25 percent; biotite from about 2 to 16 percent. Other minerals commonly present in trace amounts are opaque minerals, zircon, tourmaline, garnet, and epidote. Zircon, tourmaline, and garnet are of detritial origin. Some strata in the upper part of the section contain small amounts of calcareous material. Biotite, muscovite, and epidote are metamorphic in origin.

Parallel laminations are the most common sedimentary structures. Ripple cross-laminations in trough-shaped sets typically less than 5 cm thick are also quite common. In a only a few exposures were standing ripples were observed. Tops of graded beds and laminae are typically scoured to varying degrees during the emplacement of the next overlying bed.

## Panther Creek Section

This section was measured and studied from just south of Moyer Creek to just north of the Blackbird Creek-Panther Creek junction (pl. 5). Stratigraphic study of the Yellowjacket along Panther Creek is complicated by the presence of several faults and isoclinal overturned folds. Repetition of the section across the faults and the folds is significant; typically 500 m to 1,000 m of the section is repeated. The section measured was restricted to exposures in the canyon of Panther Creek and everywhere on the southwest side of the Panther Creek Fault (pl. 5). Outside the steep walls of the canyon rocks are deeply weathered and exposures are sparse, making stratigraphic study nearly impossible. Most of member B, all of member C, and a part of member D occur in this section (pl. 6 and measured section 3).

The section begins about 1,000 m southwest of the Moyer Creek-Panther

Creek junction on the southeast side of Panther Creek but west of the Panther Creek Fault. These stratigraphically lowest rocks are faulted against Challis Volcanics and in part are covered by landslide deposits. The section is continuous to a point just northeast of McDonald Gulch where a fault repeats the section (pl. 5).

The most argillaceous rocks found anywhere in the Yellowjacket are in the lower part of the Panther Creek section (member B). Argillaceous quartzite and siltite make up about 80 percent of the total and are arkosic wackes with from 32 to 67 percent matrix (fig. 46). Graded beds are 5 to 20 cm thick. The finest material at tops of graded beds is mudstone in composition. Colors in this part of the section are medium gray (N5) to greenish gray (5GY6/1) to brownish gray (5YR4/1). Many beds, especially the coarsest and brownish ones, are calcareous. Calcareous beds as described in the Yellowjacket Creek Section are uncommon here, but are present nearby and pinch out before reaching the line of section. This lower part of the section, member B, is about 935 m thick. The upper contact is gradational into overlying member C. In the transition, dark-gray argillite becomes increasingly abundant and the greenish-gray mudstones become less abundant. The contact is placed where argillite at the tops of graded beds and sand and silts are present in about equal amounts.

The distinctive characteristics of member C are the predominantly gray colors, from medium gray (N5) to dark gray (N3), and the ubiquitous presence of distinct argillite laminae at the tops of graded beds. The argillite laminae are sandy and have the darkest colors (dark gray, N3). In the lower part of the unit, the graded intervals are 1 cm or less in thickness; up-section the thickness increases from to 5 to 15 cm. The amount of argillite decreases upward from about 50 percent near the base to about 20 percent near

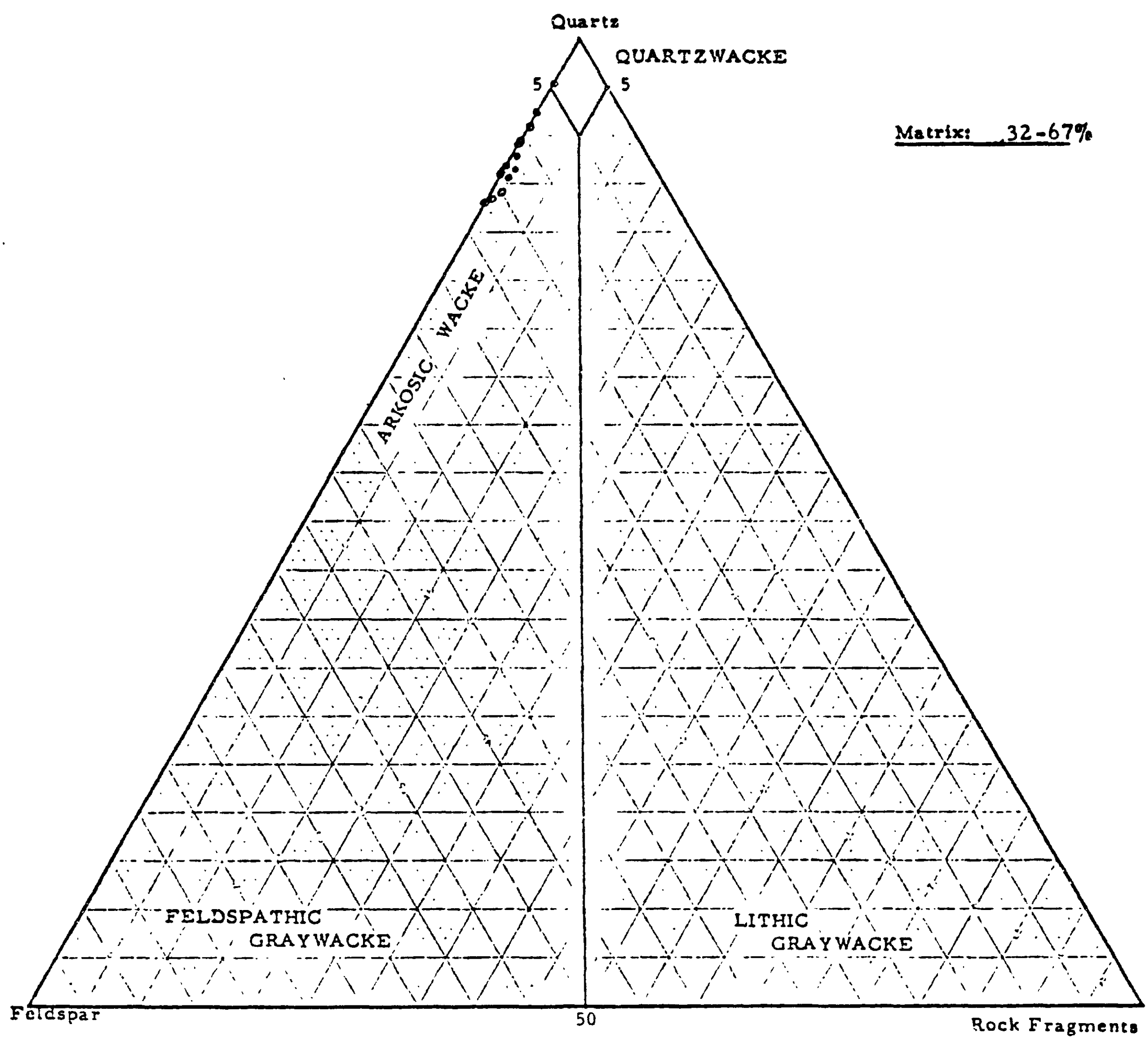



Figure 46.--Composition of quartzites, Panther Creek Section, member B, Yellowjacket Formation.

the top. The coarsest fractions increase in average grain size upward within graded beds or laminae; near the base, silt and very fine sand are about equally abundant, but higher in the section very fine sand becomes predominant. The composition of the quartzite and siltite is shown in figure 47; all samples are arkosic wacke. Parallel laminations are the predominant sedimentary structures present. Ripple cross-laminations are common, as are convolute laminations and load structures. Cut-and-fill structures are also common at bases of graded intervals. "Pseudo-mudcracks" are common in this part of the section; these are in reality the bedding-surface expression of convolute laminations and of various load structures.

The fault along Panther Creek just north of McDonald Gulch (pl. 5) causes repetition of the section; across this fault, rocks of the upper part of member B are present and grade upward into rocks of member C. About 700 m north of the fault is a zone containing two overturned synclines and two overturned anticlines. These cause various parts of the section above and below the member B-member C transition to be repeated to varying degrees. The upward progression of the section resumes past this zone of tight folding, where rocks of member C can be observed grading upward into member D. Upward in member C, the thickness of the quartzite and/or siltite fraction of graded units increases relative to that of the argillite, until in member D graded beds have no distinct argillite tops but only become darker and increasingly argillaceous upward; that is, the quartzites contain increasing amounts of argillaceous matrix upward in individual graded beds. The thickness of member C along Panther Creek is about 1,175 m.

The contact between members C and D is placed about 700 m southwest of the Copper Creek Ranger Station (main office) (pl. 5). The location of the contact is approximate, as the change from member C to D is gradational

through Figure 47

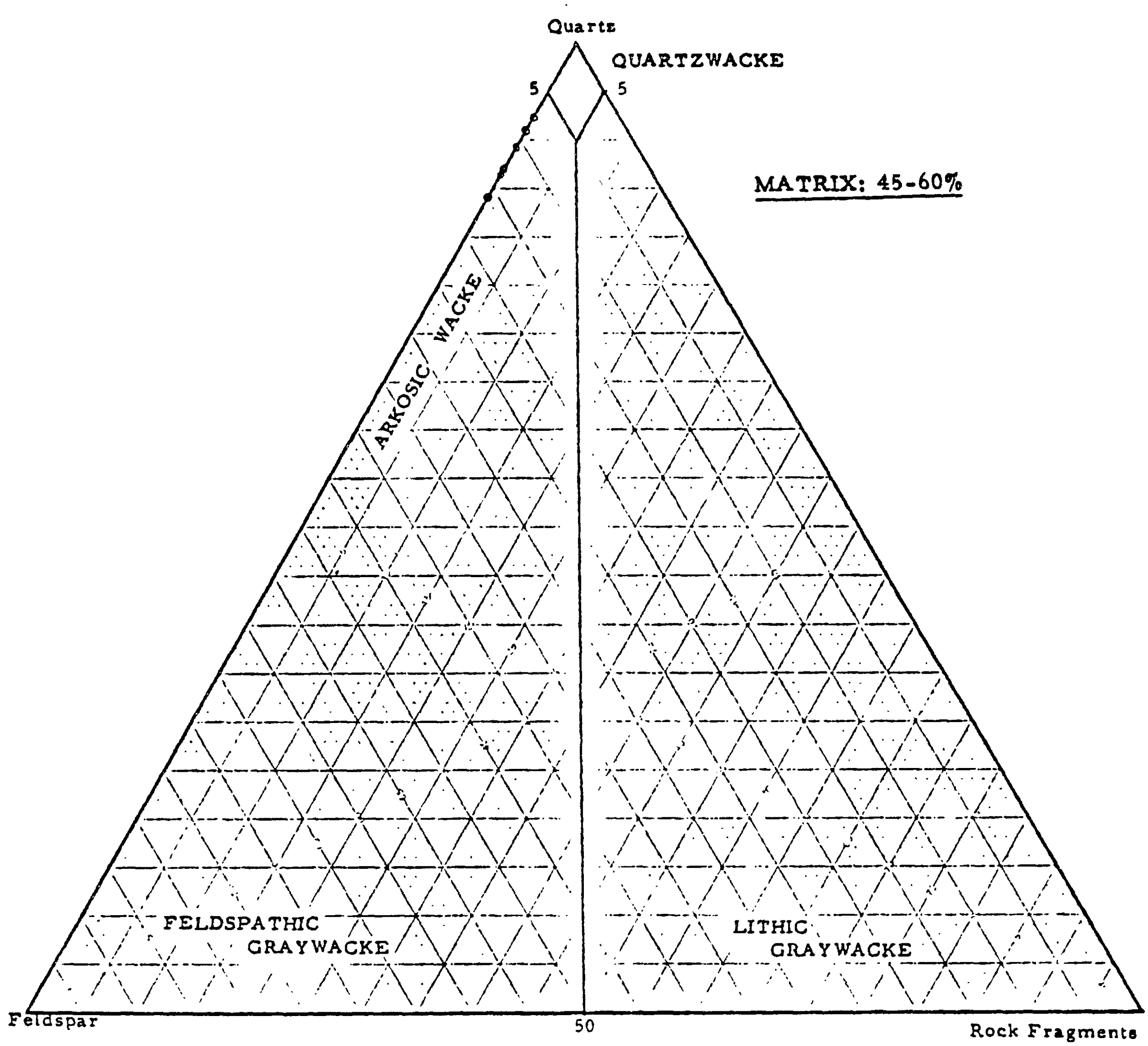



Figure 47.--Composition of quartzites, member C, Panther Creek Section.

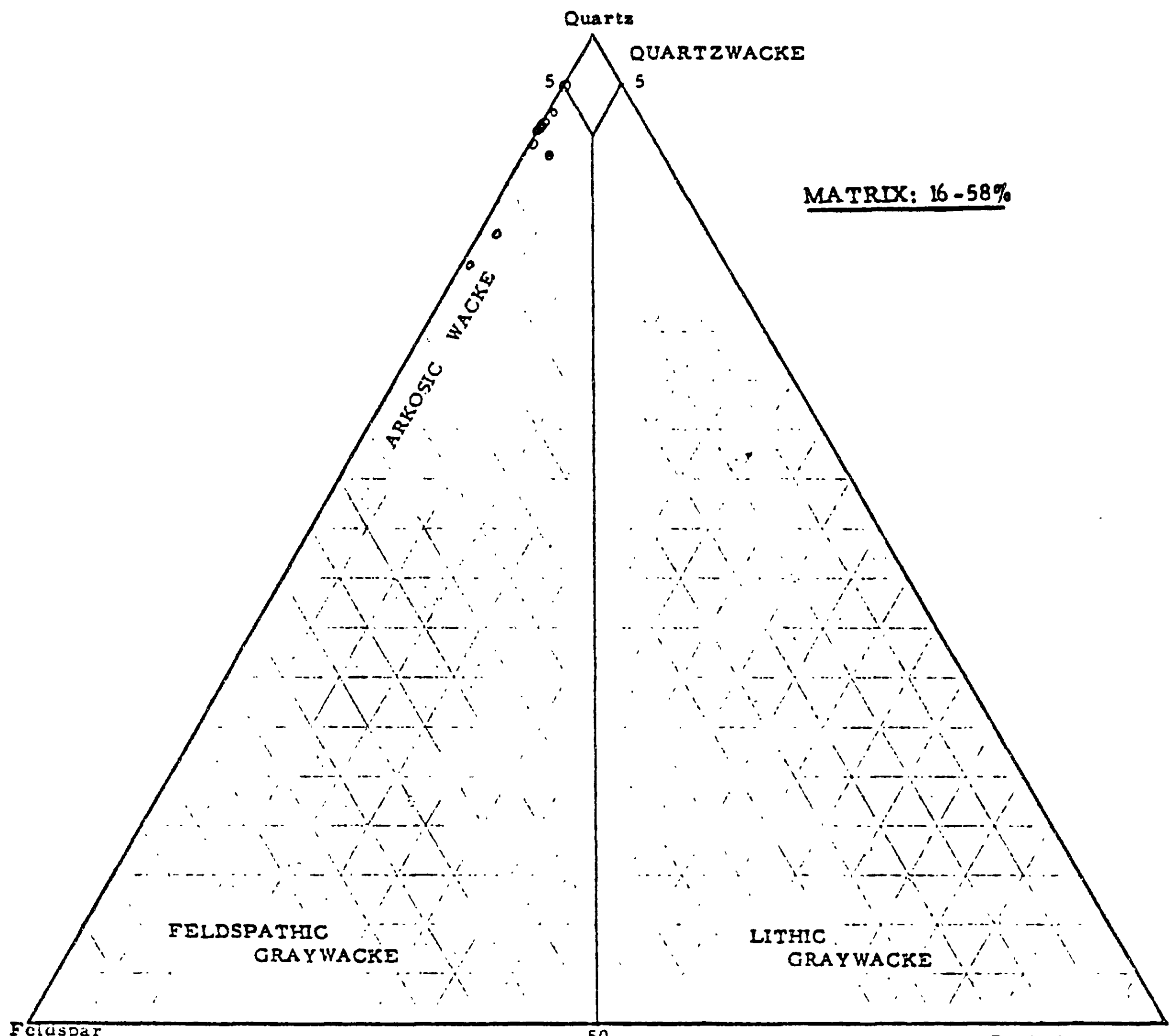



Figure 48.--Composition of quartzites, member D, Panther Creek Section.

several hundred meters. Member D is predominantly very fine grained argillaceous quartzite that is arkosic wacke in composition (fig. 48). Grading is reflected primarily in an upward increase in the amount of argillaceous matrix contained. The maximum grain size of the quartzite at the bases of graded beds seldom is more than very fine sand (pl. 6). Graded beds are 5 to 20 cm thick near the base, but increase in thickness to about 1 m high in the section. Colors are medium gray (N5) to dark gray (N3). Grading is also exhibited by darkening upward. On the hill just north of the Miller Ranch (pl. 5) are distinctive black tourmaline-rich laminae and lenses as much as 10 m thick; these are nearly totally composed of tourmaline with minor amounts of quartz and clay minerals. Parallel laminations, as in other units, are the most common sedimentary structures observed. Ripple cross-laminations and cut-and-fill structures are also common. Flute casts and ripple marks are probably more abundant than the few examples observed would indicate; but favorable exposures of bedding surfaces that would exhibit these structures are rare. A north-trending fault mapped at the Copper Creek Ranger Station only repeats the section about 250 m (pl. 5). The thickness of the part of member D exposed along Panther Creek is about 1,300 m, but the entire section is not present here. The end of the section is near the second sharp curve in the road south of the town of Cobalt (called Blackbird Townsite on pl. 5). At this point a steeply plunging overturned isoclinal fold is present (pl.5). North of this point exposures are poor and no further section was measured.

At several points throughout the Panther Creek Section are diabase dikes and sills (most are dikes)(pl. 6 and measured section 3). These are often difficult to detect because their color is not much different from that of the enclosing Yellowjacket. Most are dark gray, but some are olive black (5Y2/1) or greenish black (5GY4/1). Most are altered and metamorphosed and now consist of a fine-grained mass of plagioclase, chlorite, muscovite, biotite, clay minerals, and some orthoclase.

Well developed cleavage occurs in several areas along the Panther Creek Section, especially when one of the folds mentioned earlier is approached. In fact, the presence of well developed cleavage is an indication that the hinge of a fold is nearby. This cleavage lead Shockey (1957) to call his lower unit of the Yellowjacket the phyllite member, which resulted in a problem because similar well developed cleavage occurs locally in Shockey's upper unit, the impure gray quartzite, (member D of this report), giving the rock a phyllitic character. He mapped these as part of the phyllite member, resulting in an incorrect structural interpretation.

## Porphyry Creek Area

No section was measured here, but good exposures of calcareous rocks of Member B are present. The exposures are on the low ridge between Porphyry Creek and the South Fork of Porphyry Creek at the west edge of plate 5. Calcareous rocks are interbedded with greenish-gray and medium-gray argillaceous quartzite and argillite as described in member B in the Panther Creek section.

The calcareous rocks are about 60 m thick and lenticular, pinching out laterally within 100 m. Lithologies present are like those described in the Yellowjacket section. One lithology different from those is a white and brown parallel laminated calcareous quartzite. These rocks contain 30-50 percent calcite; the darkest bands are the most calcareous. These beds are in part brecciated. Some white limestone was observed in float, but not exposed, that appeared to be detrital in nature. Other calcareous rocks are like the banded gray and greenish-gray rocks in the Yellowjacket area. The darker laminae within these calcareous lithologies are interpreted to have been argillite and limy mud layers.

## Moyer Creek Area

Moyer Creek flows into Panther Creek from the southeast almost 3 km from the southern edge of plate 5. As seen on plate 1, the Yellowjacket is cut by at least two faults along Moyer Creek. Member B occurs along most of the length of the Moyer Creek Road. Predominantly medium-gray and greenish-gray argillaceous quartzite and sandy argillite are exposed. But at several points, calcareous quartzites like those at Yellowjacket Creek are present. As elsewhere, these quartzites are lenticular and pinch out in short distances laterally.

About 10 km from the Moyer Creek-Panther Creek junction is a fault that drops medium- to dark-gray argillaceous quartzite of member D down on the east. These rocks are like those that occur high in the Panther Creek section.

## Deep Creek Area

The Deep Creek area is shown in the northeast part of plate 5. No section was measured here due to much faulting, lack of exposure, and several slumps and landslides. Scattered exposures along a logging road from Deep Creek northeastward to Moccasin Creek are stratigraphically discontinuous, but show very well many sedimentary features. All the rocks exposed are within member D. Most of the rocks are very fine grained, and less commonly fine-grained, argillaceous quartzite in graded beds 5 cm to 1.5 m thick. Colors are predominantly medium gray to dark gray, although locally some light-gray zones occur at bases of graded intervals. Typically graded beds show sharp bases scoured into the underlying unit. Parallel laminations are the most common sedimentary structures. Ripple cross-laminations and ball-and-pillow structures are also quite common. Rarely were flute casts observed, but favorable exposures of bedding surfaces are difficult to find. Penecontemporaneous slump folds occur locally; a good exposure of one is about 3 km from Panther Creek about 10 m above the road level.

On the nose of Pepper Creek Ridge (pl. 5), Shockey (1957) mapped an anticline with rocks of the phyllite member (members B and C of this report) exposed. But such rocks are not present; instead rocks of member D are present with well developed cleavage giving them a phyllitic appearance. In addition, a fold, as mapped by Schockey, is not present, but several faults cut the Yellowjacket into blocks of different attitude.

## North Fork of Iron Creek Section

This section was measured along the North Fork of Iron Creek beginning about 2.5 km north of its junction with Iron Creek, at a fault that drops Challis Volcanics down on the south (pl. 7). The section continues upstream for 3 km, and then from that point extends another 1.8 km along a line bearing approximately N. 45$^{\circ}$ E. Most of the section is described along roads where there are good exposures in roadcuts; natural exposures in this area are very poor. The end of the section is also near a fault that has dropped the west side down (pl. 7).

The lowest part of the section here appears to be like rocks of member B of the Panther Creek section (pl. 8 and measured section 4). These are greenish-gray (5GY6/1) to medium-gray sandy argillite and very argillaceous quartzite. Compositionally these rocks are arkosic wackes, as shown in figure 49. Locally these rocks are slightly calcareous and contain veinlets and laminae of brown calcite. Parallel laminations are the most common sedimentary structures. Graded beds are 5 to 20 cm thick, grading from very fine sand or silt to mudstone. Only the top of this member is present; approximately 350 to 400 m.

Overlying rocks of member B is a sequence of wacke about 3,000 m thick that is equivalent to members C and D of the Panther Creek section, but the change between the units is not as distinct (pl. 8, measured section 4). The lowest beds are most like member C, and and the highest beds are most like member D; but lithologies typical of both are present throughout the section. The quartzite and siltite all are compositionally arkosic wackes (fig. 49). Finer grained rocks at tops of graded beds are sandy argillites. Graded beds are present throughout and are 1 to 20 cm thick, although beds 1-5 cm thick are most common in the lower half of the section. In the lower half, the coarsest fractions are silt and very fine sand. In the upper half, fine-grained sand is more common and locally small amounts of medium-grained sand occur at the bases of graded beds. Colors are predominantly medium gray to dark gray, but locally a few beds of greenish-gray (5GY6/1) rocks occur, and in the upper part light-gray fine- and medium-grained quartzite is common. As elsewhere in the Yellowjacket, grading is exhibited by darkening upward and an increase in the amount of argillaceous matrix upward. In the upper part of the section, grading of the maximum grain size can be observed from fine or medium grained sand to silt and argillite.

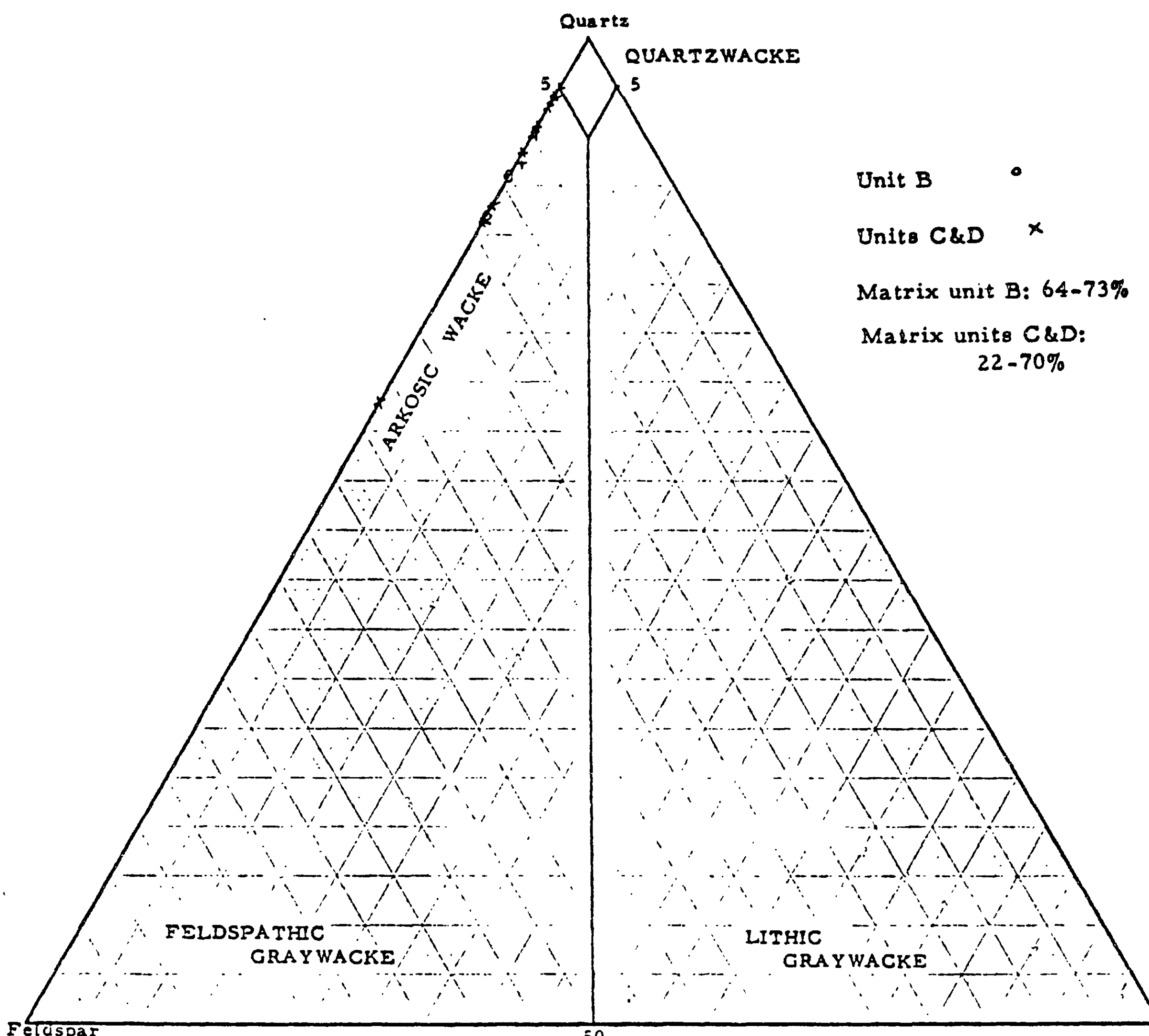



Figure 49. Composition of rocks, Yellowjacket Formation, North Fork of Iron Creek Section.

Parallel laminations are the most common sedimentary structures. Ripple cross-laminations, fluid-escape structures, load structures, and "pseudo-mudcracks" are also common. Cut-and-fill structures are extremely common at bases of graded beds, and typically cut only 1 cm or less into underlying beds.

At about 2,000 m from the base of the measured section is a zone of Cu-Co mineralization (the Little No Name Mine) (about 2.5 km, map distance from the beginning of the section); the zone is stratiform. At the margins of the deposit, sulfides can be observed concentrated along bedding surfaces in the quartzite. In the main part of the deposit, sulfides are predominant with interlaminae of argillite and quartzite. Pyrite and chalcopyrite are the main minerals observed in hand specimens. Another similar zone can be observed in a roadcut about 1.5 km southeast of this deposit (pl. 7).

## Iron Creek Section

This section was measured along Iron Creek, beginning just west of the junction with the North Fork of Iron Creek at a fault contact with Challis Volcanics (pl. 7). The section measured extends down the Iron Creek road about 1.4 km where a north-trending fault disrupts the section. No further section was measured farther downstream due to the lack of exposure and the uncertainty of the structure within the Yellowjacket.

From a distance, this section appears to differ greatly from other Yellowjacket sections, but this difference is due to extreme silicification that makes the rock more resistant and to appear to be much thicker bedded than is usual for the Yellowjacket. On close examination, graded bedding is seen to be typically 20 cm to 1 m thick, locally reaching 2 m. As elsewhere in the Yellowjacket, grading is typically exhibited by darkening upward and an increase in the amount of clay-size matrix. These rocks are probably part of member D.

Throughout the section, medium-gray to dark-gray argillaceous quartzite is the predominant lithology in graded beds 10 cm to 2 m thick (pl. 9). Very fine sand and silt are the most common grain sizes present, although a few beds are capped by thin laminae of argillite that act as partings between thicker harder argillaceous quartzite. Some of these argillites are as much as 10 cm thick.

Locally present (pl. 9 and measured section 6) are beds of light- to medium-gray, very fine and fine-grained quartzite as much as 50 cm thick; and light-gray parallel-laminated argillaceous siltite and argillite in thin graded beds from 5 mm to 2 cm thick.

Parallel laminations are the most common sedimentary structures. Load casts, ball-and-pillow structures, and ripple cross-laminations are also common. One ball-and-pillow structure observed was about 1 m wide and 0.5 m high; but most sedimentary structures are very small scale, on the order of a few centimeters.

## Hayden Creek Section

The line of this section is shown in figure 50. Here the Yellowjacket Formation is exposed in a window through the Medicine Lodge thrust, which in this area has thrusted rocks of the Lemhi Group and Swauger Formation over the Yellowjacket (Ruppel, 1978; and Ruppel and others, in press).

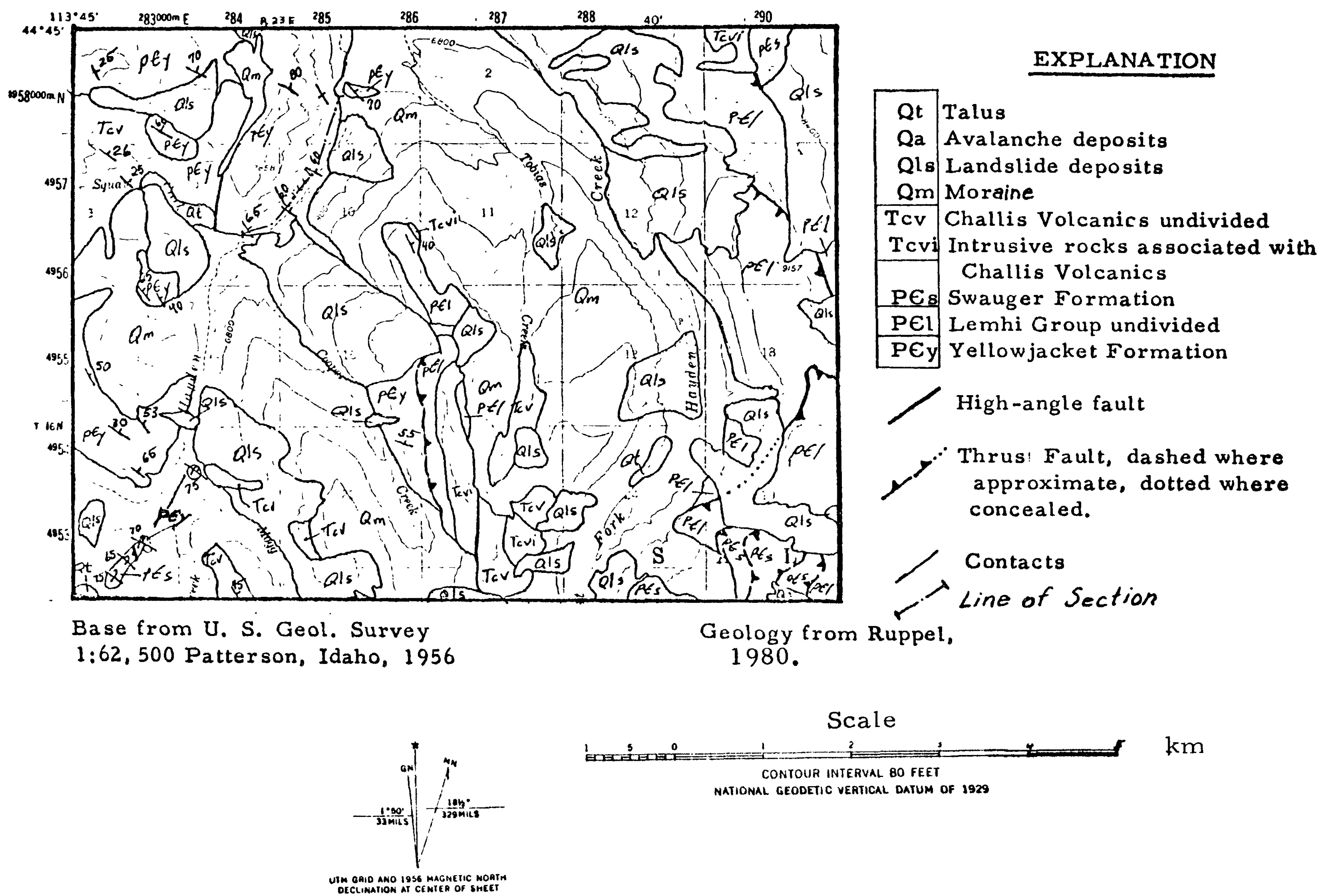



Figure 50. — Geologic map of the Hayden Creek area.

The entire section of about 1,600 m is within member B of the composite section. It is characterized by brown-speckled medium- to dark-gray calcareous quartzite interbedded with light-gray to dark-gray and greenish-gray (5G6/1) ripple cross-laminated, very fine sand and silt-size argillaceous quartzite, which is typically noncalcareous. The calcareous quartzites can be as coarse as coarse sand, but are typically very fine to fine grained. These rocks are most common in the lower half of the section and become less abundant upward in the section (measured section 7). The upper 300 m contains little or no calcareous wacke, and is composed wholly of greenish-gray to light-gray to dark-gray argillaceous quartzite of very fine to silt grain size.

Compositionally, the quartzites and siltites in this section are calcareous and noncalcareous arkosic wackes, but are nearly quartz wackes (fig. 51).

## North Fork Section

The location of this measured section is shown on figure 52, along a narrow ridge just northeast of the town of North Fork. This area is intensely faulted, which is not favorable for the preservation of thick continuous sections of Yellowjacket. The entire section, about 830 m thick, is within member D of the composite section.

All the rocks are argillaceous quartzite with varying amounts of matrix, from about 14 to 50 percent. Compositionally all are arkosic wackes (fig. 53); lithic fragments are rare. Where lithic fragments occur they are chips ripped up from the immediately underlying bed. The grain size is predominantly very fine sand; fine sand occurs locally but is rare.

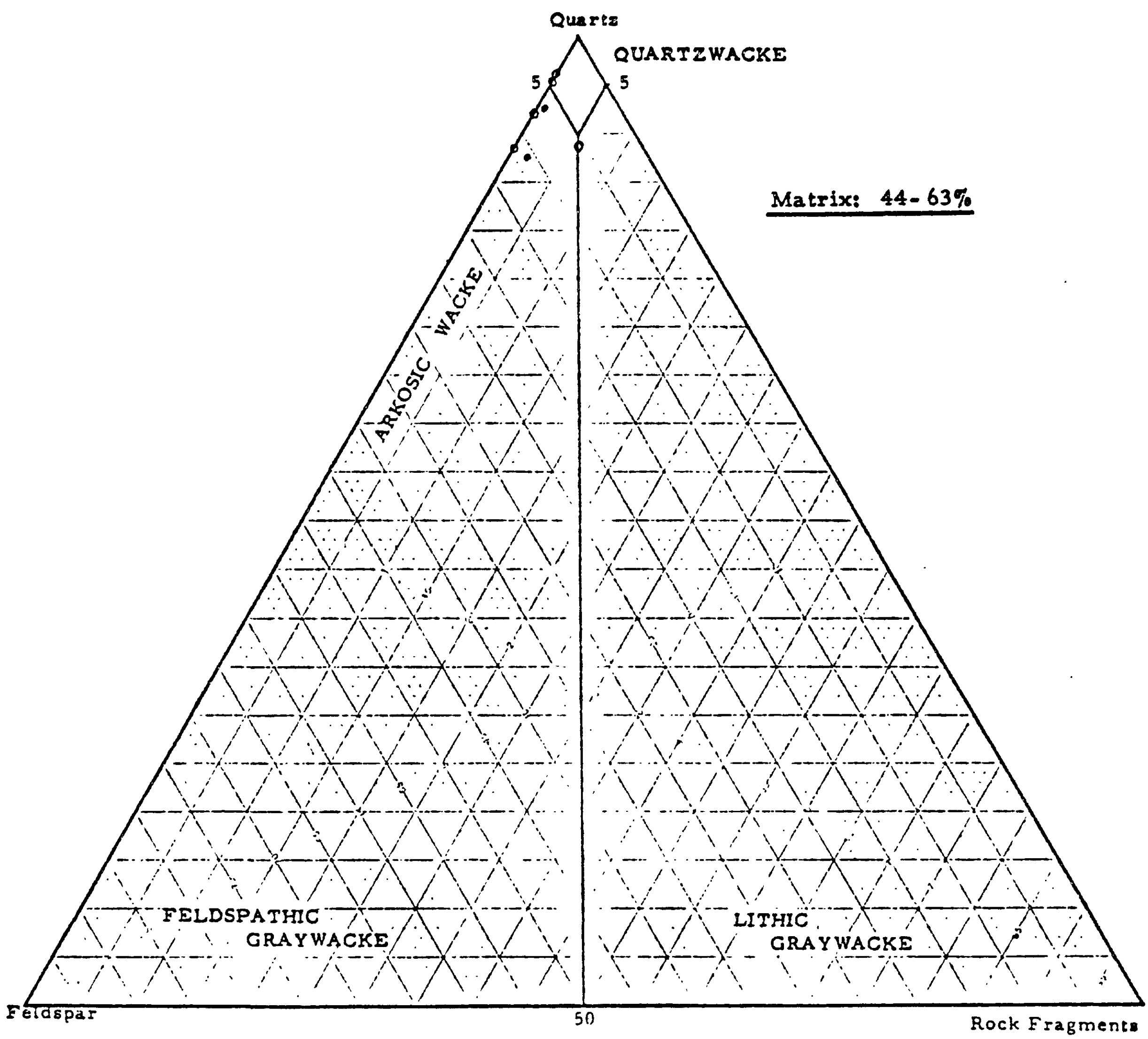



Figure 51.--Composition of rocks from the Hayden Creek Section, member B, Yellowjacket Formation.

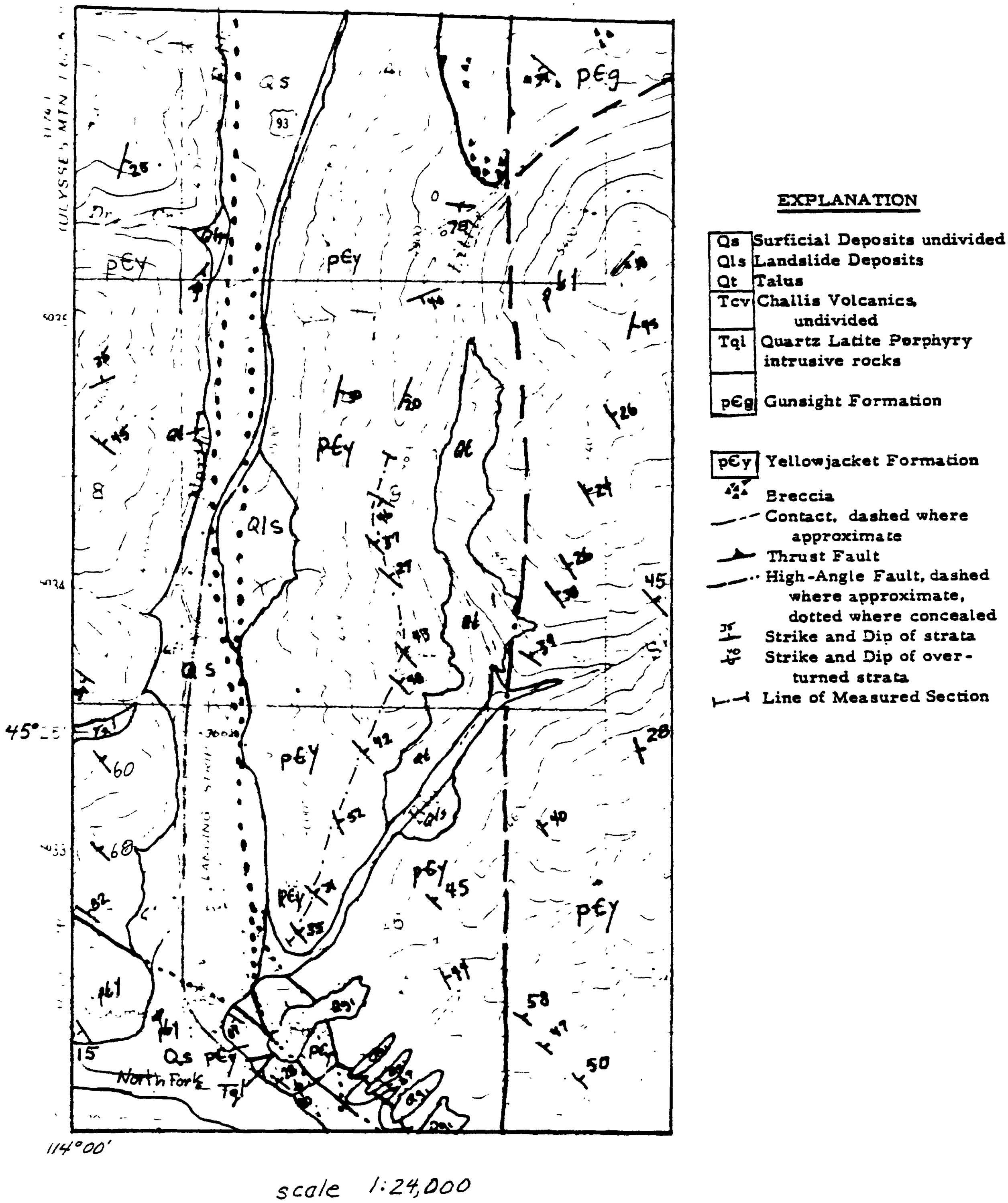



Figure 52. Geologic map of the North Fork area, Lemhi County, Idaho.

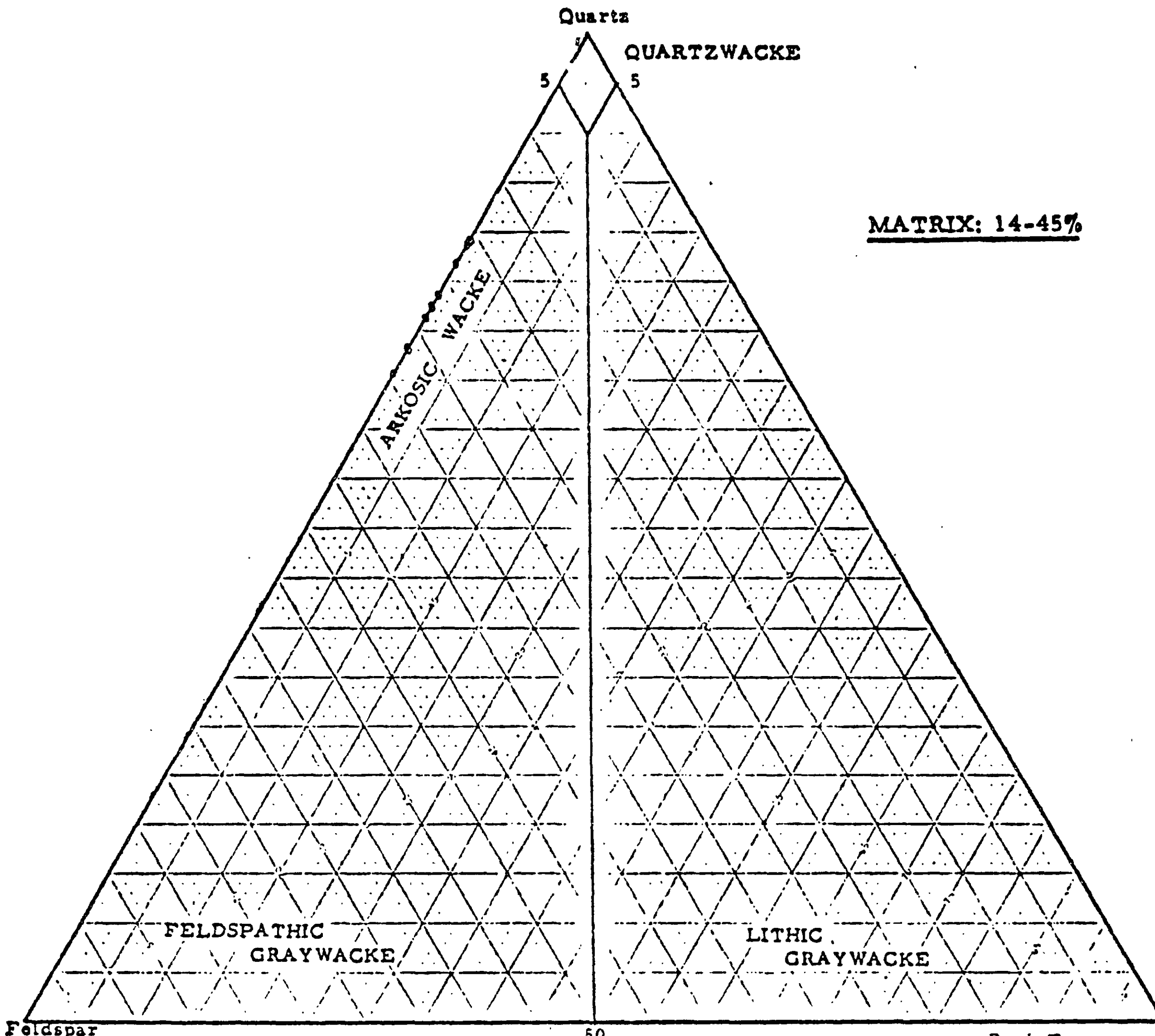


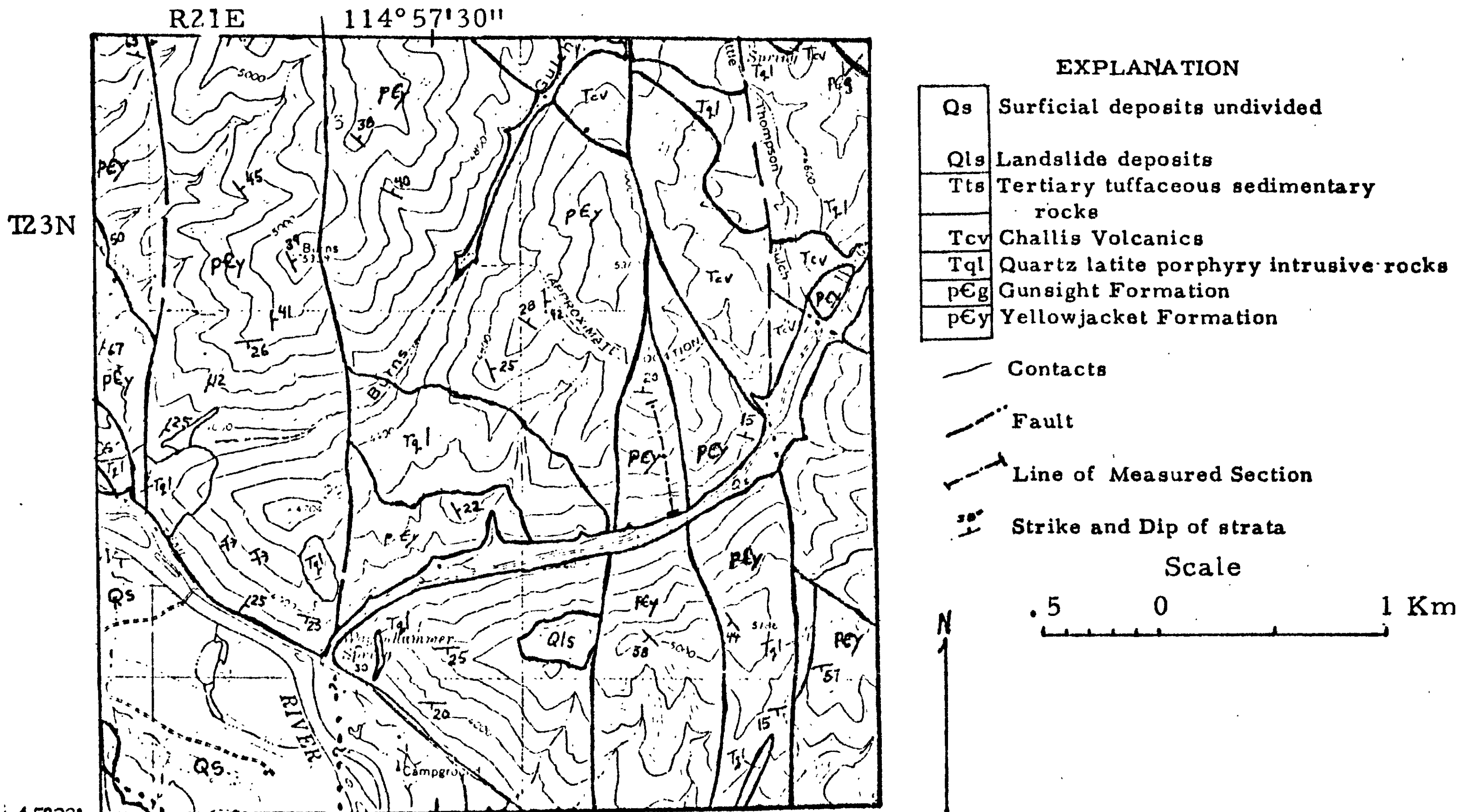

Figure 53.--Composition of rocks, member D, North Fork Section.

Grading is exhibited by an increase in the amount of argillaceous matrix and by darkening upward. The maximum grain size is nearly constant. Graded beds are about 5 cm to 1 m thick. Typically colors grade upward from medium gray to dark gray. At several points through the section are irregular secondary white bleached zones that appear to be fracture-controlled, and that in nearby areas are often associated with quartz latite porphyry intrusive bodies. Rocks in these zones are composed of quartz, feldspar and sericite (measured section 8). The most common sedimentary structures are parallel laminations, which are nearly ubiquitous. Ripple cross-laminations are also common. Some convolute laminations are present locally, as are load casts and ball-and-pillow structures. All graded beds have sharp bases and exhibiting varying amounts of scour into underlying beds. Near the base of this section are black, tourmaline-rich rocks as described in the Panther Creek section. These rocks are poorly exposed, but appear to be thin laminae and cross-cutting veinlets a few centimeters thick.

## Wagonhammer Creek Section

The Wagonhammer Creek Section was measured up a steep slope on the north side of the valley of Wagonhammer Creek about 1 mile east of its mouth (fig. 54).

These rocks are probably equivalent to the upper part of the North Fork Section. The entire section is 225 meters thick, and consists predominantly of argillaceous quartzite in graded beds 5 cm to about 1 m thick (pl. 12 and measured section 8). Grading is exhibited in darkening upward and an increase in the amount of argillaceous matrix; some graded beds are capped by sandy argillite. The grain size is rarely coarser than very fine sand.




Base from U. S. Geological Survey 1:24000 North Fork, Idaho (1966).

Geology by D. Lopez, 1978.

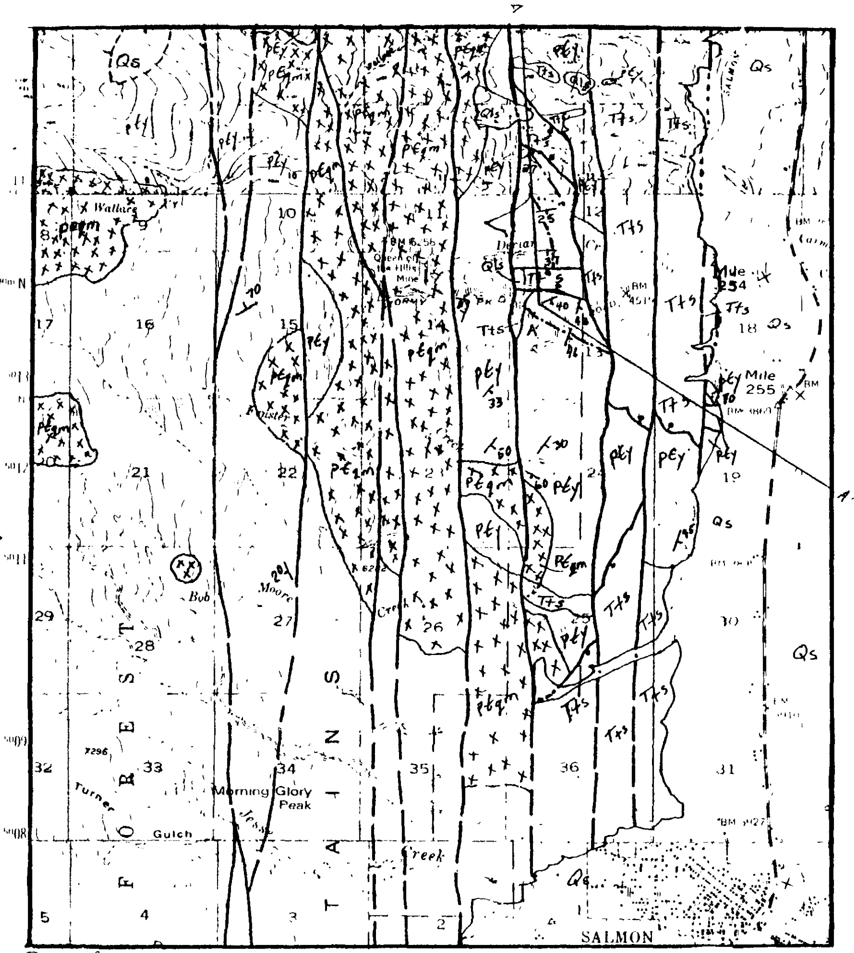
Figure 54. Geologic Map of the Wagonhammer Creek area, Lemhi County, Idaho.

Colors vary from light gray to dark gray; darker colors being the most common. Parallel laminations are nearly ubiquitous. Cut-and-fill structures at the bases of graded intervals are also common. Ripple cross-laminations are present in a few beds, as are ripple marks and load structures.

## Deriar Creek--Stormy Peak Road Section

This section is about 5 miles north-northwest of Salmon, Idaho and was measured from about 1 mile north of Deriar Creek southward to the area of the Stormy Peak Road (fig. 55). A fault block of Tertiary sedimentary rocks cuts the section into two segments as shown in figure 55 and 55a.

The thickness of the section measured here is about 660 m and encompasses a stratigraphic interval considered to be transitional from member D to member E (pl. 13 and measured section 9). The base of the section is faulted against Tertiary sedimentary rocks and the top is a fault within the Yellowjacket Formation. The lowest part of the section contains predominantly medium-dark-gray to dark-gray argillaceous quartzite in graded beds 5 cm to 1 m thick. Up-section, the thickness of the graded beds increases and the number of medium- and light-gray, less argillaceous beds increases. These less argillaceous beds are about on the borderline between arenites and wackes (containing 12 to 18 percent matrix) and are quite resistant, forming ridges and dip slopes. The composition of these rocks is arkosic wacke and subarkose (fig. 56). The grain size of most of the these rocks is very fine sand, but fine-grained sand is more common in the upper part of the section.




Base from U. S. Geol. Survey
Bird Creek, Idaho 1: 24000 (1966)
and Salmon, Idaho 1:62500 (1950)

Geology by D. Lopez,
1979.

EXPLANATION

Qs Surficial deposits undivided

Qls Landslide deposits

Tts Tertiary tuffaceous sedimentary rocks

P€qm Porphyritic quartz monzonite

P€y Yellowjacket Formation

Contacts, dashed where approximate dotted where concealed

Fault, dashed where approximate, dotted where concealed

Strike and dip of inclined strata

Line of measured section

SCALE

0 1 2 3 4 km

Figure 55. -- Geologic map of the Deriar Creek--Stormy Peak Road Section

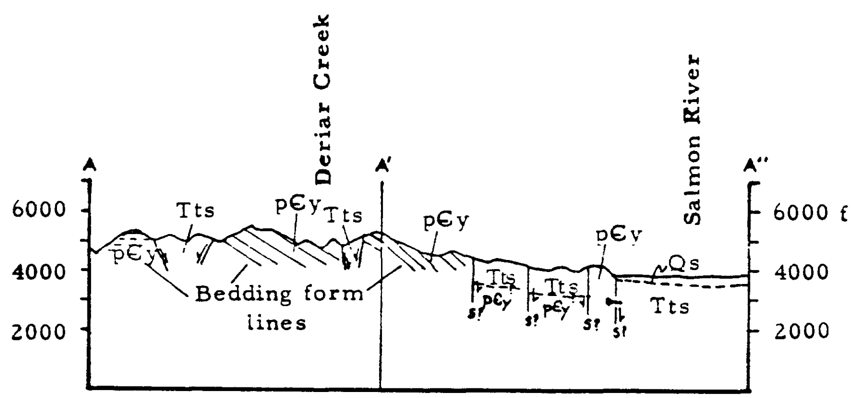



Figure 55A. — Cross-section for geologic map of figure 55. Scale is the same as that in figure 55. Elevations given in feet because contour intervals and elevations on map are in feet.

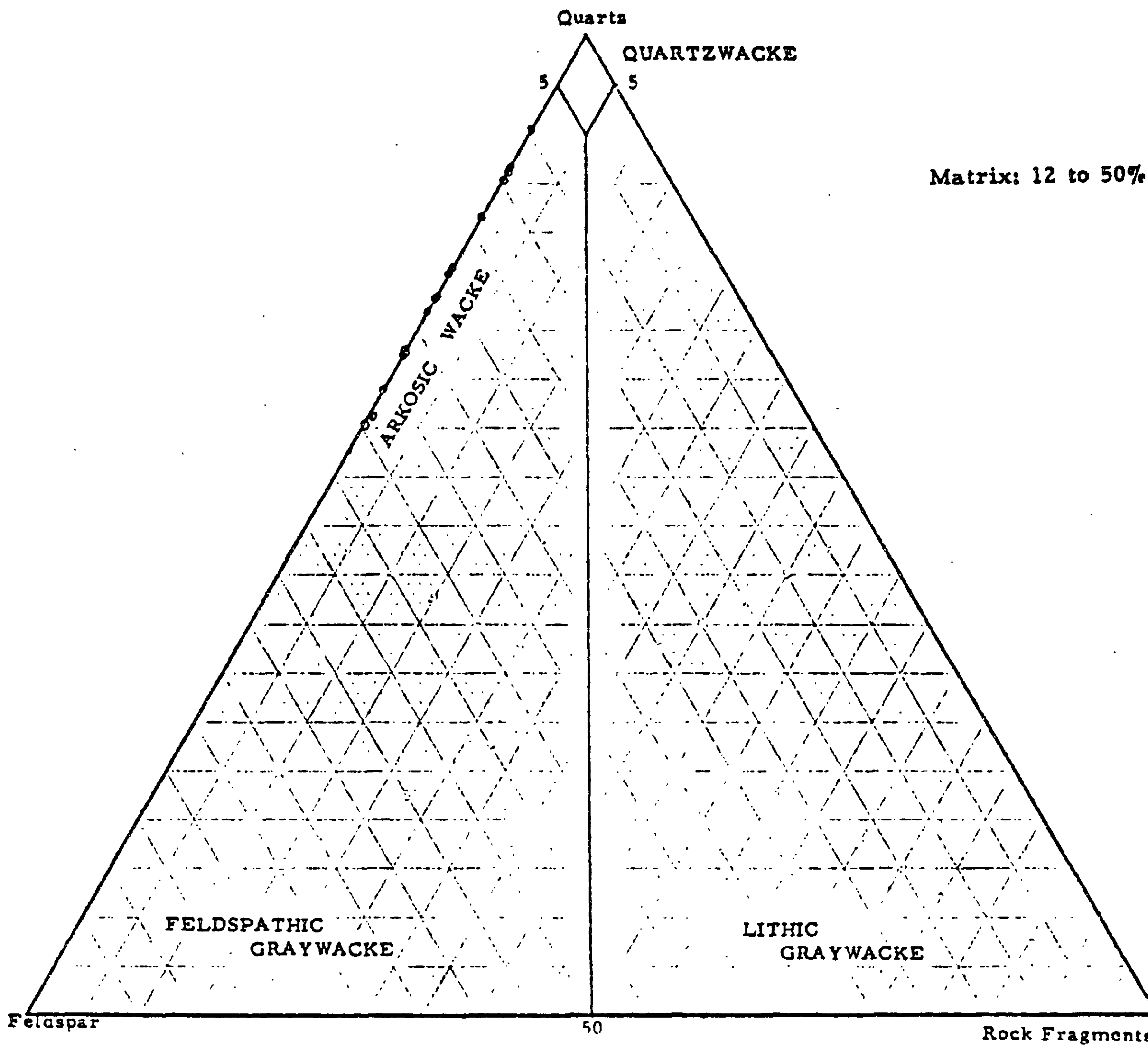



Figure 56. Composition of rocks in the Deriar Creek—StormyPeak Road Section.

## Napoleon Ridge Area

Napoleon Ridge, the high ridge just southwest of North Fork, Idaho, (pl. 1) is capped by a resistant, relatively clean quartzite unit. These rocks are like the medium-gray rocks described in the Deriar Creek-Stormy Peak Road section and may be equivalent to one of the thicker units in that section. They are medium- to light-gray, fine to very fine grained quartzite in graded beds from 10 cm to 1.5 m thick. Parallel laminations are nearly ubiquitous. Ripple cross-laminations and some convolute laminations are also common. Exposures off the ridge to the east and west are poor, making determination of stratigraphic relations nearly impossible; in addition, several north-trending faults present in these areas add further difficulty. To the north, these resistant rocks are faulted against rocks that appear to be equivalent to those described in the North Fork Section. To the south, structural relations could not be determined due to lack of exposure, but rocks that appear to be lower in the section are present. These resistant rocks are considered to be part of member E.

## Iron Lake Road Area

The Iron Lake Road crosses several fault blocks containing rocks from different stratigraphic levels of the Yellowjacket Formation, of the Big Creek Formation, the Apple Creek Formation, and Challis Volcanics (pl. 1).

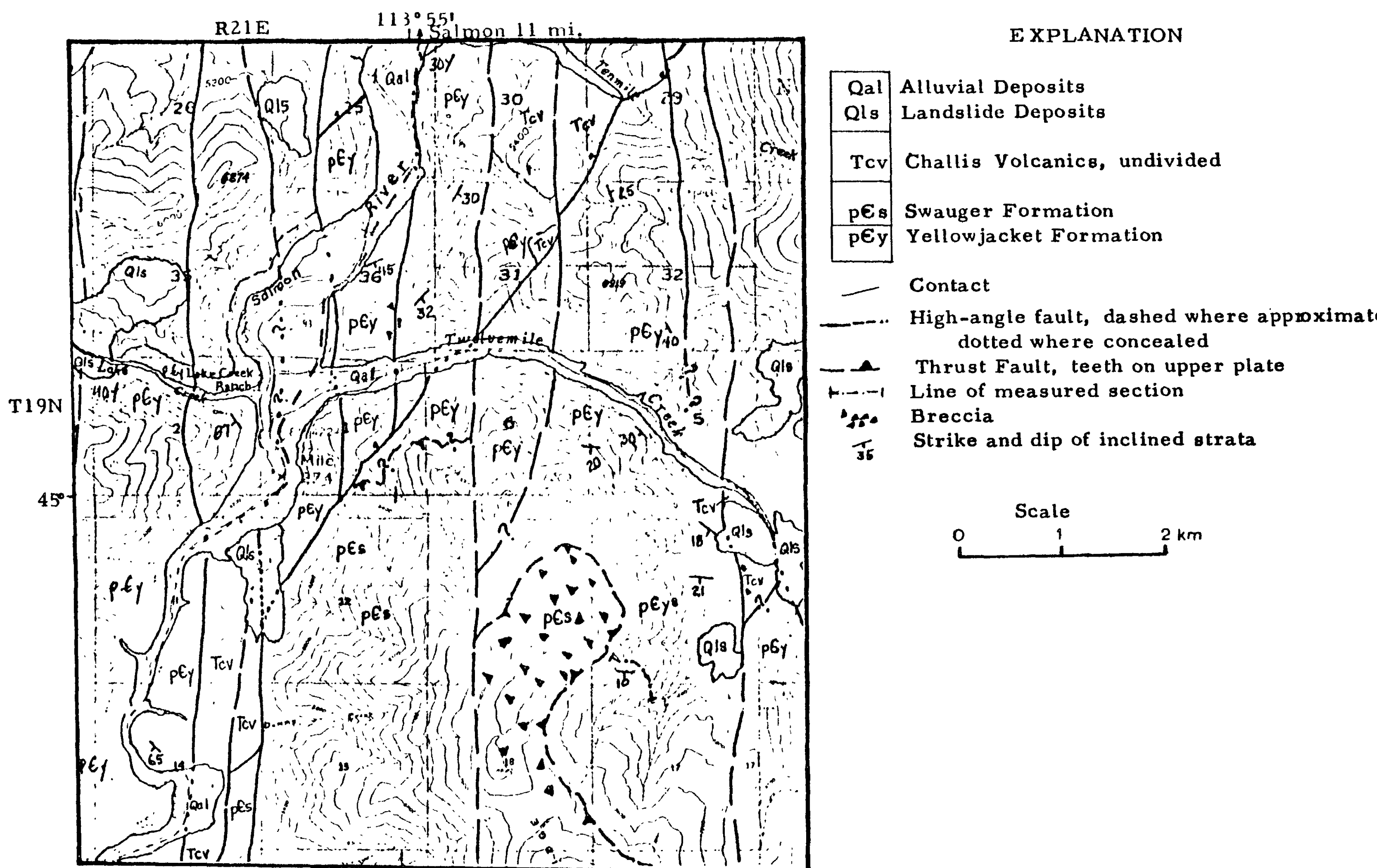
About 4.5 km south of Williams Creek Summit, the road passes from a fault block capped by Challis Volcanics to a block of Yellowjacket rocks. Here again, relatively clean rocks of member E are present. These rocks are light-gray to medium-gray very fine and fine-grained, parallel-laminated quartzite in graded beds 30 cm to 1 m thick. Upward within graded intervals the rock becomes increasingly argillaceous and darker colored. Southward, down-section, increasingly argillaceous, darker colored rocks occur, which are typical of member D as described in the North Fork Area. Exposures here are scattered; therefore a section was not measured.

About 12.5 km south of the Williams Creek Summit, the road passes into a fault block of Yellowjacket that contains rocks of member C. These rocks are argillaceous quartzite and siltite and sandy argillite in thin graded beds typical of member C described in the Panther Creek section.

About 16 km south of Williams Creek Summit, measured along the road, is a thrust plate containing rocks of the Apple Creek Formation lying on rocks of the Yellowjacket (pl. 1). The road continues in Apple Creek to Iron Lake where rocks of the Big Creek Formation are present.

## Twelve-Mile Creek Section

The Twelve-Mile Creek section is near the northern end of the Lemhi Range about 15 miles south of Salmon (fig. 57 and pl. 1). As shown on figure 57, the section was measured immediately beneath a thrust plate containing rocks of the Swauger Formation. The Yellowjacket here is probably within member D of the composite section. The quartzites here are mostly very fine grained in graded beds 5 to 50 cm thick (pl. 14 and measured section 10), typically grading is exhibited as increased content of argillaceous matrix upward and darkening from medium or medium dark gray to dark gray upward. The rocks are intensely sheared. Most of the shearing appears to have been taken up in the most argillaceous fractions where argillaceous material has been




Base modified from USGS 1:24000 Goldbug Ridge(1962) and Poison Peak(1962) and 1:62500 Salmon(1950)

Geology by D. Lopez, 1975 and 1979.

Figure 57. Geologic Map of the Twelve-Mile Creek Area

recrystallized as sericite and muscovite oriented at a low angle to bedding, approximately parallel to the thrust fault above the Yellowjacket.

The composition is, as elsewhere, arkosic wacke and is illustrated in figure 58.

## Lemhi Pass Area

Only a brief reconnaissance examination was made of the rocks in this area which is east of Tendoy, Idaho and includes the easternmost exposures of rocks definitely known to be within the Yellowjacket Formation (pl. 1). The area has been mapped in detail by Staatz (1972, 1973). Precambrian rocks present in the area include parts of the Big Creek Formation, Apple Creek Formation, Gunsight Formation, Swauger Formation and the Yellowjacket Formation (Staatz, 1973, and E. T. Ruppel, oral communication, 1979). Much of what Staatz mapped as quartzite and siltite units is Yellowjacket. According to Staatz' mapping, the Yellowjacket has to be at least 600 m thick in the area. Reconnaissance examination indicates that these rocks probably correspond to part of member D. Much of the Yellowjacket here is like that described in the Twelve-Mile Creek area. Argillaceous quartzite is in graded beds that are 10 to 30 cm thick and that locally are about 1 m thick. Grading is exhibited by an upward increase in the amount of argillaceous matrix, as well as by darkening upward. The grain size is most typically very fine sand, although locally fine sand occurs at the bases of graded beds. Colors range from light gray to dark gray and dark greenish gray. Sedimentary structures present are typical of member D elsewhere. They include nearly ubiquitous parallel laminations, ripple cross-laminations, asymmetrical ripple marks, cut-and-fill structures, load casts, and recumbent penecontemporaneous slump folds.

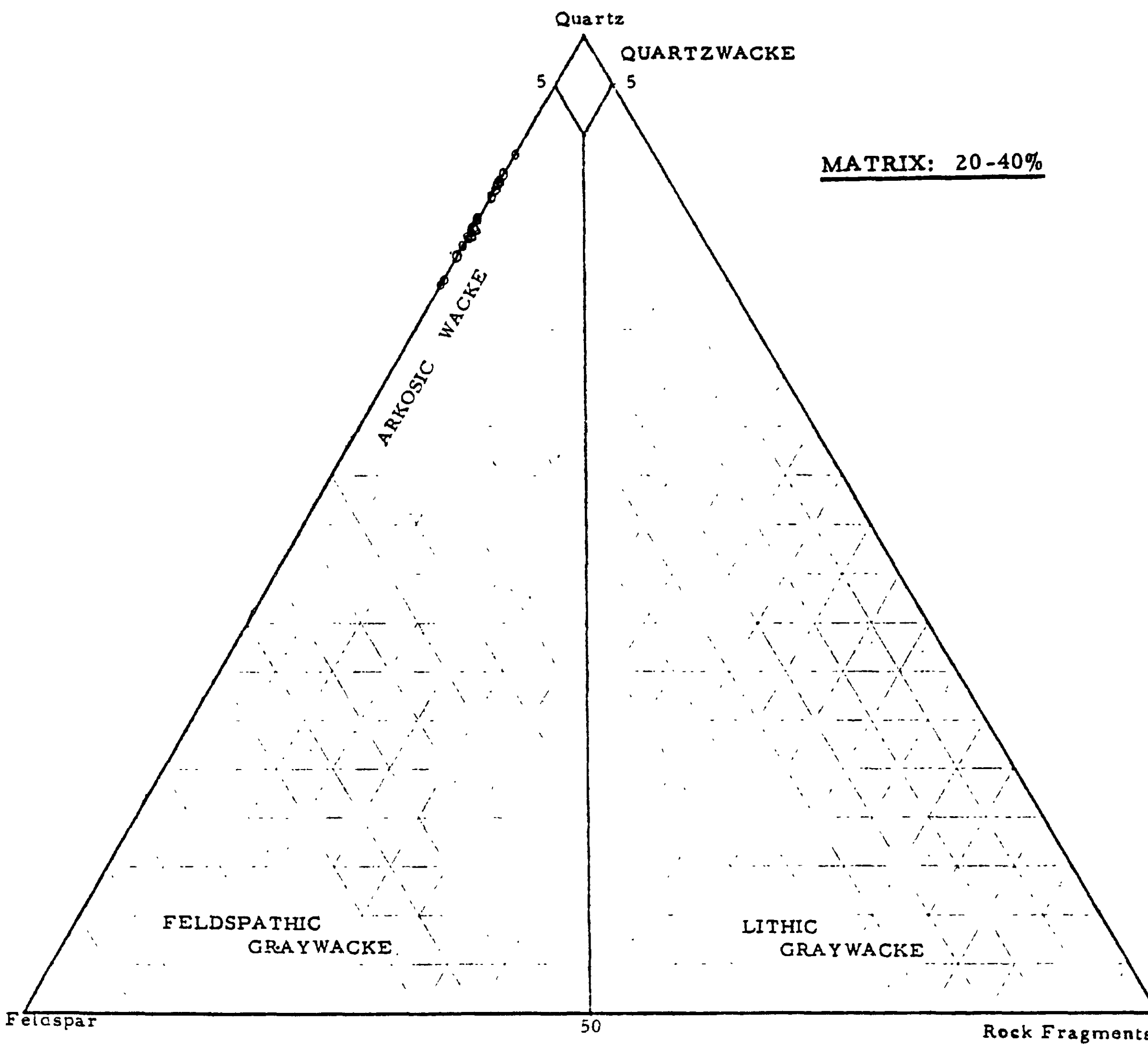



Figure 58. Composition of rocks of the Twelve-Mile Creek Section.

# APPENDIX II

## MEASURED SECTIONS

# MEASURED SECTIONS

## Explanation

In the measured sections that follow, the units numbered along the left margin are intervals of beds that are relatively uniform in composition and other sedimentary features. Due to the nature of the study and the great thickness of the Yellowjacket Formation relative to the small scale of the sedimentary structures and the thickness of bedding, the numbered intervals were used for convenience in measuring and describing sections. The same intervals were used on the stratigraphic columns (pl. 4, 6, 8, 9-14).

Colors used in the measured sections are from the Geological Society of America Rock Color Chart (1975); both descriptive color terms and numerical designations are used.

Section 1. Reference Section of the Yellowjacket Formation at Yellowjacket Creek.

| Member B | Thickness, in meters |
|---|---|
| 13. Argillaceous quartzite, argillite and calcareous quartzite;quartzite and argillite mostly dark-gray (N3)parallel laminated, ripple cross laminated intensely fractured, exposures very poor. Calcareous quartzite, white to medium gray (N5),in part interlaminated with dark gray (N3) and greenish-black (5GY2/1) argillite, and mottled with similar appearing clots of metamorphic minerals, intensely fractured, very poorly exposed. .......................................... | 130 |
| 12. Quartz latite porphyry, light-brownish-gray(5YR6/1) in part very coarsely porphyritic, euhedral plagioclase and potassium feldspar up to 3 cm long, quartz 1 to 2 mm across ...................................... | 80 |
| 11. Argillaceous quartzite, very calcareous, white, very fine grained has discontinuous laminae of argillaceous materials in 13 ................ | 165 |
| 10. Quartzite, very calcareous, as in 13, but here argillite laminae are more abundant and reach 5 cm in thickness; argillite laminae are not calcareous ............................ | 60 |
| 9. Quartzite and argillaceous quartzite, very calcareous, light gray (N7) to medium gray (N4), has fewer interlaminations of argillite; some siltite laminae, dark gray (N3), noncalcareous ................................ | 20 |
| 8. Quartz latite porphyry, as at 12 ......................... | 80 |
| 7. Argillaceous quartzite, calcareous, light gray (N7) to medium gray (N5), contains interlaminations and clots as in 13, ripple cross laminations, some slightly convolute laminations ........................................ | 70 |
| 6. Quartz latite porphyry, as at 12 ......................... | 110 |
| 5. Quartzite, dark gray, very fine grained, only slightly calcareous, in graded beds, parallel laminated, poorly exposed, mostly float, argillaceous .................................... | 505 |

| | |
|---|---|
| 4. Quartz latite porphyry, as at 12 .......................... | 250 |
| 3. Argillaceous quartzite as at 5, contains few interlaminations of calcareous material ........................................ | 180 |
| 2. Quartzite, as at 5, very fine sand to silt-size, some beds ripple cross laminated, graded beds, parallel laminations common ............... | 365 |
| 1. Quartzite, as at 2, graded beds, no calcareous material detected, some beds pyritic .................. | 1070 |
| Total exposed thickness of member B of the Yellowjacket Formation at Yellowjacket Creek excluding cumulative thickness of dikes ........................................ | 2565 |

Section 2. Reference section of the Yellowjacket Formation at Shovel Creek (plotted graphically as plate 4).

| Member A | Thickness in meters |
|---|---|
| 8. Argillaceous quartzite and sandy and silty argillite, argillaceous quartzite predominantly dark gray (N3), mainly fine grained and very fine grained minor amounts of medium and coarse sand occurs at bases of graded beds, graded beds are 5 to 20 cm thick, parallel laminations very common, ripple cross laminations also common; sandy argillite grayish black N(2) to dark gray N(3), minor amounts of dark greenish gray (5GY4/1) material, parallel laminated .......................... | 38 |
| 7. Argillaceous quartzite and argillite as above, standing ripples observed ...................... | 32 |
| 6. Quartzite, as above but contains minor amounts of medium to coarse grained, pinkish gray (5YR8/1) quartzite at bases of a few graded beds. Sandy argillite laminae much more sparse, only one thick bed observed, which was 10 cm thick and finely laminated ............................ | 33 |
| 5. Quartzite, coarse to fine grained in graded beds 5 cm to 1 m thick, increasingly argillaceous upward; few strata are mostly fine and very fine grained, parallel laminated, coarsest material pinkish gray (5YR8/1) to brownish gray (5YR4/1) and medium to dark gray colors (N4 to N3) occur in the finest material, ripple cross laminations in trough-shaped sets common ............. | 173 |
| 4. Quartzite as above but with smaller amount of very fine quartzite ................................ | 62 |
| 3. Argillaceous quartzite and argillite medium to dark gray (N4-N3), medium to fine grained quartzite in graded beds 5 cm to 20 cm thick, parallel laminated and ripple cross laminated; bedding accented by argillite laminae that act as partings in the argillaceous quartzite ............................ | 163 |
| 2. Quartzite, as above, some pinkish gray (5YR8/1) and brownish gray (5YR8/1) medium to coarse grained sand, minor dark gray very fine quartzite in float ................ | 131 |

| | |
|---|---|
| 1. Quartzite as above, medium light gray (N6) to medium gray (N5), coarse to fine grained, quartzite at bases of graded beds and grade upward into quartzites that are finer grained, darker and more argillaceous; as elsewere in section tops of graded intervals are typically scoured by the next higher bed ........................ | 56 |
| Total thickness, member A, Yellowjacket Formation in Shovel Creek ............................... | 688 |

Section 3. Reference Section of the Yellowjacket Formation along Panther Creek (plotted graphically in plate 6).

| Member D | Thickness in meters |
|---|---|
| 35. Argillaceous quartzite, medium dark gray to dark gray, darkening upward in graded beds; graded beds 10 cm to 1 m thick, very fine and fine grained, graded beds become more argillaceous upward, parallel laminated. Has well developed cleavage. Two thin diabase dikes occur here about 1 meter thick, cut bedding at angle of about 30`, dark gray to olive black (5Y2/1) .................. | 30 |
| 34. Argillaceous quartzite, as above .......................... | 83 |
| 33. Argillaceous quartzite medium gray to dark gray, very fine grained, graded beds to 1 m thick, grading exhibited by increase in amount of argillaceous matrix upward, few ball and pillow structures about 5 to 10 cm across. Diabase sill, black, about 1 m thick .................................. | 107 |
| 32. Argillaceous quartzite medium gray to dark gray; in graded beds 10 cm to 1 m thick, some fine grained argillaceous quartzite at bases of graded units, but very fine grained quartzite predominant; grading occurs as increase in amount of argillaceous matrix upward, lightest colors at bases, darkest at tops, some of the least argillaceous quartzites approach arenites in composition; unit contains distinctive black argillite laminae and thicker lenses up to 10 cm thick consisting predominantly of tourmaline with very minor amounts of quartz and clay minerals. Load structures, convolute laminae, are common, few slump folds with amplitudes of about 5 to 10 cm; parallel laminations most common sedimentary structure ................................. | 282 |
| 31. Argillaceous quartzite medium gray to dark gray, very fine grained in graded beds as above. Parallel laminations and ripple cross laminations ........................... | 18 |
| 30. Argillaceous quartzite as above ......................... | 40 |
| 29. Argillaceous quartzite as above, cut and fill structures common at bases of graded beds. Contains diabase sill about 3 m thick, greenish black (5GY2/1) ......................... | 67 |

28. Argillaceous quartzite as above, but medium gray to grayish black (N2); cut-and-fill structures common; graded beds 10 cm to 30 cm, some have sandy argillite at tops ............... 77

27. Argillaceous quartzite as above, but no argillite; graded beds 3 to 10 cm, becoming increasingly argillaceous and darker upward ........................................ 183

26. Argillaceous quartzite as above, but some medium gray quartzite at bases of graded beds, approaches arenite in composition, very fine grained, minor fine grained quartzite ........................................... 60

25. Argillaceous quartzite, dark gray to grayish black; very fine grained, has a zone of graded laminae 5 mm thick or less, contains finely disseminated sulfide grains, mainly pyrite, along bedding surfaces, especially in thinly laminated rock. Intruded by diabase sill, 2 m thick, like dikes and sills described above ........................ 110

24. Argillaceous quartzite as above, but without thin laminae ........................................ 220

FAULT: Repeats section 235 m beds 22 and 23 show the same sequence as in 24 and 25. The thickness of intervals 22 and 23 is not included in total thickness tabulated at the end on the measured section (repeated intervals are shown on pl. 6).

23. Argillaceous quartzite, medium dark gray to dark gray, has graded laminae identical to those of 25 above. These are graded, about 5 mm thick, and grade from very fine quartzite or siltite to sandy argillite, argillite is about equally abundant as the coarser fraction; pyritic ............................ 30

22. Argillaceous quartzite medium gray to dark gray, very fine grained, in graded beds 5 to 20 cm thick grading as described above, pyritic ............................................ 205

Total thickness exposed, member D, Panther Creek Section ........................................ 1277

Member C

21. Argillaceous quartzite and sandy argillite, medium gray to dark gray; in graded beds 1 to 5 cm thick. Argillaceous quartzite at bases of graded beds typically make up 70 to 85 percent of total; argillite at tops of graded beds. Argillaceous quartzite very fine sand to silt in grain size, medium gray to medium dark gray. Parallel laminations are the only sedimentary structures observed, but well developed cleavage may have obscured others ...................... 180

20. Argillaceous quartzite and argillite as above, but some graded beds about 50 percent argillite ....................................... 30

ZONE OF TIGHT FOLDING: Begins here about 400 m southwest of Copper Creek, which causes several repetitions of the section. Measured section resumes just south of fault at McDonald Gulch (pl. 5). Repeated part of section is deleted both here and in plate 6, and the thickness of this deleted zone is not included in the total thickness tabulated at the end of the measured section.

19. Argillaceous quartzite and argillite as at 20 above, in graded beds 2 to 5 cm thick; argillaceous quartzite medium gray to medium dark gray, very fine grained, some silt size; argillite from 25 percent of graded intervals to just partings between sand beds, dark gray to grayish black; parallel laminated, well developed cleavage ........... 30

18. Argillaceous quartzite and argillite as above, but argillite more prominant 25 to 40 percent of graded intervals, parallel laminated; Convolute laminations, load structures, water escape structures common; these produce "pseudo-mudcracks that are sinuous to linear on bedding surfaces ................. 110

17. Argillaceous quartzite and argillite, as above ................................ 150

16. Argillaceous quartzite and argillite as above, but here contains some light gray (N7) to greenish gray (5GY6/1) argillaceous quartzite, graded beds 1 cm to 5 cm thick, argillaceous quartzite and argillite occur in about equal proportions, the light colored argillaceous quartzites occur in beds to 10 cm thick ................................... 244

| | |
|---|---|
| 15. Argillaceous quartzite and argillite as above .................................................. | 182 |
| 14. Argillaceous quartzite and argillite as above, but here contains a few beds of greenish gray (5GY6/1) sandy argillite, compositionally mudstone ................................ | 190 |
| 13. Argillaceous quartzite and argillite in graded beds as above, 1 to 3 cm ........................ | 90 |
| Total thickness member C, Panther Creek Section ................................................ | 1176 |
| Member B | |
| 12. Argillaceous quartzite, light gray to medium gray, to greenish gray in graded beds 3 to 10 cm thick, tops of graded beds are mudstones; contains interbedded graded beds and laminae as in Member C above, medium gray to medium dark gray argillaceous quartzite and siltite at base grading into dark gray argillites at top ............................ | 181 |
| 11. Argillaceous quartzite as above, but has fewer dark colored graded beds. Argillaceous quartzite calcareous in part, medium dark gray to greenish gray. Graded beds 2 cm to 20 cm thick; sandy argillite at tops of graded beds slightly more abundant than coarser fractions .................... | 32 |
| 10. Argillaceous quartzite, medium gray to greenish gray, very fine sand to silt in graded beds to 20 cm thick, some thin 2 to 3 cm zones of calcareous material with brownish color ........................................ | 81 |
| 9. Argillaceous quartzite very fine grained sand to silt, mostly greenish gray but has some beds up to 30 cm thick of dusky green (5G3/2) silt size argillaceous quartzite. Very little calcareous material ............................................... | 97 |
| 8. Argillaceous siltite and sandy argillite medium gray to greenish gray. Contains interbeds 2 to 3 cm thick of brownish gray (5YR4/1) very calcareous quartzite, very fine grained, about 50 to 60 percent carbonate ............................................. | 93 |

| | |
|---|---|
| 7. Argillaceous quartzite, very little calcareous material, includes some interlaminae of brownish gray very fine sand and silt size quartzite that is not calcareous | 48 |
| 6. Argillaceous quartzite, very fine grained, about 50 percent brownish weathering calcareous quartzite and about 50 percent white weathering noncalcareous quartzite; in graded beds 2 to 10 cm thick | 65 |
| 5. Argillaceous quartzite, very fine grained, predominantly brownish gray calcareous quartzite, but also includes greenish gray noncalcareous argillaceous quartzite. Limonite stain on weathered surfaces common | 48 |
| 4. Argillaceous quartzite as above | 50 |
| 3. Argillaceous quartzite as above, smaller proportion of calcareous quartzite, here only about 40 percent | 48 |
| 2. Argillaceous quartzite and sandy argillite in graded beds 5 to 15 cm thick; sandy argillite about 20 to 30 percent of total, greenish gray; argillaceous quartzite medium gray, to greenish gray, very fine grained sand and silt, coarsest fractions commonly calcareous and have brownish color | 32 |
| 1. Argillaceous quartzite and sandy argillite as above, in graded beds 10 to 40 cm thick; argillaceous quartzite makes up 50 to 70 percent of total, calcareous as above | 161 |
| End at landslide near faulted Challis Volcanics | |
| Total thickness member B, Panther Creek Section | 936 |
| Total exposed thickness Yellowjacket Formation, Panther Creek Section | 3389 |

Section 4. Reference Section of the Yellowjacket Formation in the North Fork of Iron Creek (plotted graphically in plate 8).

| Member D | Thickness in meters |
|---|---|
| 29. Argillaceous quartzite, medium to dark gray, very fine grained; contains approximately 10 percent light gray fine grained to medium grained quartzite; and about 10 percent dark gray argillite; in graded beds 10 to 50 cm thick; lightest, coarsest fractions at base, darkest most argillaceous at tops; scoured bases common, parallel laminated, some ripple cross laminations .......................................... | 175 |
| 28. Argillaceous quartzite as above, mainly dark gray .......................................... | 125 |
| 27. Argillaceous quartzite as above, light gray colored beds more abundant, about 20 percent, beds as thick, as 15 to 20 cm; also contains zones of thinly interlaminated, 1-2 mm, argillite and argillaceous quartzite and siltite that commonly contain convolute laminations exhibited as "psuedo-mud cracks" on bedding surfaces; parallel laminations, standing ripples, load casts, and ball and pillow structures also present ..................... | 125 |
| 26. Argillaceous quartzite as above, light gray quartzite is nearly 50 percent of total, has some thinly laminated argillite and quartzite about 1 to 2 mm thick with abundant convolute laminations and fluid escape structures ............................ | 117 |
| 25. Argillaceous quartzite as above, light colored quartzite is minor; graded beds 3 to 10 cm thick ....................................... | 104 |
| 24. Argillaceous quartzite as above, some beds dark greenish gray (5GY4/1) and brownish gray (5YR4/1); most graded beds are 1 to 3 cm thick; upper 6 m contains several beds of light gray quartzite about 10 cm thick .......................................... | 117 |
| 23. Argillaceous quartzite as above, predominantly medium dark gray to dark gray; minor laminae of fine and medium grained quartzite at bases of graded beds and argillite at tops; graded beds 2 to 10 cm ............. | 108 |

| | |
|---|---|
| 22. Argillaceous quartzite as above, more thinly laminated no light colored quartzite, some greenish gray (5G6/1) beds ........................ | 65 |
| 21. Argillaceous quartzite predominantly very fine grained, medium gray to dark gray; graded beds 1 to 10 cm thick, but most commonly 3 to 5 cm thick; light gray fine to medium grained quartzite occurs locally at bases of graded beds; grading exhibited by decreases in maximum grain size, darkening and increase in amount of argillaceous matrix; rarely tops of graded beds are argillite .............................................. | 59 |
| 20. Argillaceous quartzite as above ........................... | 39 |
| 19. Argillaceous quartzite very fine grained, light gray to dark gray, darkening upward in graded beds 1 to 5 cm thick; lenticles of light gray quartzite occur in "pinch and swell" structures .................................. | 86 |
| 18. Argillaceous quartzite as above ........................... | 21 |
| 17. Argillaceous quartzite medium to dark gray, very fine grained in graded beds 3 to 10 cm thick, becoming darker and more argillaceous upward; parallel laminations most common sedimentary structures; sulfides present disseminated along bedding planes; some secondary Cu-carbonate coatings on weathered surfaces ............... | 39 |
| 16. Argillaceous quartzite as above .......................... | 248 |
| 15. Argillaceous quartzite and stratiform massive sulfide; at Little No Name Mine; margins have sulfides concentrated along bedding surfaces of the quartzite; but in the main part of the deposit sulfides are predominant and contain interlaminae of argillite and quartzite; chalcopyrite and pyrite predominant minerals observed; hydrothermally altered to kaolinite and sericite, also present are limonite and jarosite ............................................ | 35 |

14. Argillaceous quartzite medium dark gray to dark gray, very fine grained, graded beds 2 to 5 cm; grading exhibited by darkening upward and the increase in the amount of argillaceous matrix; parallel laminations and cut-and-fill structures common; sulfides disseminated along bedding planes ............. 57

13. Argillaceous quartzite as above, limonite stained ............................................... 85

12. Argillaceous quartzite as above; contains disseminated sulfides medium dark gray to dark gray, also contains few greenish gray beds (5GY6/1) .................................. 195

11. Argillaceous quartzite as above ......................... 132

Total thickness member D, North Fork of Iron Creek ............................................ 1912

Member C

10. Argillaceous quartzite, minor argillite, minor medium to light gray quartzite at bases of graded beds; parallel laminated, splits into thin sheets 2 to 4 cm thick contains sulfides; jarosite-limonite stains common ........................................ 230

9. Argillaceous quartzite, very fine grained, medium dark gray to dark gray, parallel laminated; in graded beds darkening upward, 2 to 5 cm thick, minor light gray quartzite and dark gray argillite ...................... 195

8. Argillaceous quartzite, dark gray, very fine grained, in graded beds becoming darker and increasingly argillaceous upward, and capped by argillite, graded beds 3 to 15 cm thick ................................ 173

7. Argillaceous quartzite, as above, medium dark gray to dark gray, very fine sand to silt, some argillite at tops of graded beds ........................................... 92

6. Argillaceous quartzite, as above, with about 30 percent argillite at tops of graded beds; graded beds 5 to 30 cm thick; includes zone of magnetite mineralization conformable with bedding, also includes pyrite, chalcopyrite, and erytherite ......................... 166

| | |
|---|---|
| 5. Argillaceous quartzite, as above, argillite slightly less abundant graded beds 5 to 20 cm thick ........................................ | 144 |
| 4. Argillaceous quartzite, medium light gray to medium dark gray, very fine grained; minor argillites at tops of graded beds 3 to 10 cm thick ........................................ | 105 |
| Total thickness member C, North Fork of Iron Creek Section ........................................ | 1105 |

Member B

| | |
|---|---|
| 3. Argillaceous quartzite and sandy argillite argillaceous quartzite medium light gray to greenish gray, silt and very fine sand; sandy argillite, mostly greenish gray; coarser fractions locally calcareous some thin veinlets and laminae of secondary calcite ........................................ | 94 |
| 2. Argillaceous quartzite, and sandy argillite as above, parallel laminated graded beds 2 to 3 cm thick, ripped up mud chips common; contains few beds very fine grained argillaceous quartzite 15 to 20 cm thick ........................................ | 169 |
| 1. Argillaceous quartzite and sandy argillite as above; very fine grained argillaceous quartzite is minor, mostly silt size. Beginning section faulted against Challis Volcanics ........................................ | 142 |
| Total exposed thickness member B, North Fork of Iron Creek Section ........................................ | 405 |
| Total thickness Yellowjacket Formation in North Fork Iron Creek Section ........................................ | 3442 |

Section 5. Reference Section of the Yellowjacket Formation in Iron Creek (plotted graphically in plate 9).

| Member D | Thickness in meters |
|---|---|
| 10. Argillaceous quartzite and quartzite; argillaceous quartzite predominant (about 80 percent), dark gray, very fine grained; quartzite medium gray, fine to very fine grained; occur in graded beds 5 cm to 50 cm thick, quartzite when present is at base, graded beds darken upward and become more argillaceous; parallel laminations, ripple cross laminations, load casts present; a few beds occur that are silt sized argillaceous quartzite up to 1 m thick .............................................. | 60 |
| 9. Argillaceous quartzite, as above, quartzite rare, graded beds 10 cm to 50 cm, tops of graded beds locally capped by argillite ranging from partings to beds as much as 10 cm thick ........................................... | 120 |
| 8. Argillaceous quartzite as above, but in float tourmaline breccia was observed, tourmaline as cement between argillaceous quartzite, clasts; breccia was not located in place ...................................... | 114 |
| 7. Argillaceous quartzite, as above, but contains 6 m thick zone of light gray fine grained parallel laminated argillaceous quartzite ................................. | 69 |
| 6. Argillaceous quartzite, as above, without light colored rocks, graded beds up to 2 m thick, argillite partings at tops of graded beds; parallel laminated, ripple cross laminated; intensely silicified .......................................... | 70 |
| 5. Argillaceous quartzite, as above, with minor amounts of light gray quartzite as in 7 above; graded beds 20 cm to 1 m thick, highly silicified ............................... | 116 |
| 4. Argillaceous quartzite as above, but contains a 3 m thick zone of thinly laminated light gray interbedded argillaceous siltite and argillite in graded beds 1 to 3 cm thick ......................................... | 125 |

| | |
|---|---|
| 3. Argillaceous quartzite, as above, without thin bedded light gray zones, intensely silicified ........................................ | 75 |
| 2. Argillaceous quartzite, as above; graded beds 10 to 2 m thick; very fine grained; intensely silicified .................................. | 111 |
| 1. Argillaceous quartzite, as above; graded beds 2 cm to 10 cm thick; light gray to medium gray at base, darkening upward to dark gray; some graded beds capped by thin argillite laminae that form partings between successive graded intervals; parallel laminations, load casts, ball-and-pillow structures, cut and fill structures, and ripple-cross laminations common ...................................... | 138 |
| Beginning section at fault contact with Tcv | |
| Total exposed thickness member D, Yellowjacket Formation Iron Creek Section .......................................... | 998 |

Section 6. Reference Section of the Yellowjacket Formation in Hayden Creek (plotted graphically as plate 10).

| Member B | Thickness in meters |
|---|---|
| Section begins at zone of intense shearing and some brecciation. | |
| 8. Argillaceous quartzite, greenish gray to dark gray, very fine grained in graded beds to 10 cm thick becoming more argillaceous and darker upward; parallel laminated, ripple cross laminated ...................... | 130 |
| 7. Argillaceous quartzite, as above, but mostly greenish gray ........................................ | 135 |
| 6. Argillaceous quartzite, as above, but here contains about 10 percent calcareous argillaceous quartzite, which is brown speckled medium to medium dark gray .................... | 125 |
| 5. Argillaceous quartzite as above, but here contains less calcareous rocks, about 5 percent ............................................ | 270 |
| 4. Argillaceous quartzite, subequal proportions of brown speckled medium gray calcareous fine to medium grained argillaceous quartzite, and light gray argillaceous siltite and very fine grained noncalcareous argillaceous quartzite; parallel laminated, ripple cross laminated; graded beds 10 cm to 50 cm thick ................................ | 260 |
| 3. Argillaceous quartzite, as above, but contains some 2 to 5 cm thick brown very calcareous laminae .................................. | 238 |
| 2. Argillaceous quartzite as in 4 above ..................... | 211 |
| 1. Argillaceous quartzite as in 4 above, here some of the calcareous argillaceous quartzites reach coarse grain size, some ripple-cross laminated siltites exhibit standing ripples .................................... | 215 |
| Total exposed thickness Yellowjacket Formation, member B, Hayden Creek Section ..................... | 1584 m |

Section 7. Reference Section of the Yellowjacket Formation at North Fork (plotted graphically as plate 11).

| Member D | Thickness in meters |
|---|---|
| 86. Argillaceous quartzite; medium dark gray to dark gray; very fine grained; in graded beds 30 cm to 1 m thick, grade upward into very argillaceous dark gray argillaceous quartzite; least argillaceous parts of beds approach quartzite and are very hard (give sharp ring/when struck with pick); darker argillaceous upper parts of beds are about 1/3 of total; parallel laminated, rare ripple-cross laminations .......................................... | 17.0 |
| 85. Argillaceous quartzite, very argillaceous; medium dark gray; very fine grained; parallel laminated ...................................... | 1.0 |
| 84. Covered ...................................................... | 3.0 |
| 83. Argillaceous quartzite, as in 86; but here darker argillaceous Argillaceous quartzite is predominant ............................... | 17.0 |
| 82. Argillaceous quartzite as in 86; graded beds 15 to 50 cm thick ................................ | 8.0 |
| 81. Argillaceous quartzite, as above, medium gray and dark gray fractions are present in about equal amounts; some graded intervals are capped by sandy argillite laminae ................................................ | 21.0 |
| 80. Sandy argillite, dark gray, parallel laminated ............................................. | 0.5 |
| 79. Argillaceous quartzite, as in 81; argillite laminae seldom more than 2 cm thick; most appear as partings between coarser fractions ........... | 19.0 |
| 78. Argillaceous quartzite, as above, but medium gray fractions predominant; some fine grained sand present at bases of graded beds, but uncommon; graded eds 10 to 35 cm thick .......................................... | 32.0 |
| 77. Covered, float as above ................................ | 26.0 |
| 76. Argillaceous quartzite as in 78 ........................... | 2.0 |
| 75. Covered ...................................................... | 45.0 |

74. Argillaceous quartzite, medium dark gray, very fine grained parallel laminated, graded beds 30 to 50 cm thick, limonite stained ........................................ 2.5

73. Covered ........................................ 14.0

72. Argillaceous quartzite as in 74; not limonite stained ........................................ 1.0

71. Covered ........................................ 12.0

70. Argillaceous quartzite as in 74, limonite stained ........................................ 6.0

69. Covered ........................................ 3.0

68. Argillaceous quartzite, medium gray, approaching quartzite, fine to very fine grained ........................................ 1.0

67. Covered ........................................ 7.0

66. Argillaceous quartzite; very fine grained; medium gray and medium dark gray in about equal amounts; parallel laminated ........................ 3.0

65. Argillaceous quartzite, dark gray to grayish black, very fine grained; graded beds 20 to 30 cm thick, becoming darker and more argillaceous (softer) upward; contains one 10 cm bed of medium gray argillaceous quartzite ................................ 5.0

64. Argillaceous quartzite; very fine grained; medium dark gray and dark gray in graded beds 2 to 10 cm thick, darkening upward and becoming more argillaceous; lightest colored beds slightly more abundant .................... 7.0

63. Covered ........................................ 14.0

62. Argillaceous quartzite, dark gray, parallel laminated, in graded beds 2 to 5 cm thick, intensely fractured ............................ 2.0

61. Covered ........................................ 9.0

60. Argillaceous quartzite, medium gray to medium dark gray with minor very argillaceous dark gray quartzite at tops of graded beds; parallel laminated, ripple cross laminated ................................ 25.0

| | |
|---|---|
| 59. Sandy argillite, grayish black, parallel laminated ............................................ | 1.0 |
| 58. Argillaceous quartzite as in 60 .......................... | 4.5 |
| 57. Argillaceous quartzite; white, very fine grained, altered, in irregular zones, now quartz, feldspar and sericite ...................... | 2.0 |
| 56. Argillaceous quartzite, medium dark gray to dark gray, very fine grained, parallel laminated, in part ripple cross laminated; graded beds 10 to 20 cm thick, with sandy argillite laminae at tops, ripped up mud chips occur at bases of a few beds ..................... | 40.0 |
| 55. Argillaceous quartzite, white, altered as at 57 ............................................ | 4.0 |
| 54. Covered .................................................... | 6.0 |
| 53. Argillaceous quartzite, dark gray, very fine grained, parallel laminated ....................... | 2.0 |
| 52. Covered .................................................... | 5.0 |
| 51. Argillaceous quartzite, dark gray, very fine grained, parallel laminated, graded beds 20 to 50 cm thick ...................................... | 3.0 |
| 50. Argillaceous quartzite, dark gray, very fine grained, parallel laminated, feldspathic, biotitic, hard ............................ | 15.0 |
| 49. Argillaceous quartzite, altered, white, as in 57 ............................................ | 1.0 |
| 48. Argillaceous quartzite, medium dark gray to dark gray; very fine grained; in graded beds to 10 cm thick, has few thin sandy argillite laminae at tops of graded beds ............................................ | 6.0 |
| 47. Argillaceous quartzite and sandy argillite as above ............................................ | 15.0 |
| 46. Argillaceous quartzite and sandy argillite as above ............................................ | 14.0 |
| 45. Covered .................................................... | 74.0 |
| 44. Argillaceous quartzite; medium gray to dark gray; in graded beds 10 to 30 cm thick; become more argillaceous and darker upward; parallel laminated ............................ | 15.0 |

| | |
|---|---|
| 43. Argillaceous quartzite, altered, white, as in 57 ........................................ | 6.0 |
| 42. Argillaceous quartzite; alternating medium gray and dark gray in graded beds to 20 cm thick, darkest colors at tops; some beds contain ripped up chip at bases of graded beds ........................................ | 11.0 |
| 41. Covered ........................................ | 23.0 |
| 40. Argillaceous quartzite; medium gray to dark gray; in graded beds 10 to 40 cm thick; very fine grained; few sandy argillite laminae occur at tops of graded beds; cut-and-fill structures very common .................... | 25.0 |
| 39. Covered ........................................ | 6.0 |
| 38. Argillaceous quartzite, medium gray to dark gray; in graded beds 5 to 20 cm thick, darkening upward and becoming more argillaceous upward; very fine grained ................. | 2.5 |
| 37. Covered, float is as above .............................. | 12.0 |
| 36. Argillaceous quartzite, medium gray, parallel laminated with about 25 cm of dark gray very argillaceous quartzite at the top ................. | 1.0 |
| 35. Argillaceous quartzite, white, altered as in 57 ........................................ | 6.0 |
| 34. Covered ........................................ | 3.0 |
| 33. Argillaceous quartzite; medium gray and dark gray in graded beds with dark gray fractions forming thin laminae at tops; parallel laminated .................................... | 20.0 |
| 32. Argillaceous quartzite, medium dark gray, very argillaceous, parallel laminated, in graded beds 5 cm thick or less ...................... | 2.5 |
| 31. Argillaceous quartzite; medium dark gray to dark gray; in graded beds up to 25 cm thick; sandy argillite laminae common at tops of graded beds, which form partings between coarser fractions, parallel laminated, minor ripple cross laminations, cut and fill structures common; hard ................... | 26.0 |

| | |
|---|---|
| 30. Argillaceous quartzite, as above, but mostly medium gray, some sandy argillite laminae reach 2 cm thick and are very biotitic | 20.0 |
| 29. Covered | 6.0 |
| 28. Argillaceous quartzite, as in 30; but here contains fine disseminated pyrite; parallel laminated | 5.0 |
| 27. Argillaceous quartzite; medium gray to dark gray; very fine grained; in graded beds 5 to 20 cm thick; sandy argillite laminae at tops of graded beds commomly form partings between coarser fractions | 18.0 |
| 26. Covered | 2.0 |
| 25. Argillaceous quartzite as in 27 | 10.0 |
| 24. Argillaceous quartzite, altered, white, as in 57; parallel laminations and cross laminations preserved | 5.0 |
| 23. Argillaceous quartzite, dark gray, very fine grained; parallel laminated in graded beds 3 to 15 cm thick | 7.0 |
| 22. Argillaceous quartzite, white, altered, as in 57 | 0.5 |
| 21. Argillaceous quartzite, medium gray and dark gray; in graded beds lightest colored rocks at bases becoming more argillaceous and darker upward; lightest colored rocks also hardest some argillite partings; parallel laminated | 6.0 |
| 20. Argillaceous quartzite, white alterd, as in 57 | 1.5 |
| 19. Argillaceous quartzite, as in 21 | 4.0 |
| 18. Argillaceous quartzite, white, altered as in 57 | 2.0 |
| 17. Argillaceous quartzite, dark gray and medium dark gray; very fine grained in graded beds 5 to 25 cm thick; some thin sandy argillite laminae at tops of graded beds which form partings between coarser fractions; parallel laminated; ripple-cross laminated, cut-and-fill structures also common | 10.0 |

| | |
|---|---|
| 16. Argillaceous quartzite, white as in 57; sedimentary structures preserved some pyrite and limonite ...................................... | 0.5 |
| 15. Argillaceous quartzite; medium gray and dark gray; in graded beds 10 to 30 cm thick, darkening and becoming more argillaceous upward; parallel laminated ............................. | 12.0 |
| 14. Covered .................................................... | 9.0 |
| 13. Argillaceous quartzite, as in 15 .......................... | 7.5 |
| 12. Covered .................................................... | 3.0 |
| 11. Argillaceous quartzite, as in 15 .......................... | 1.0 |
| 10. Covered .................................................... | 5.0 |
| 9. Argillaceous quartzite as in 15 ........................... | 10.0 |
| 8. Covered .................................................... | 4.0 |
| 7. Argillaceous quartzite as in 15; graded beds 5 to 10 cm thick ................................. | 6.0 |
| 6. Argillaceous quartzite; predominantly medium gray, graded beds 5 to 20 cm thick with thin zones of dark gray more argillaceous quartzite at tops; ripple cross laminations common as well as cut-and-fill structures; some magnetite and biotite ............................. | 7.5 |
| 5. Argillaceous quartzite, as above but light and dark fractions in subequal amounts ................. | 4.0 |
| 4. Covered .................................................... | 3.0 |
| 3. Argillaceous quartzite; medium gray to dark gray; in graded beds 5 to 30 cm thick, darkening upward; some beds have some fine grained quartzite at bases but very fine quartzite predominant; some convolute laminations but parallel laminations most common; some float of black tourmaline-rich "argillite" ...................... | 8.0 |
| 2. Covered .................................................... | 2.0 |
| 1. Argillaceous quartzite, as in 3 above .................... | 2.0 |
| Total thickness exposed of member D, Yellowjacket Formation at North Fork ................... | 835.0 |

Section 8. Reference Section of the Yellowjacket Formation at Wagonhammer Creek (plotted graphically as plate 12).

| Member D | Thickness in meters |
|---|---|
| 23. Argillaceous quartzite; medium gray to dark gray; very fine grained graded beds 2 to 30 cm thick, becoming increasingly argillaceous and darker colored upward, some are capped by sandy argillite up to 2 cm thick; parallel laminated; cut-and-fill structures common .......................... | 12.0 |
| 22. Argillaceous quartzite as above, but some graded beds have light gray quartzite at bases .................................................. | 12.0 |
| 21. Argillaceous quartzite and quartzite as above; quartzite is argillaceous but less than 15 percent .................................... | 6.0 |
| 20. Argillaceous quartzite and quartzite as above, thinly bedded, graded beds are 1 to 10 cm thick ........................................ | 2.0 |
| 19. Argillaceous quartzite and quartzite as at 21 .................................................... | 4.0 |
| 18. Argillaceous quartzite and quartzite in graded beds 10 cm to 1 m thick, quartzite at bases becoming more argillaceous upward; very fine grained, rarely fine grained at bases of graded beds; no argillite occurs at tops of graded intervals; parallel laminated; ripple cross-laminated in part ................................ | 12.0 |
| 17. Argillaceous quartzite; medium gray to dark gray; very fine grained; in graded beds 5 cm to 1 m thick, becoming more argillaceous and darker upward, sandy argillite laminae present at tops of graded beds ............................................ | 12.0 |
| 16. Argillaceous quartzite; medium gray to medium dark gray; very fine grained; graded beds 1 cm to 10 cm thick, some light gray sandy argillite occurs at tops of graded beds; parallel laminated ..................... | 3.0 |

| | |
|---|---|
| 15. Argillaceous quartzite; medium gray to dark gray; in graded beds 20 cm to 1 m thick, dark gray rocks minor at tops of graded intervals; parallel laminated, cut and fill structures common at bases of graded intervals ........................................ | 5.0 |
| 14. Argillaceous quartzite, white, bleached, altered; now quartz, feldspar and sericite; irregular zone ........................................ | 12.0 |
| 13. Argillaceous quartzite, medium gray to dark gray, in graded beds 20 cm to 1 m thick, commonly grading upward into sandy argillite; highly fractured; limonite stained; parallel laminated, ripple cross laminated, load casts common, bases of graded beds sharp commonly exhibiting cut-and-fill structures ................................ | 13.0 |
| 12. Argillaceous quartzite, as above, but sandy argillite less common; parallel laminated, ripple-cross laminated in part (about .1 of beds) ...................................... | 38.0 |
| 11. Argillaceous quartzite, as above sandy argillite more abundant, beds reach 10 cm thick ............................................ | 30.0 |
| 10. Argillaceous quartzite, as above; sandy argillite abundant only 2 or 3 beds present, less than 5 cm thick .......................... | 7.0 |
| 9. Argillaceous quartzite, in graded beds 5 cm to 1 m thick, no argillite grading exhibited in darkening upward and increase in argillaceous matrix; very fine grained; parallel laminated few beds ripple cross laminated, bedding discontinuous ........................................ | 6.0 |
| 8. Argillaceous quartzite, as above, very argillaceous, splits into slabs 5 cm or less in thickness .................................... | 1.0 |
| 7. Sandy argillite, dark gray .............................. | 1.0 |

| | |
|---|---|
| 6. Argillaceous quartzite; light gray to dark gray; very fine grained; in graded beds 5 cm to 1 m thick, sandy argillite rarely present at tops of graded beds, grading exhibited by darkening and increase in amount of argillaceous matrix upward; parallel laminated, few beds ripple cross laminated, some asymmetricl ripple marks, cut-and-fill structures common; load casts present in several beds .......................... | 22.0 |
| 5. Sandy argillite, light gray, massive ...................... | 0.5 |
| 4. Argillaceous quartzite; medium gray to dark gray; very fine grained in graded beds 10 cm to 1.5 m thick, sandy argillite rarely occurs at tops of graded beds, more commonly quartzite with less argillaceous matrix grades upward into more argillaceous and darker quartzite; parallel laminated ..................................... | 13.0 |
| 3. Argillaceous quartzite, as above, sandy argillites at tops of graded beds are less than 1 cm thick ................................. | 7.0 |
| 2. Argillaceous quartzite, as above, minor sandy argillite ....................................... | 3.0 |
| 1. Argillaceous quartzite; as above; sandy argillite at tops of graded beds more common, up to 10 cm thick; parallel laminations highlighted by concentrations of dark heavy minerals; ripple cross laminations in few beds; splits into thin sheets 0.3 cm to 3 cm thick ............................ | 4.0 |
| Total thickness of Yellowjacket Formation, member D, Wagonhammer Creek Section ...................... | 222.5 |

Section 9. Reference Section of the Yellowjacket Formation in the Deriar Creek-Stormy Peak Road Area (plotted graphically as plate 13).

| Member E | Thickness in meters |
|---|---|
| 36. Argillaceous quartzite; medium gray and dark gray; in graded beds 5 tro 10 cm thick, lighter colors at base more argillaceous and darker upward; very fine grained, light colored rocks make up about 70 percent of section parallel laminated ........................................ | 36 |
| 35. Argillaceous quartzite as above, but dark colored, most argillaceous material only about 10 percent of total; graded beds 1 to 2 m thick ........................................ | 58.0 |
| 34. Argillaceous quartzite as above; graded beds medium gray at base grading upward into dark gray at top, dark gray rocks most argillaceous and make up less than 20 percent of total 20 cm to 1 m thick, sharp upper and lower contacts; parallel laminated; biotitic; feldspathic ...................... | 41 |
| 33. Covered ................................................ | 3 |
| 32. Argillaceous quartzite, as at 34, but medium dark gray, very little dark gray very argillaceous rock ................................ | 33 |
| 31. Argillaceous quartzite, medium gray to medium dark gray, in graded beds 30 cm to 2 m thick, dark colored and more argillaceous rocks the top, locally capped by sandy argillite; lighter colored rocks are the hardest and make up about 85 percent of section; parallel laminated ........................................ | 46 |
| Total thickness member E, Deriar Creek-Stormy Peak Road Sectiom .................................. | 217 |
| **Member D** | |
| 30. Argillaceous quartzite; dark gray; very fine grained; graded beds 15 to 50 cm thick, becoming more argillaceous upward; parallel laminations ripple-cross-laminations, convolute laminations ..................... | 2 |

29. Argillaceous quartzite, medium gray, very fine grained, much less argillaceous than above, parallel laminated .............................. 4

28. Argillaceous quartzite, as at 30 ......................... 5

27. Argillaceous quartzite; medium gray to dark gray in graded beds up to 1 m thick, darker upward and become more argillaceous upward, dark gray most argillaceous rocks about 40 percent of total volume; parallel laminations, convolute laminations, cut and fill structures; very fine grained ............................................ 8

26. Argillaceous quartzite, dark gray, very fine grained, graded beds 10 to 50 cm thick ................................................. 4

25. Argillaceous quartzite as at 27 .......................... 3

24. Argillaceous quartzite as at 30 .......................... 8

23. Covered ................................................... 3

22. Argillaceous quartzite as at 30 .......................... 5

21. Covered ................................................... 9

20. Quartzite, white, silicified, altered argillaceous quartzite .................................. 3

19. Argillaceous quartzite as at 30, contains small amount medium gray argillaceous quartzite at bases of graded beds, graded beds 15 cm to 1 m thick ................................ 7

18. Argillaceous quartzite as at 30, but medium dark gray ............................................... 16

17. Argillaceous quartzite as above with very minor amounts of medium gray cleaner argillaceous quartzite at bases of graded beds .................................................. 15

FAULT; repeats about 77 m of section (see fig. 44). Description here does not include repeated section. And thickness of deleted part of section is not included in tabulated total thickness at end of measured section and is not included in graphic plot of this measured section (pl.13).

16. Argillaceous quartzite, medium dark gray, very fine grained in graded beds up to 1 m thick, typically capped by 5 to 20 cm of dark gray very argillaceous quartzite, parallel laminated ...................................... 15

| | |
|---|---|
| 15. Argillaceous quartzite as above, but contains more dark gray very argillaceous rock ............................................ | 46 |
| 14. Argillaceous quartzite, dark gray, parallel laminated .......................................... | 4 |
| 13. Argillaceous quartzite as at 16 ........................... | 2 |
| 12. Argillaceous quartzite as at 30 ........................... | 1 |
| 11. Argillaceous quartzite as at 16 ........................... | 6 |
| 10. Argillaceous quartzite as at 30 ........................... | 1 |
| 9. Argillaceous quartzite as at 16, contains minor sandy argillite at tops of a few graded beds, graded beds 5 cm to 1 m thick ............. | 6 |
| 8. Argillaceous quartzite as at 30 ........................... | 4 |
| 7. Argillaceous quartzite as at 16 ........................... | 4 |
| 6. Argillaceous quartzite; dark gray; in graded beds 10 cm to 50 cm thick, more argillaceous upward and darker in color, locally sandy argillite caps graded beds parallel laminations ripple-cross laminations, ripple marks, cut-and-fill structures, flute casts ................................ | 18 |
| 5. Argillaceous quartzite, as above, but has less argillaceous material and is predominantly medium dark gray ......................... | 112 |
| 4. Covered ............................................... | 10 |
| 3. Argillaceous quartzite, as at 6 .......................... | 61 |
| 2. Covered ............................................... | 15 |
| 1. Argillaceous quartzite at 6 ............................. | 46 |
| Total thickness member D ................................ | 443 |
| Total exposed Yellowjacket Formation Deriar Creek-Stormy Peak Road Section ........................ | 660 |

Section 10. Reference Section of the Yellowjacket Formation at Twelve-Mile Creek (plotted graphically as plate 14)

| Member D | Thickness in meters |
|---|---|
| 14. Argillaceous quartzite, medium gray to dark greenish gray (5GY4/1) and dark gray; very fine grained; in graded beds 5 cm to 30 cm thick, becoming more argillaceous and darker upward; parallel laminations, ripple-cross laminations, load casts; feldspathic, biotitic, and very sericitic | 12 |
| 13. Argillaceous quartzite, as above, but contains some light olive gray rock (5Y6/1), and some graded beds are capped by thin laminae of sandy argillite | 34 |
| 12. Argillaceous quartzite as at 14 | 10 |
| 11. Covered | 6 |
| 10. Argillaceous quartzite, as at 14, graded beds up to 50 cm thick | 14 |
| 9. Covered | 47 |
| 8. Argillaceous quartzite, as at 14, graded beds 15 to 30 cm thick with sharp scoured bases, and ripple marked | 18 |
| 7. Argillaceous quartzite, as above but has light gray Argillaceous quartzite at bases of graded beds, which grade upward into very argillaceous light olive gray (5Y6/1) quartzite, graded beds 20 cm to 1.5 m thick | 7 |
| 6. Covered | 2 |
| 5. Argillaceous quartzite as at 7 | 20 |
| 4. Argillaceous quartzite as above but brownish gray (5YR4/1) | 2 |
| 3. Argillaceous quartzite as at 7; graded beds 30 cm to 1.5 m thick, commonly capped by thin laminae of sandy argillite; cut and fill structures very common, parallel laminations nearly ubiquitous, ripple cross laminations; biotitic feldspathic, and abundantly sericitic | 27 |

| | |
|---|---|
| 2. Argillaceous quartzite, as above but mainly medium gray to dark greenish gray and dark gray .......................................... | 15 |
| 1. Argillaceous quartzite as above, graded beds 5 cm to 50 cm thick, still capped by thin laminae of sandy argillite ..................... | 15 |
| Total exposed thickness member D, Yellowjacket Formation in Twelve-Mile Creek Section .................. | 229 |

APPENDIX III

EXPLANATION OF STRATIGRAPHIC COLUMNS

## Explanation of Stratigraphic Columns

## (pls. 4, 6, 8-14)

The Yellowjacket Formation is a thick succession of relatively thin-bedded argillaceous quartzite and sandy argillite. Because of these characteristics, it is difficult to graphically illustrate the sedimentary features in stratigraphic columns of the types normally drawn for sections 10's to 100's of meters thick. Therefore, a system is devised to show small scale features for thick sections of 1000's of meters and at a scale that makes the columns of manageable size. The approach used is a series of parallel columns in which different types of features are described. Bouma (1962) described a similar graphical approach, but it is not entirely applicable to this study because of the thickness of the Yellowjacket and the reconnaissance nature of the study. Bouma's system was designed for very detailed study of sections typically less than 100 m thick and some even only 100's of cm thick. Some of the types of columns and symbols described by Bouma are incorporated and/or modified here.

The explanation, which follows, describes individual columns as they appear on the graphic plots from left to right.

Column 1: Member

A, B, C,. D, or E of the composite stratigraphic section of the Yellowjacket Formation.

Column 2: Interval from Measured Section

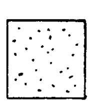
The same numbered intervals used for convenience in measuring and describing the sections appear here, except for plates 4, 11, 12, 13, and 14 where the intervals measured were too thin for the scale of the stratigraphic columns.

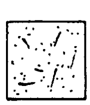
Column 3: Thickness

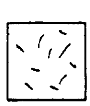
Given in meters; scale is 1:5000.

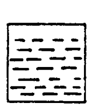
Column 4: Lithology

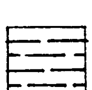
Lithologies are shown symbolically as follows:

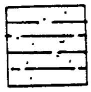
 Quartzite

 Argillaceous quartzite

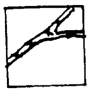
 Argillaceous siltite

 Argillaceous siltite, compositionally mudstone

 Argillite

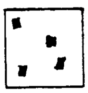


Sandy argillite

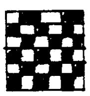


Diabase dike or sill

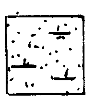
Tourmaline rock



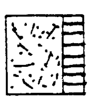
Sulfides disseminated



Massive sulfides with interlaminated argillaceous quartzite



Calcareous quartzite



Associated interbedded or interlaminated lithologies in approximate proportions shown, for example, 75 percent argillaceous quartzite and 25 percent argillite. Vertical representation necessary because typical lithologies are interlaminated on a cm or mm scale.

Column 5: Color

From G. S. A. Rock Color Chart, 1975 reprint, designations used are as follows:

| | |
|---|---|
| N7: light gray | 5Y2/1: olive black |
| N6: medium light gray | 5GY6/1: greenish gray |

N5: medium gray

5GY4/1: dark greenish gray

N4: medium dark gray

5G4/1: dark greenish gray

N3: dark gray

5G3/2: dusky green

N2: grayish black

5YR8/1: pinkish gray

5YR4/1: brownish gray

Column 6: Bedding plane features

A. Type

Bedding planes between successive genetic units typically slightly irregular and distinct.

B. Structures present on bedding surfaces

- Small scale scour pockets (mm depths)
- Load cast
- Asymmetrical ripple marks
- Flute cast
- "Psuedo-mudcracks"

Column 7: Current direction

Measured predominantly from cross lamination attitudes; direction of current is plotted, for example, as follows:

↑ N      ← W      ↗ N50°E

Column 8: Layer features

Sedimentary structures observed within beds, shown symbolically as follows:

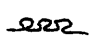
 Parallel lamination

 Ripple-cross lamination

 Climbing ripple lamination

 Graded bedding

 Slump structures

 Convolute lamination

 Load structures

 Fluid-escape structure

 Sand-injection structure

 Pull apart

 Breccia

Column 9: Thickness of graded beds

Given in meters

Column 10: Size range in graded beds

Wentworth size classes were used; first range of sizes listed is the most common, others that follow are also present but less common.

Column 11: Grain size distribution

Wentworth size classes; distribution determined in thin section. Shown in histogram form: 0.1 in = 20 percernt.

Column 12: Mineralogy

Modal composition as determined in thin section. Percentages of quartz, plagioclase, orthoclase, microcline, biotite, and muscovite + sericite are given in histogram form (0.1 in =20 percent). An X appears in the columns for minerals not detected. Accessory minerals are listed in abbreviated form as follows:

| | |
|---|---|
| o = opaque minerals | e = epidote |
| cal = calcite | cl = clinozoisite |
| to = tourmaline | g = garnet |
| z = zircon | s = sulfide |
| chl = chlorite | |

Columns 13-18: ppm Cu, Pb, Zn, Co, Ag, and B.

Content of these elements given for rock samples of the Yellowjacket taken at stratigraphic position indicated by position of line in column 13 (Cu). All analyses done by emission spectroscopy, except Zn, which was done by atomic absorption spectroscopy. N implies element not detected; L implies element detected but at a level below the instrumental detection limit for that element.

# APPENDIX IV

## TRACE-ELEMENT GEOCHEMICAL DATA

## FROM YELLOWJACKET ROCK SAMPLES

Explanation

All data are given in ppm, except for Fe, Mg, Ca, and Ti, which are given in percent. Analyses were done by emission spectroscopy except for Zn analyses on 79- samples, which were done by atomic absorption spectroscopy. Methods of analyses are described in the section of the report on economic geology. N implies an element was not detected; L implies an element was detected but at a level lower than the instrumental detection limit for that element. Ag, As, Au, Bi, Cd, Nb, Sb, W, and Th were not detected in any of the samples of the Yellowjacket analyzed and are therefore not included in the table that follows.

## Trace-Element Geochemistry of the Yellowjacket Formation

| Sample no. | Fe | Mg | Ca | Ti | Mn | B | Ba | Be | Co | Cr | Cu | La | Mo | Ni | Pb | Sc | Sn | Sr | V | Y | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 78-1 | 5.0 | 1.5 | 0.3 | 0.5 | 300 | 50 | 500 | 2 | 15 | 200 | N | 70 | N | 30 | N | 20 | 15 | 150 | 150 | 30 | N | 200 |
| 78109 | 2.0 | 0.5 | .15 | 0.3 | 200 | 20 | 300 | 1 | 10 | 70 | 20 | 50 | N | 15 | 10 | 10 | 10 | 100 | 100 | 20 | N | 15 |
| 78116 | 1.0 | 0.3 | 0.1 | .15 | 200 | 20 | 700 | 1 | 5 | 30 | N | 50 | 5 | 10 | 10 | 5 | N | 200 | 50 | 15 | N | 200 |
| 78128 | 1.5 | 0.3 | 0.1 | 0.2 | 150 | 20 | 700 | 1 | 15 | 50 | 30 | 20 | N | 15 | 10 | 7 | 10 | 150 | 70 | 20 | N | 150 |
| 78149 | 2.0 | 0.7 | 0.1 | .15 | 200 | 15 | 200 | 1 | 10 | 50 | 5 | 50 | N | 15 | 10 | 7 | N | 150 | 70 | 30 | N | 100 |
| 78157 | 2.0 | 0.5 | .07 | 0.2 | 200 | 30 | 500 | 1.5 | 10 | 50 | N | 20 | N | 20 | L | 7 | N | 100 | 70 | 20 | N | 150 |
| 78161 | 3.0 | 0.7 | .15 | 0.3 | 300 | 50 | 500 | 1.5 | 10 | 100 | N | 70 | N | 20 | N | 15 | N | 100 | 100 | 30 | N | 100 |
| 78177 | 5.0 | 0.7 | .05 | 0.3 | 200 | 15 | 500 | 1.5 | 10 | 100 | N | 20 | N | 30 | N | 15 | 10 | 100 | 100 | 20 | N | 150 |
| 78188 | 1.0 | 0.5 | 0.1 | .15 | 150 | 30 | 300 | 1 | 7 | 30 | 15 | 30 | N | 10 | L | 7 | N | 100 | 30 | 15 | N | 100 |
| 78189 | 1.5 | 0.5 | .07 | 0.2 | 150 | 50 | 500 | 1.5 | 7 | 50 | N | 50 | N | 15 | L | 10 | N | 100 | 70 | 20 | N | 100 |
| 78190 | 1.0 | 0.2 | .07 | .15 | 100 | 50 | 300 | 1 | 5 | 50 | L | 20 | N | 10 | N | 7 | L | L | 50 | 15 | N | 150 |
| 78191 | 3.0 | 0.7 | 0.1 | 0.3 | 300 | 50 | 1500 | 1 | 15 | 150 | N | 20 | N | 30 | N | 15 | 10 | 150 | 100 | 20 | N | 200 |
| 78206 | 3.0 | 0.7 | 0.1 | 0.2 | 150 | 70 | 300 | 1.5 | 10 | 70 | N | 50 | N | 20 | N | 10 | L | 150 | 70 | 20 | N | 200 |
| 78220 | 3.0 | 1.0 | 0.1 | 0.2 | 300 | 30 | 200 | 2 | 10 | 70 | 5 | 70 | N | 20 | 20 | 10 | L | 150 | 100 | 30 | N | 150 |
| 78222 | 2.0 | 0.7 | .15 | 0.2 | 200 | 50 | 500 | 1.5 | 7 | 70 | N | 30 | 5 | 20 | N | 10 | L | 100 | 70 | 20 | N | 150 |
| 78223 | 0.7 | .15 | .05 | 0.7 | 70 | 30 | 1000 | 1 | 5 | 150 | 5 | 30 | N | 5 | 15 | 15 | 20 | 150 | 100 | 10 | N | 200 |
| 78236 | 1.5 | 0.2 | .07 | 0.2 | 150 | 15 | 1000 | 1 | 5 | 50 | 10 | 20 | N | 15 | 30 | 7 | N | 150 | 70 | 20 | N | 200 |
| 78244 | 0.7 | .15 | .07 | 0.2 | 50 | 30 | 700 | 1 | N | 70 | 50 | 30 | 20 | 10 | 70 | 10 | 15 | 150 | 70 | 20 | N | 200 |
| 78263 | 3.0 | 0.7 | .07 | 0.3 | 150 | 50 | 1000 | 1 | 10 | 70 | N | 30 | N | 20 | N | 10 | 15 | 250 | 100 | 20 | N | 200 |
| 78299 | 5.0 | 0.5 | .15 | 0.3 | 150 | 50 | 500 | 1.5 | 10 | 70 | N | 20 | N | 20 | N | 10 | L | 100 | 100 | 20 | N | 300 |
| 78340 | 5.0 | 1.0 | 0.1 | 0.5 | 200 | 30 | 700 | 1 | 10 | 100 | N | 30 | N | 20 | N | 15 | 10 | 150 | 150 | 20 | N | 200 |
| 7937 | 5.0 | 0.7 | 0.7 | 0.3 | 700 | 20 | 500 | 3 | 15 | 30 | L | 30 | N | 30 | L | 7 | N | 100 | 50 | 15 | 20 | 500 |
| 7938 | 5.0 | 0.5 | 0.7 | 0.3 | 200 | 20 | 500 | 2 | 15 | 30 | L | 30 | N | 30 | 10 | 7 | N | 100 | 50 | 15 | 15 | 300 |
| 7939 | 7.0 | 0.7 | 0.2 | 0.3 | 150 | 20 | 700 | 1.5 | 10 | 30 | N | 30 | N | 30 | N | 7 | N | 100 | 70 | 15 | 15 | 200 |
| 7940 | 5.0 | 0.5 | 0.2 | 0.3 | 200 | 30 | 700 | 1.5 | 10 | 30 | L | 20 | N | 20 | N | 7 | N | 100 | 70 | 10 | 15 | 300 |
| 7942 | 2.0 | 0.5 | 0.2 | 0.2 | 50 | 10 | 150 | 2 | N | 20 | N | L | N | 15 | N | 5 | N | 100 | 50 | L | 15 | 70 |
| 7943 | 2.0 | 0.5 | 0.1 | 0.2 | 50 | 15 | 700 | 1.5 | N | 30 | N | L | 5 | 15 | 10 | 5 | N | 100 | 70 | L | 10 | 150 |
| 7944 | 0.7 | 0.3 | 0.3 | 0.3 | 50 | 10 | 70 | 1.5 | N | 20 | N | 70 | N | L | L | 5 | N | 100 | 50 | 20 | 10 | 1000 |

Trace-Element Geochemistry of the Yellowjacket Formation (Cont)

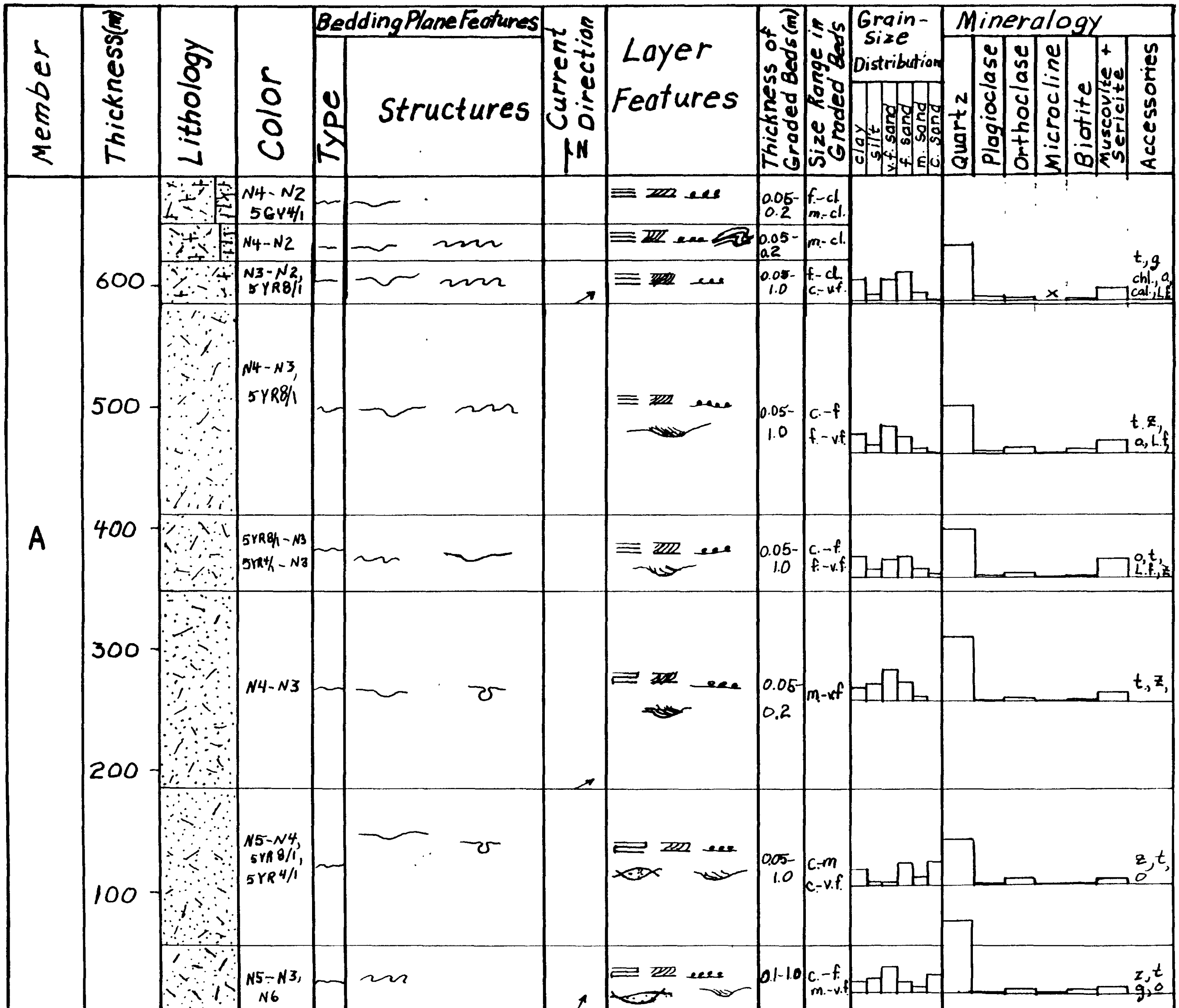
| Sample no. | Fe | Mg | Ca | Ti | Mn | B | Ba | Be | Co | Cr | Cu | La | Mo | Ni | Pb | Sc | Sn | Sr | V | Y | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7945 | 7.0 | 1.0 | 0.3 | 0.3 | 300 | 15 | 700 | 2 | 15 | 30 | N | 70 | 5 | 30 | 15 | 10 | N | 100 | 70 | 30 | 20 | 300 |
| 7948 | 5.0 | 0.5 | 0.7 | 0.2 | 100 | 10 | 300 | 1.5 | N | 20 | L | 50 | N | 15 | N | 7 | N | 150 | 70 | 50 | 10 | 200 |
| 7949 | 7.0 | 1.0 | 0.7 | 0.3 | 300 | 20 | 1000 | 1.5 | 15 | 100 | N | 150 | N | 50 | N | 15 | N | 100 | 150 | 50 | 15 | 500 |
| 7952 | 5.0 | 0.5 | 0.7 | 0.2 | 70 | 10 | 1000 | 1.5 | N | 30 | N | 30 | N | 10 | L | 5 | N | 100 | 70 | 100 | 10 | 300 |
| 7979 | 10 | 1.5 | 0.1 | 0.5 | 500 | 50 | 1000 | 3 | 10 | 70 | L | 50 | N | 20 | 15 | 15 | N | 100 | 100 | 50 | 65 | 300 |
| 7981 | 10 | 1.0 | 0.2 | 0.5 | 500 | 70 | 1000 | 3 | 15 | 100 | 5 | 30 | N | 30 | N | 15 | N | 100 | 150 | 15 | 25 | 300 |
| 7983A | 5.0 | 0.7 | L | 0.3 | 1000 | 15 | 300 | 1 | 7 | 20 | 10 | 20 | N | 15 | N | 5 | N | L | 50 | 15 | 30 | 200 |
| 7983B | 10 | 1.0 | 0.3 | 0.3 | 1500 | 20 | 700 | 3 | 20 | 30 | 30 | 100 | N | 50 | N | 10 | N | 100 | 100 | 50 | 70 | 200 |
| 7987 | 7.0 | 0.7 | .05 | 0.5 | 1000 | 300 | 700 | 2 | 15 | 100 | 5 | 30 | N | 30 | N | 15 | L | 100 | 150 | 20 | 40 | 300 |
| 7989 | 10 | 1.5 | 0.1 | 0.5 | 200 | 100 | 700 | 2 | 10 | 50 | N | N | N | 20 | N | 15 | N | 100 | 150 | 30 | 30 | 300 |
| 7990 | 10 | 1.0 | 0.7 | 0.5 | 1500 | 200 | 700 | 2 | 15 | 100 | 50 | 50 | N | 30 | 20 | 15 | L | 100 | 150 | 30 | 55 | 300 |
| 7991 | 7.0 | 1.0 | 0.7 | 0.3 | 1000 | 30 | 700 | 2 | 10 | 20 | 15 | 50 | N | 20 | 30 | 7 | N | 150 | 70 | 30 | 60 | 300 |
| 7992 | 7.0 | 1.0 | 0.7 | 0.3 | 700 | 30 | 1000 | 2 | 15 | 50 | 15 | 50 | N | 30 | N | 7 | L | 100 | 100 | 30 | 55 | 500 |
| 7998 | 10 | 1.0 | 0.5 | 0.3 | 500 | 100 | 300 | 2 | 15 | 20 | 5 | N | N | 20 | N | 7 | N | L | 10 | 15 | 25 | 200 |
| 79153 | 7.0 | 1.0 | .05 | 0.5 | 500 | 2000 | 700 | 1.5 | 7 | 30 | L | N | N | 10 | N | 15 | N | 100 | 100 | 10 | 5 | 500 |
| 79210 | 2.0 | 0.5 | 0.5 | 0.3 | 300 | 30 | 200 | 1 | 10 | 20 | L | 20 | N | 20 | 50 | 7 | N | 150 | 50 | 20 | 90 | 150 |
| 79211 | 3.0 | 1.0 | .07 | 0.5 | 500 | 50 | 300 | 1.5 | 15 | 50 | L | 50 | N | 20 | 20 | 10 | N | 150 | 100 | 30 | 25 | 200 |
| 79212 | 3.0 | 1.0 | .15 | 0.5 | 200 | 50 | 300 | 1.5 | 7 | 50 | 10 | 30 | N | 20 | 15 | 10 | N | 100 | 100 | 20 | 30 | 300 |
| 79213 | 2.0 | 1.0 | 0.3 | 0.3 | 150 | 20 | 500 | 2 | 5 | 15 | N | 50 | N | 10 | 10 | 7 | N | 100 | 50 | 50 | 15 | 200 |
| 79214 | 5.0 | 1.5 | .15 | 0.5 | 500 | 30 | 700 | 1.5 | 5 | 50 | N | 50 | N | 20 | 15 | 15 | L | 100 | 100 | 50 | 25 | 200 |
| 79215 | 5.0 | 0.7 | .15 | 0.3 | 150 | 20 | 300 | 1 | 15 | 20 | 20 | 30 | N | 15 | 10 | 10 | L | 100 | 70 | 30 | 20 | 200 |
| 79216 | 3.0 | 0.7 | .05 | 0.5 | 150 | 20 | 200 | 1 | 15 | 20 | N | N | N | 15 | L | 10 | L | L | 70 | 30 | 25 | 200 |
| 79217 | 5.0 | 2.0 | 0.7 | 0.7 | 500 | 30 | 500 | 1.5 | L | 100 | 5 | 100 | N | 20 | 15 | 30 | N | 300 | 150 | 70 | 30 | 300 |
| 79218 | 3.0 | 1.0 | .05 | 0.5 | 150 | 50 | 700 | 1 | 30 | 50 | 30 | 30 | 7 | 20 | L | 20 | N | N | 100 | 50 | 20 | 200 |
| 79219 | 5.0 | 1.0 | .05 | 0.3 | 150 | 30 | 500 | 1 | 30 | 30 | L | 30 | N | 30 | L | 10 | L | N | 70 | 20 | 30 | 100 |
| 79221 | 3.0 | 0.7 | 0.1 | 0.3 | 300 | 15 | 100 | 3 | 15 | 20 | 20 | 50 | N | 10 | 10 | 7 | N | 100 | 30 | 100 | 30 | 300 |
| 79222 | 3.0 | 1.5 | 0.5 | 0.7 | 300 | 30 | 700 | 2 | 15 | 70 | N | 70 | N | 30 | 20 | 20 | N | 100 | 150 | 70 | 40 | 200 |
| 79308 | 3.0 | 1.0 | .15 | 0.5 | 1000 | 50 | 500 | 2 | 7 | 50 | N | N | N | 15 | 15 | 20 | N | L | 100 | 70 | 30 | 300 |
| 79309 | 5.0 | 0.7 | .07 | 0.3 | 1000 | 50 | 150 | 2 | 7 | 50 | 20 | N | 7 | 15 | 15 | 10 | N | N | 100 | 20 | 55 | 200 |

Trace-Element Geochemistry of the Yellowjacket Formation (Cont)

| Sample no. | Fe | Mg | Ca | Ti | Mn | B | Ba | Be | Co | Cr | Cu | La | Mo | Ni | Pb | Sc | Sn | Sr | V | Y | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 79310 | 5.0 | 0.5 | 0.1 | 0.3 | 1500 | 30 | 200 | 1.5 | 7 | 30 | 20 | L | 5 | 30 | 15 | 10 | N | L | 70 | 15 | 540 | 100 |
| 79311 | 3.0 | 0.7 | 0.2 | 0.5 | 700 | 50 | 500 | 2 | 7 | 50 | 15 | 20 | N | 20 | 30 | 15 | N | 100 | 100 | 20 | 150 | 150 |
| 79312 | 2.0 | 0.5 | .15 | 0.3 | 1000 | 30 | 500 | 1 | 10 | 30 | L | 20 | N | 20 | 20 | 10 | N | L | 70 | 20 | 190 | 150 |
| 79313 | 3.0 | 0.5 | .15 | 0.3 | 500 | 70 | 300 | 2 | 5 | 30 | N | 20 | N | 10 | L | 10 | N | L | 70 | 30 | 50 | 300 |
| 79314 | 3.0 | 0.7 | 0.2 | 0.5 | 300 | 50 | 300 | 1.5 | 5 | 30 | 5 | 20 | N | 15 | 20 | 10 | N | L | 70 | 30 | 45 | 200 |
| 79315 | 3.0 | 0.5 | .05 | 0.2 | 100 | 20 | 150 | 1 | N | 15 | L | 20 | N | 15 | L | 5 | N | N | 30 | 20 | 55 | 150 |
| 79317 | 1.0 | 0.2 | 1.0 | 0.3 | 200 | 30 | 300 | 1 | N | 15 | 700 | 30 | N | 5 | L | 5 | N | 100 | 20 | 30 | 20 | 300 |
| 79319 | 2.0 | 0.5 | .05 | 0.2 | 20 | 30 | 300 | 1 | N | 20 | N | 20 | N | 15 | L | 5 | N | L | 30 | 15 | 20 | 150 |
| 79321 | 3.0 | 2.0 | 0.3 | 0.5 | 300 | 30 | 700 | 1.5 | 10 | 50 | N | 50 | 7 | 20 | L | 15 | N | 150 | 100 | 50 | 40 | 200 |
| 79324 | 2.0 | 0.3 | .05 | 0.2 | 50 | 70 | 200 | L | N | 15 | N | 50 | N | 10 | 10 | 7 | N | N | 50 | 50 | 15 | 300 |
| 79327 | 2.0 | 0.5 | 0.2 | 0.3 | 150 | 50 | 300 | 1.5 | 10 | 20 | N | 50 | N | 20 | L | 10 | N | L | 70 | 30 | 60 | 200 |

# PLATE 4

## Shovel Creek Section




Open File Report 81-1088 For Explanation see Appendix 3

# PLATE 12

## Wagonhammer Creek Section

| Member | Thickness (m) | Lithology | Color | Bedding Plane Features: Type | Bedding Plane Features: Structure | Current Direction | Layer Features | Thickness of graded beds (m) | Size-Range in Graded Beds | Grain-size Distribution (clay, silt, v.f. sand, f. sand, m. sand, c. sand) | Mineralogy (Quartz, Plagioclase, Orthoclase, Microcline, Biotite, Muscovite + Sericite) | Accessories | ppm Cu | ppm Pb | ppm Zn | ppm Co | ppm Ag | ppm B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | 200 | | N5-N3 | | | | | 0.05-1.0 | v.f. v.f.-cl | | | o, t, z | L | N | | 5 | N | 50 |
| | 150 | | N5-N3 | | | | | 0.05-1.5 | v.f. vf.-cl. | | | | | | | | | |
| | 100 | | N5-N3 | | | | | 0.05-1.0 | v.f. v.f.-cl. | | | o, t, | | | | | | |
| | | | N6-N3 | | | | | 0.10-1.0 | v.f. v.f.-cl. | | | | 5 | L | | 10 | N | 30 |
| | 50 | | N5-N3 | | | | | 0.10-1.5 | v.f v.f.-cl. | | | o, t, z | | | | | | |

Open File Report 81-1088

For Explanation See Appendix 3

# PLATE 13

## DERIAR CREEK–STORMY PEAK ROAD SECTION

| Member | Thickness (m) | Lithology | Color | Bedding Plane Features: Type | Bedding Plane Features | N Current Direction | Layer Features | Thickness of Graded Beds (m) | Size Range in Graded Beds | Grain-Size Distribution (clay, silt, v.f. sand, f. sand, m. sand, c. sand) | Mineralogy (Quartz, Plagioclase, Orthoclase, Microcline, Biotite, Muscovite + Sericite) | Accessories | ppm Cu | ppm Pb | ppm Zn | ppm Co | ppm Ag | ppm B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E | 600 | | N6-N4 | | | | | 0.30-2.0 | v.f. f.-cl. | | | o, z cl. | | | | | | |
| | | | N6-N4, N3 | | | | | 0.30-2.0 | v.f. f.-s | | | o, cl, | | | | | | |
| | 500 | | N6-N4 | | | | | 0.30-2.0 | v.f f.-s. | | | o, t, cl, | N | L | 10 | N | N | 10 |
| D Fault | 400 | | N5-N3 | | | | | 0.05-1.0 | v.f. v.f-cl. | | | o, cl, | L | N | 10 | N | N | 10 |
| see meas. sec. 9 | 300 | | N5-N3 | | | | | 0.05--1.0 | v.f. v.f-cl. | | | o, L.f, t | N | 10 | 10 | N | N | 15 |
| D | | | N4-N3 | | | | | 0.05-1.0 | v.f v.f-cl. | | | | N | N | 15 | N | N | 10 |
| | 200 | | N5-N3 | | | | | 0.10-0.50 | v.f. v.f-cl. | | | L.f., o, z g. | L | N | 15 | 10 | N | 30 |
| | 100 | | N5-N3 | | | | | 0.10-0.50 | v.f v.f-cl c.-cl. | | | o, t, z | N | N | 15 | 10 | N | 20 |
| | | | N4-N3 | | | | | 0.10-0.50 | v.f. v.f-cl. c.-cl. | | | t, o, L.f, cl, z | L | L | 20 | 15 | N | 20 |



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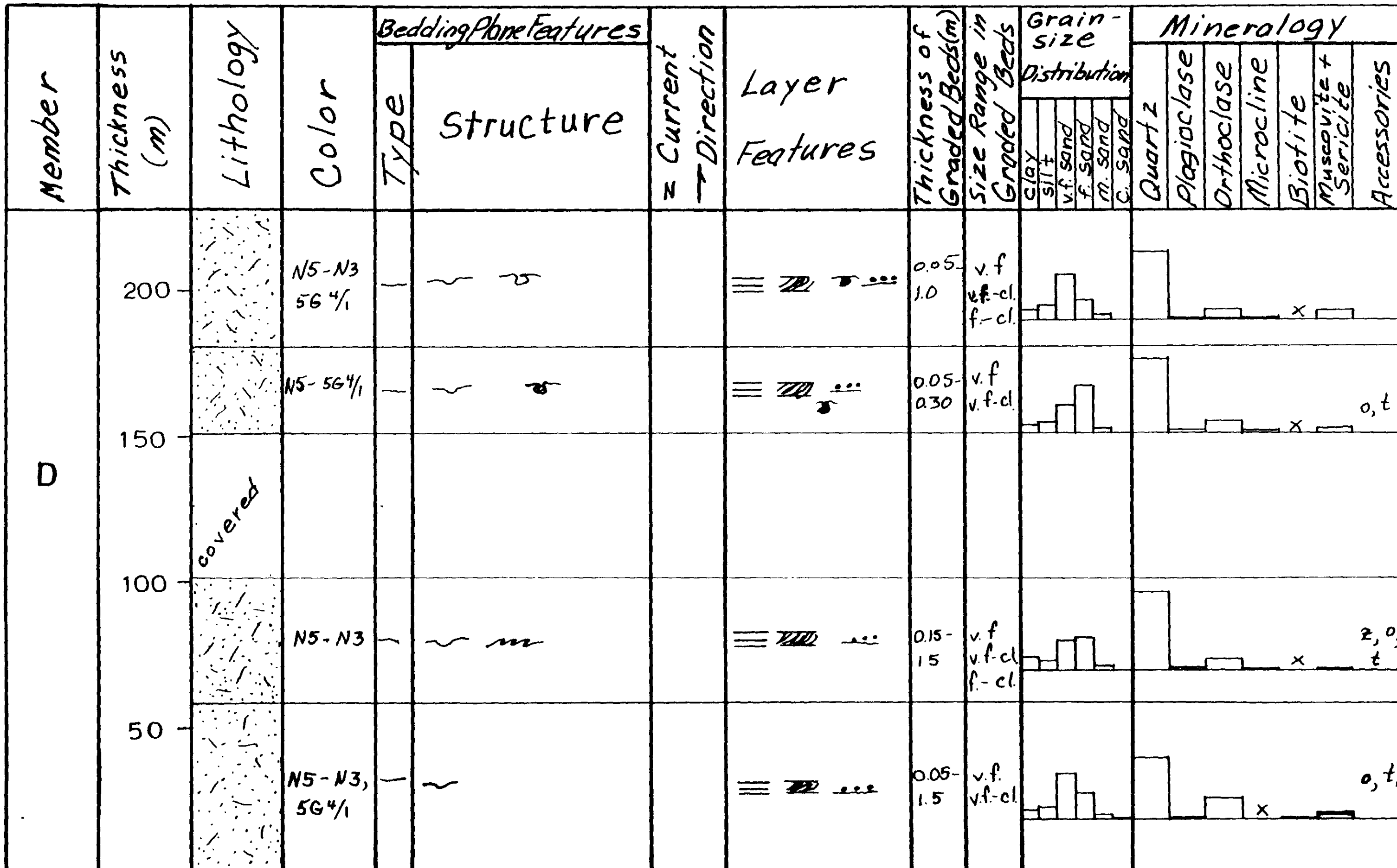
For Explanation See Appendix 3

# PLATE 14

# TWELVE-MILE CREEK SECTION

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For Explanation See Appendix 3