U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

SCAPOLITIC METAEVAPORITE AND CARBONATE ROCKS OF PROTEROZOIC YELLOWJACKET FORMATION, MOYER CREEK, SALMON RIVER MOUNTAINS, CENTRAL IDAHO

by

R.G. TYSDAL[1] and G.A. DESBOROUGH[1]

Open-File Report 97-268

[1]Denver, Colorado

1997

CONTENTS

ABSTRACT

Interstratified scapolite-rich rock and metalimestone occur along Moyer Creek in the eastern part of the Salmon River Mountains of east-central Idaho, and correlate with similar strata in the lower part of the Yellowjacket Formation of the type area. Repetition of three interbedded lithologies characterize the Moyer Creek strata: (1) metalimestone, metamorphosed silty limestone; (2) scapolite-rich rock, metamorphosed silty carbonate rock that originally contained halite and probably dolomite; and (3) scapolitic siltite, metamorphosed siltstone that originally contained some halite. A fourth lithology is metalimestone that contains a disrupted sedimentary fabric and contains abundant tourmaline and phlogopite. These lithologies are interpreted as components of an evaporite sequence that was metamorphosed to biotite-grade greenschist facies. The depositional setting likely was marginal marine, based on the sequence of strata within which the metaevaporites are contained, and on the absence of lithologies that typically characterize lacustrine evaporites. Concealed (meta)evaporites of this sequence may have supplied chlorine and associated elements to syndepositional and (or) post-depositional hydrothermal mineralizing fluids in the region.

Scapolite of the Yellowjacket Formation of the Moyer-Yellowjacket Creek study area ranges from Me_{20} to Me_{50}, and is rich in sodium and chlorine. For scapolites in equilibrium with both calcite and albite (excess Ca and Na), the composition is 30 percent meionite. These compositions are similar to those observed by previous workers for scapolite in Proterozoic strata north and east of the Idaho batholith. Chemical data presented here show high values of chlorine, bromine, fluorine, and boron (in one sample) and are inferred to indicate that the strata originated in an evaporite environment.

INTRODUCTION

Scapolite-rich rock and interstratified metalimestone occur along Moyer Creek in the eastern part of the Salmon River Mountains of east-central Idaho (figs. 1, 2). Scapolite of the compositions observed in the study area requires NaCl as a source of the abundant chlorine and sodium. Halite of evaporites may have supplied these elements because the volume of sodium in the scapolite is much greater than that which could have been derived from other types of source rocks. The focus of this paper is on the sedimentology and mineralogy of the interstratified scapolite-rich rock and metalimestone, to establish the previously unrecognized evaporite precursor of these metamorphosed strata.

Mineral deposits of the region may have been markedly affected by the evaporites, but investigations concerning interrelationships of evaporites and mineral deposits are not pursued here. Nevertheless, we emphasize that evaporites (1) may have made a significant contribution to the composition of mineralizing fluids and (2) may need to be accomodated in interpretations of the regional depositional setting for exhalative deposits. Mineralizing fluids, whether of post-evaporite syndepositional exhalative deposits or later hydrothermal mineral deposits, likely would have moved upward through the evaporites. Halogen elements would have been scavenged, forming brines that

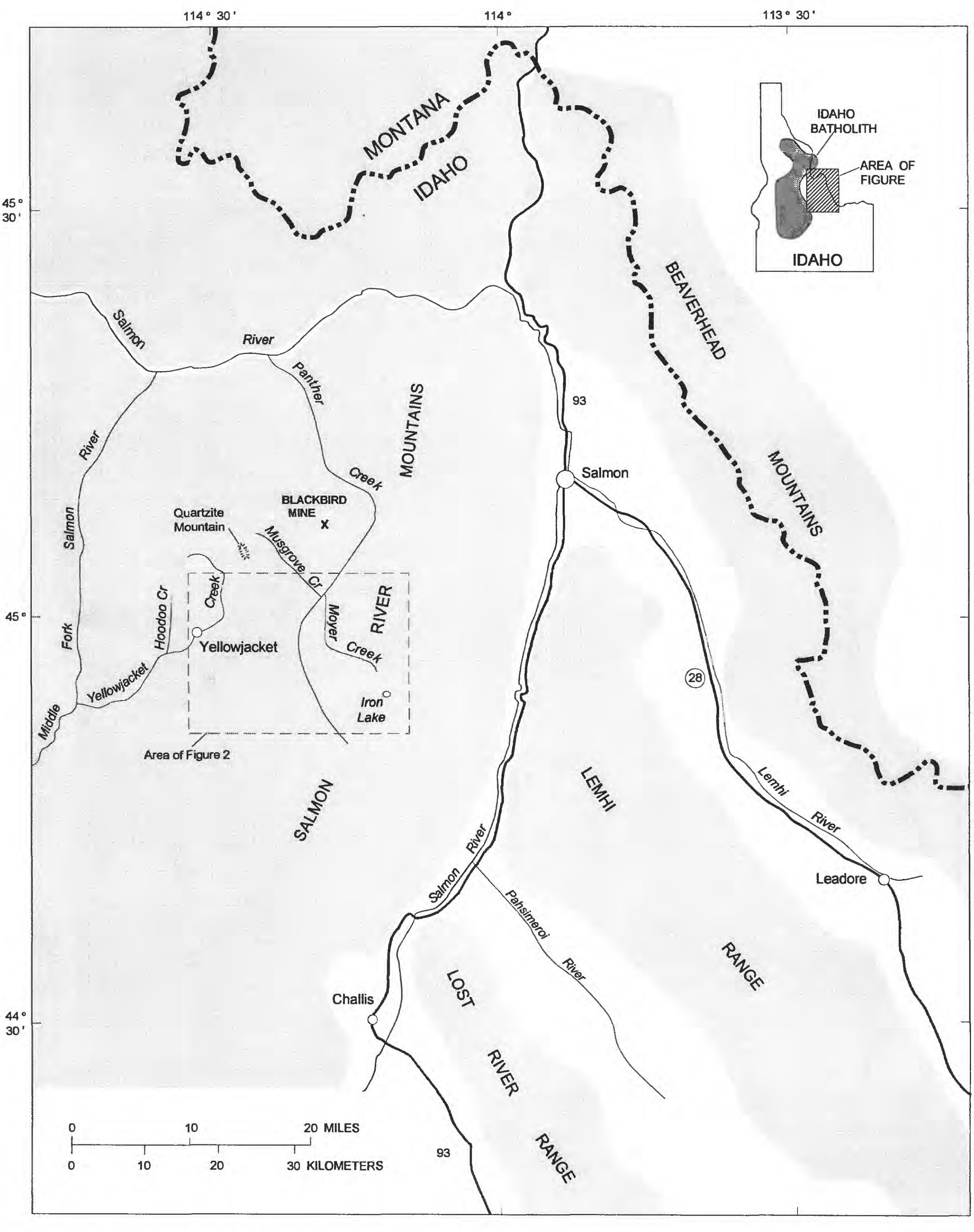
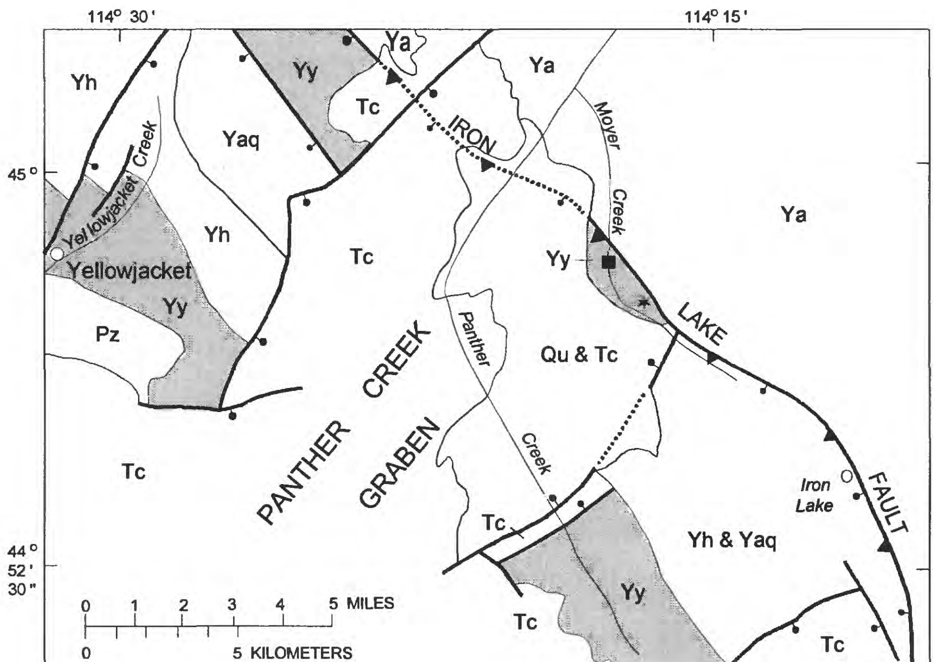


Figure 1. Index map of east-central Idaho, showing geographic features in vicinity of Moyer Creek.



EXPLANATION

Qu	Quaternary sediments, undivided
Tc	Eocene Challis Volcanic Group
Pz	Paleozoic rocks, undivided
	Middle Proterozoic units
Ya	Apple Creek Formation, undivided
Yaq	Unnamed unit (argillaceous quartzite of Ross, 1934)
Yh	Hoodoo Quartzite
Yy	Yellowjacket Formation (as unit defined by Ross, 1934)

- Contact
- Normal fault; ball-and-bar on downthrown side
- Thrust fault, with later normal fault movement
- * Site of Moyer Creek measured section
- ■ Site of sample 93ITz109

Figure 2. Geologic map of Moyer Creek area, southern part of Salmon River Mountains. Mapping from Ekren (1988), modified by Tysdal (unpub. mapping, 1995-96).

themselves became efficient at scavenging metallic elements from any rocks (or sediments) through which they moved. The Cu-Co-Au deposits of the Blackbird mining district (fig. 1) and contiguous terrane, for example, are stratabound Fe-silicate facies rocks that are rich in biotite, iron, and chlorine; some Fe-rich biotite contains as much as 1.87 percent Cl (Nash and Connor, 1993). Evaporites may have yielded this chlorine.

Examination of the interstratified scapolite-rich rock and metalimestone was undertaken initially to evaluate their limestone content for possible application in reclamation of mine waste. The small volume of limestone, and the intimately interbedded relationship with the scapolitic rock, deemed the strata unacceptable for the intended reclamation use. The abundance and sedimentologic characteristics of the scapolite-rich strata led us to make further investigations, however, because of the aforementioned implications for geologic and geochemical relationships with mineralization in the Salmon National Forest.

Scapolite in the Middle Proterozoic Wallace Formation of the Belt Supergroup of northern Idaho and western Montana has been the object of study for several authors (Hietenan, 1967; La Tour, 1974; Mora and Valley, 1989, 1991). These studies focused on mineralogy and, except for La Tour (1974), called on the occurrence of halite in the sediments to account for the needed sodium and chlorine to form the scapolite. None of the reports, however, presented sedimentological data to support the mineralogical transformation from halite-bearing sediments to the scapolite-bearing metamorphic rocks. In this paper, we make a preliminary interpretation of depositional setting of the Moyer Creek strata based on our reconnaissance examination, which includes a measured section (fig. 3). We also examined, sampled, and analyzed similar rocks in the principal reference section[1] of the Yellowjacket Formation along Yellowjacket Creek, correlating the Moyer Creek strata with those of the formation in the vicinity of the townsite of Yellowjacket, where the formation was originally mapped and named by Ross (1934). Our discussion is primarily concerned with the Moyer Creek strata, however, which afforded the best exposures.

FIELD RELATIONSHIPS

The interstratified scapolite-rich rock and metalimestone of Moyer Creek were shown at the leading edge of a thrust plate by Rember and Bennett (1979) and Connor (1990, fig. 2a), or displaced by a reverse fault (Ekren, 1988; Fisher and others, 1992); we follow the thrust fault interpretation. In addition, our mapping in the Moyer Creek area shows that a steeply dipping normal fault delimits the northeast side of the strata. Hence, these rocks occur at the leading edge of a thrust plate that has been downfaulted.

---

[1]Naming of the Yellowjacket Formation preceded the designation of a type section as required by guidelines of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Hence, Ekren (1988) designated the section measured by Ross (1934) along Yellowjacket Creek (fig. 2), for about 7 km north from the townsite of Yellowjacket, as the principal reference section of the Yellowjacket Formation and the overlying Hoodoo Quartzite.

STRATIGRAPHY

The interbedded metalimestone and scapolite-rich rocks of Moyer Creek are similar to strata that Ross (1934), Carter (1981), and Ekren (1988) reported to occur locally within the Yellowjacket Formation in the vicinity of the townsite of Yellowjacket (figs. 1, 2). Rember and Bennett (1979) and Ekren (1988, pl. 2) included the scapolitic rock and metalimestone of Moyer Creek within undivided Yellowjacket Formation, which their correlation charts show to underlie Hoodoo Quartzite. In contrast, in a structural section that crosses Moyer Creek, Connor (1990, fig. 3) included the scapolitic rock and metalimestone within strata that he showed as directly overlying the Hoodoo Quartzite, and assigned the rocks to his lower subunit of the Yellowjacket Formation. [Tysdal (work in progress) reassigned the subunit to the coarse siltite unit of the Apple Creek Formation.] Strata that directly and conformably overlie the Hoodoo are an unnamed unit of argillaceous quartzite of Ross (1934), who originally defined the Yellowjacket, Hoodoo, and overlying unnamed unit in the vicinity of the townsite of Yellowjacket (fig. 2). The scapolitic rock and metalimestone are unlike any strata known to us within the unnamed argillaceous quartzite unit in the vicinity of the principal reference section or in the vicinity of Iron Lake, near Moyer Creek (fig. 2). We interpret the metalimestone and scapolite-rich rock of Moyer Creek to be part of the Yellowjacket, as the formation was originally defined by Ross (1934), conformable beneath the Hoodoo Quartzite.

STRUCTURE

The interbedded scapolite-rich rock and metalimestone of Moyer Creek form a wedge-shaped sliver of strata bordered by the Iron Lake fault on the northeast, and by volcanic rocks of the Eocene Challis Volcanic Group and Quaternary sediments on the southwest (fig. 2). The Iron Lake name was introduced by Ekren (1988) who interpreted the structure as a reverse fault. The fault previously was interpreted as a southwest dipping thrust on the map of Rember and Bennett (1979) who showed it to delimit the Hoodoo Quartzite and the overlying unnamed unit that were displaced northeastward in the vicinity of Iron Lake (fig. 2). The Iron Lake fault is here interpreted as a thrust fault that underwent later normal (back-slip) displacement. Such a reversal of movement is a pattern observed along some faults in the Lemhi Range (Tysdal, 1996a, b; Tysdal and Moye, 1996).

The steeply southwest-dipping segment of the Iron Lake normal fault that delimits the northeast side of the wedge separates the scapolitic rock and metalimestone from turbidites to the northeast. The fault segment is marked by the high contrast in rock types on opposite sides of it, nearly opposed strike directions of rocks on opposite sides, and local sulfide mineralization along the fault.

Southwest of the Iron Lake fault, the wedge of Yellowjacket strata along Moyer Creek lies within a down-faulted block of the Panther Creek graben, between northeast trending faults of the Tertiary Trans-Challis fault system (fig. 2). Relative to the Hoodoo Quartzite and the conformably overlying unnamed unit of argillaceous quartzite in the Iron Lake area to the southeast, however, the wedge of Yellowjacket strata is upthrown. This seeming paradox is explained by the wedge of Yellowjacket strata having been displaced upward a greater amount during thrusting, and later downdropped a lesser amount during normal displacement along the Iron Lake fault, than the strata of the Iron Lake area.

The foregoing interpretation indicates that rocks southwest of the Iron Lake fault were displaced to the northeast, as interpreted by Rember and Bennett (1979), Ekren (1988), and Connor (1990), later downfaulted by a normal fault on the northeast, perhaps concurrently with downfaulting of the wedge within the Panther Creek graben (fig. 2).

METAMORPHISM

Rocks of Moyer Creek and along Yellowjacket Creek have been metamorphosed to the biotite grade of the greenschist facies. As a result, the original depositional textures of some rocks were destroyed during recrystallization. The metamorphic environment likely was an open system; some chemical elements of evaporites are highly mobile and may have escaped during heating, changing the original bulk chemistry of the strata. Hence, the interpretations of depositional environments presented here required looking through a mask of metamorphic minerals and processes. The Moyer Creek measured section is composed of three main interbedded lithologies: (1) metalimestone, metamorphosed silty limestone; (2) scapolite-rich rock, metamorphosed silty carbonate rock that originally contained halite and probably dolomite; and (3) scapolitic siltite, metamorphosed siltstone that originally contained some halite. Scapolite clearly is a key metamorphic mineral in these rocks and it and several other metamorphic minerals are discussed in the following section. Scapolite is discussed at some length because it is important to the inference of the precursor minerals and to the sedimentological interpretation of the host strata.

Mineralogy and Geochemistry

Major and minor minerals of 17 samples from Yellowjacket Creek and Moyer Creek are given in table 1. All contain major or minor amounts of quartz. Nine contain major amounts of phlogopite. Four samples have major amounts of albite and these have no detectable scapolite. Microcline is a major mineral (to 20 percent) in seven samples but was not detected in seven other samples. Major amounts of calcite were found in five samples but it was undetected in 11 other samples; the metalimestones contain about 35 to 60 percent calcite. Tourmaline was identified in two samples where it occurs only in small amounts. Minor or major amounts of scapolite (to 40 percent) were detected in 12 of the 17 samples (table 1). The compositions reported for scapolites in table 1 are based on estimates using the X-ray diffraction method of Burley and others (1961) after removal of calcite from the samples using 10 wt. percent HCl. Up to 60 percent albite is present in siltites of Yellowjacket Creek where all of the siltites have albite as the major Na-rich mineral. In contrast the siltites of Moyer Creek contain scapolite, phlogopite, and microcline but no albite.

Scapolite composition ideally ranges from end members meionite ($Ca_4[Al_6Si_6O_{24}]CO_3$) to marialite ($Na_4[Al_3Si_9O_{24}]Cl$). In nature scapolite occurs in a solid solution series in which Ca, Na, and K (substituting for Na) are present in the crystal lattice; the mineral composition is expressed as percent meionite (Burley and others, 1961). La Tour (1974) studied scapolite-bearing greenschist metasedimentary rocks of the Wallace Formation along the east flank of the Idaho batholith, near Skalkaho Pass, Montana (fig. 1--about 50 km north of the area of figure 1, vicinity of 114° W. long., 46° 15° N. lat.), which is about 150 km north-northeast of the present study area (fig. 1). He reported as much as 25 percent scapolite (meonite 21-45 percent) in calcite-rich (to 80 percent) rocks that contained up to 45 percent albite and up to 12 percent microcline; phlogopite was the dominant mica. He also reported dolomite of 15 and 30 percent in two samples with no associated phlogopite. In contrast, no dolomite was present in samples that contained up to 30 percent phlogopite. La Tour (1974) also found talc (7 samples) and actinolite (12 samples) to be mutually exclusive in the scapolite-bearing and associated strata. He pointed out that Gordon and Greenwood (1970) recognized the reaction: dolomite + quartz + water ⇋ talc + calcite + CO_2, but talc is sparse or absent in many metamorphosed siliceous dolomites because of small amounts of Al_2O_3 or K_2O in the system; either chlorite (Fawcett and Yoder, 1966) or phlogopite (Gordon and Greenwood, 1970), respectively, may be formed instead, as follows:

talc + K-feldspar ⇋ phlogopite + 4 quartz

We believe dolomite that may have been present in our study area was converted to phlogopite and calcite during metamorphism because of the abundance of K and Al (table 2) in the originally impure dolomitic limestones. Sample 93ITZ109 (tables 1, 2), a phlogopite-rich metalimestone, has the most MgO (7.6 wt. percent). All of the samples have between 5.4 and 17 percent Al_2O_3, and 0.6 to 6.8 percent K_2O (except the albite-quartz rock--96ITz104A).

Scapolite of the Yellowjacket Formation in the Moyer-Yellowjacket Creek study area ranges from Me_{20} to Me_{50} (table 1), thus is toward the marialite end of the compositional spectrum and is rich in Na and Cl (table 2). The composition of these scapolites in equilibrium with both calcite and albite (excess Ca and Na) in rocks of Moyer-Yellowjacket Creek area is 30 percent meionite (table 1--96ITZ2B). This scapolite composition is in good agreement with the data of Mora and Valley (1989, table 3) who reported scapolite composition ranging from 32.5 to 38.0 percent meionite for 11 biotite-carbonate granofels samples that contained both calcite and albite (Ab_{85-99}) and are considered to be greenschist facies rocks by Hietenan (1967). The scapolites studied by Hietenan (1967) and Mora and Valley (1989) are in the Wallace Formation of Middle Proterozoic Belt Supergroup in the area along the northern margin of the Idaho batholith (fig. 1, inset map). Scapolite compositions reported by La Tour (1974, p. 26) for greenschist facies rocks that contained "tremolite + quartz + calcite ± plagioclase (approx. An_{10-25})" ranged from 21-45 percent meionite. A study of scapolite compositions in the Mt. Lofty area of South Australia by Kwak (1977, fig. 3) gave compositions of about 42-58 percent meionite for greenschist rocks within 1 km of amphibolite facies rocks. All of these previous investigators of scapolites generated by metamorphism of evaporite-bearing strata showed that the calcium to sodium ratio increases with progressive metamorphic grade between greenschist facies and higher metamorphic grades, as Hietenan (1967) originally noted. Kwak (1977, fig. 3) diagrammed the data presented by Hietenan (1967), and Evans and others (1969) from some of the same samples, and showed that an abrupt increase in meionite content occurred near the beginning of the amphibolite facies of metamorphism. Mora and Valley (1989) reconfirmed this observation for the area of Hietenan (1967) and from other places as well.

The chemical data given in table 2, which show high values of chlorine, bromine, fluorine, and boron (in one sample), are inferred to indicate that the strata originated in an evaporite environment. Hietenan (1967) and Mora and Valley (1989) attributed the scapolitic rocks of northern Idaho to the presence of halite, citing the occurrence of halite hoppers in the Wallace Formation several tens of kilometers to the east, in northwestern Montana. La Tour (1974) did not specify the metamorphic reactions that might have formed scapolite in the Skalkaho area of western Montana, but noted the importance of dolomite and the need for chlorine.

LITHOFACIES

The three main types of interbedded lithologies of the Moyer Creek measured section (fig. 3) are metalimestone, scapolite-rich rock, and siltite. In addition, an isolated outcrop area that cannot be related to the measured section is composed of a metalimestone that displays a disrupted fabric, birdseye structures, and clastic limestone. This lithofacies is referred to as disrupted limestone.

METALIMESTONE

Limestone forms beds 1.5 to 6 m thick within the Moyer Creek section (fig. 3). It was recrystallized into equant calcite grains during metamorphism and most of the original fine depositional textures were destroyed. Fine layering is preserved, locally, however. Some of these metalimestone beds contain silt grains of quartz and feldspar, indicating a significant siliciclastic component, a feature confirmed by the fairly high Zr content (table 1) of these rocks. Recrystallization of the $CaCO_3$ modified depositional textures and the siliciclastic grains commonly are isolated within calcite. No scapolite was formed in the limestone beds during metamorphism. This is believed to be due to an absence of Na and Cl, indicating that the metalimestone lacked a halite component.

Most of the metalimestone units of the measured section contain minor phlogopite (ideally, $K_2(MgFe_2)_6[Si_6Al_2O_{20}](OH,F)_4)$. This suggests they may have contained some dolomite as a source of Mg, which, if originally present, was entirely consumed during metamorphism because no dolomite was observed in outcrop, thin section, or by X-ray diffraction. Precursor dolomite could have been deposited as an evaporite mineral transitional between limestone and halite-bearing strata.

Syngenetic Fold Structure

A fold structure (fig. 4) occurs in metalimestone from low in the measured section (fig. 3, unit 4). The structure lies between horizontal (unfolded) beds, indicating a nontectonic origin and development prior to deposition of the overlying strata. The structure is the only one present in the measured section or found in the outcrop area; other structures possibly would be found at this horizon if the bed could be traced laterally. The structure may have formed from solution-collapse processes, in which dissolution of evaporite beds causes fracturing and collapse of overlying beds (Middleton, 1961); or it may have formed from collapse caused by volume changes that take place during replacement of dolomite by calcite (dedolomitization) (for example, Blount and Moore, 1969). The thickening and thinning of some of the folded beds shown in figure 4 suggest flowage. The solution-collapse process generally results in development of a breccia; some breccia, not visible at the outcrop, was observed in a slabbed sample. Heavy lines shown in figure 4b (above hammer handle and below folded beds) delimit discordant layers produced by the collapse processes.

The collapse structure is somewhat similar to those illustrated in "wavy beds" associated with evaporitic and carbonate strata of the Permian Capitan shelf margin (Smith, 1974b). Smoot and Castens-Seidell (1994) pictured similar, although smaller, features beneath salt crusts composed primarily of halite in saline mudflats. The crusts form by the complete evaporation of saline groundwater at the sediment-air interface, and the sediment founders when the halite at the base of the crust dissolves in undersaturated waters below the surface.

Figure 4 also has some of the characteristics of tepee structures, which are antiform deformational structures formed at the margins of polygonal cracks in peritidal sediments. In plan view, the antiforms are ridges arched along the margins of a network of polygonal cracks in a cemented evaporite surface crust (Demicco and Hardie, 1994). In cross section they appear as inverted V's or disharmonic folds, and can be up to several meters across. Most workers attribute tepee structures to expansive growth of early cements within a host sediment. The initial buckling is caused by precipitation of fine-grained cements within the intergranular voids of permeable sandy beds to produce a compressionally disrupted hardground. The process causes open fractures at the crests of buckles, flow of water through the fractures, and deposition of cements therefrom. Repeated expansion, fracturing, and cementation results in repeated arching, rupturing, and expansion of the antiforms (Demicco and Hardie, 1994). Smith (1974a) found strata near crests of tepees to be folded, a tendency that is most common where there is no continuous axial fracture. In some tepee structures, the expanded sedimentary layers of one polygon are thrust over the strata of an adjacent polygon (Warren, 1982). Some tepees are markedly asymmetric, including a few in which tilted-up beds rest against the broken edges of undisturbed strata (Smith, 1974a, p. 64). Tepees generally occur in well defined stratigraphic units bounded above and below by parallel beds that show the tepee structures to be syngenetic (Wilson, 1975, p. 84). Modern tepee structures are known from caliche profiles, submarine hardgrounds, and, in Australia, in coastal salinas and tidal flats (Demicco and Hardie, 1994).

The structure of the Moyer Creek measured section probably formed in a subtidal to supratidal setting because it is directly upsection of the basal unit of siltite believed to be of intertidal origin. No evidence of caliche features was found in the Moyer Creek rocks. The fold structure of figure 4 includes an arched crest and tilted-up beds that abut broken edges of other beds of the structure. In contrast, it lacks an axial fracture system that became filled with secondary cement, which is one of the most common features of tepee structures. It also lacks the typical cross-sectional tepee shape.

SCAPOLITE-RICH BEDS

Scapolite-rich units range up to 7.5 m thick and are composed of light-gray scapolite-rich beds 1-20 cm thick that alternate with dark-gray laminae 1 mm to 2 cm thick (fig. 5). The beds are composed of about equal parts scapolite and equant grains of quartz, and less than 10 percent calcite, microcline, muscovite, and a trace of pyrite. Most beds contain minor phlogopite, suggesting that some scapolite-rich beds may have contained dolomite. Each light-gray bed is of fairly uniform thickness along the outcrop face but gentle undulatory thickness changes are present. A few metalimestone bed truncate the underlying bed at a very slight angle. Some beds display a very low angle of crossbedding.

Two kinds of dark-gray layers were observed within the scapolite-rich units. (1) Light- and dark-gray 1-10 mm thick layers alternate with each other. The dark-gray laminae at the tops of the light-gray beds are of less uniform thickness, some pinching out along strike. There is no correlation between thickness of the light- and dark-gray layers: thick beds of light-gray rock are commonly capped by a 1 mm to 2 cm thick dark-gray layer. Locally, dark-gray beds are thicker, forming lenses. One dark-gray lens is about 13 m long in cross section and attains a maximum thickness of 60 cm in the central part of its length. Thin sections reveal that these dark-gray beds are commonly siltite, chiefly composed of quartz, feldspar, and biotite/phlogopite, the latter giving the dark color. Siltites similar to these are described more extensively later. (2) Dark-gray laminae drape the surface of the scapolite-rich beds. There is no increase in thickness of these laminae within lows of undulatory bedding surface of scapolite-rich beds or over highs of the beds (fig. 5). These dark-gray laminae may be cryptalgal[2] stromatolite mats. We examined only a few strata during our reconnaissance study. A more thorough examination is needed to determine the relationships of the two kinds of dark-gray layers.

The following paragraphs further describe the 1-3 mm laminae because they contain tourmaline, lack biotite/phlogopite, and are important to the interpretation of the depositional environment of the scapolite-rich strata. In unit 19 of the measured section (fig. 3), the 1-3 mm thick dark-gray laminae are rich in tourmaline and lack biotite/phlogopite; general compositions are as follows:

THICKNESS	MINERALOLOGY	COMPOSITION
1+ m	scapolite-rich bed	$(NaCa)_4[Al_3Si_9O_{24}]Cl$
1-2 mm	dravite tourmaline	$NaMg_3Al_6B_3Si_6O_{27}(OH)_4$
1-2 mm	albite + microcline	$NaAlSi_3O_8 + KAlSi_3O_8$
1-2 mm	dravite tourmaline	
1+ m	scapolite-rich bed	$(NaCa)_4[Al_3Si_9O_{24}]Cl$

[2]Cryptalgal structures are features in which the original organic material is not preserved. The former existence of the algae is inferred from sedimentary structures that are analogous to those produced in modern algal-bearing sediments (Aitken, 1967).

Origin

This section presents a general interpretation for the depositional setting of the scapolite-rich beds and briefly mentions three possible interpretations of origin for the associated tourmaline-bearing layers.

The scapolite-rich beds are interpreted as subaqueous deposits because they lack desiccation features such as mudcracks, rip-up clasts, birdseye structures, and fabric suggestive of desiccation. The tourmaline-bearing fine laminae at the tops of the beds have the appearance of stromatolite mats (fig. 5), but if they are mats, the mats are not broken and do not display curled-up edges as if exposed and dehydrated. The thinness of these laminae and the absence of biotite/phlogopite that characterizes clastic siltite layers, suggests that the dark layers may be (metamorphosed) clays. The clays originally may have been trapped on algal mats.

Clays readily acccomodate boron in their crystal lattices, and boron is known to be concentrated in marine clays. Hence, (1) one possibility for the origin of tourmaline in the dark laminae of the Moyer Creek strata is that it formed during metamorphism of boron-bearing clays, as suggested for other strata by Moine and others (1981, p. 406) and Henry and Guidotti (1985, p. 11). (2) The boron in clays is liberated during clay decomposition in a brine whose saline content is progressively increased as the brine waters decrease in volume (Sonnenfeld, 1984, p. 221). Hence, a variation of the above interpretation is that the boron-enriched laminae (now metamorphosed to tourmaline) of the Moyer Creek strata formed from evaporation of saline water concentrated beyond the halite facies of precipitation (Holser, 1979; Palmer, 1991, p. 118). Little is currently known about the exact composition of tourmalines developed in halite, but optical properties suggest they are dravitic (Henry and Dutrow, 1996, p. 529) (ideal dravite, $NaMg_3Al_6B_3Si_6O_{27}(OH)_4$). In the evaporation of seawater, boron is sufficiently concentrated to precipitate as a salt directly following precipitation of NaCl. Tourmaline layers and the intervening albite layer are only a millimeter or so thick at the top of each halite-bearing (now scapolite-rich) bed, are of uniform thickness along bedding surfaces, and directly overlie the scapolite-rich beds. Anderle and others (1979), for example, described borates in laminae of claystone and sylvite (KCl) in evaporites of New Brunswick, Canada. The borates formed crystals 1-4 mm in diameter, some in distinct laminae. This possible analogy could explain the differing chemical composition of the laminae of the metaevaporites of the scapolite-rich beds of the Moyer Creek strata, their thinness, an association with metaevaporites believed to have contained siginificant halite, occurrence of the laminae at the tops of the metahalite-bearing evaporite beds, and the fairly high percent of potassium (table 2) in the beds.

(3) A third possiblity is the introduction of boron from hydrothermal sources, yielding finely zoned layering. Producing layers of the same uniform thickness at every bedding surface within each scapolite-bearing unit seems unlikely. We found no tourmaline layers that cut across beds and no evidence of tourmaline-bearing fractures or other fluid conduit. If the boron was from a hydrothermal source, it seems unlikely that tourmaline would be associated only with the scapolite-bearing beds, and only at the uppermost part of each bed. We would expect the hydrothermal fluids to have penetrated the siltites because these clastic rocks should have afforded the greatest permeability. Further, we would not expect tourmaline to be confined solely to beds but to display cross-cutting relationships. Nevertheless, a hydrothermal source cannot be ruled out because of the

limited area of exposures of the strata of Moyer Creek. Cross-cutting relationships may exist, or may have existed in now-eroded strata, elsewhere in the vicinity of the Moyer Creek outcrops. Tourmaline occurs locally in outcrops that are widespread in the general region of the Blackbird mine-Quartzite Mountain area (fig. 1), as shown on the map of Evans and Connor (1993).

Tourmaline was observed in one other lithofacies, which is not within the Moyer Creek measured section and is known in only one isolated outcrop. The occurrence is described in the following section.

DISRUPTED LIMESTONE

This lithofacies crops out only in the northern part of the Moyer Creek area, along the road near the creek (fig. 2, station 93ITz109). The relationship of the outcrop to the measured section is uncertain, but most likely the strata lie stratigraphically higher than rocks of the section. The metalimestone of station 93ITz109 displays a disrupted fabric, similar to the structure created where a cyanobacterial mat has been disrupted by the growth of anhydrite or gypsum crystals (for example, fig. 22B of Kendall, 1992, p. 392). At the present metamorphic grade, however, no anhydrite or gypsum is preserved. The rock displays a network (or boxwork) of horizontal to vertical calcite "veinlets" that range up to 1 mm thick. The network disrupted the dark-gray limestone mat layers into a mosaic of isolated rectangular fragments that range up to granule and locally pebble size. Some of the rock displays slightly upward concave crusts, a few millimeters thick and 10-15 cm across. Crusts, suggestive of desiccated algal mats, are underlain by 1-5 mm thick white calcite layers that have the same shape as the crusts.

Other beds from this station display "birdseye" structures (vugs), which are characteristic of carbonate muds in modern supratidal envrionments. Small birdeyes formed during desiccation and development of gas bubbles that later became rimmed with carbonate cement and filled with calcite (Shinn, 1968). A unit of clastic metalimestone cuts irregularly across part of the outcrop, formed of an intraclastic breccia of millimeter-size fragments in a finer grained matrix that contains silt grains of quartz and feldspar.

Thin section and X-ray diffraction examination (table 1) of the disprupted metalimestone shows rock of the lower greenschist facies, composed of calcite, quartz, phlogopite, tourmaline, and some opaques, probably pyrite. The outcrop contains the most abundant tourmaline found in the Moyer Creek area, confirmed in thin section, by X-ray diffraction (table 1), and by 1500 ppm boron detected by geochemical analysis (table 2). No anhydrite or gypsum was detected by X-ray diffraction or in thin sections.

Origin

The above described strata are suggestive of evaporite sediments deposited in a supratidal zone, perhaps a sabkha. The strata were bound together by algal mats, before crystallization of anhydrite. The intraclastic breccia may be comprised of thin reworked sediment of a tidal flat, concentrated into a small runoff channel. The presence of detrital quartz and calcic and perhaps potassic feldspar in the breccia is suggestive of windblown clastics common on some modern supratidal flats of carbonate provinces.

Because anhydrite or gypsum beds of sabkhas are associated with dolomite, the absence of dolomite needs explanation. Phlogopite is abundant in rocks from station 93ITz109. The formation of phlogopite requires abundant Mg, possibly supplied by dolomite that was all converted into calcite + phlogopite during metamorphism. The absence of anhydrite or gypsum in the rocks also is attributed to metamorphism. Metamorphism of $CaSO_4$ would release sulfur, which could be accounted for in the pyrite grains that are dispersed throughout the outcrop.

The abundant tourmaline of the disrupted limestone lithofacies (1) may have been leached from rocks elsewhere (outside the Moyer Creek area) and introduced by hydrothermal fluids, as suggested by Palmer (1991) for the origin of tourmalines associated with evaporite terranes.

(2) Another possibility is that the tourmaline of the disrupted limestone lithofacies may be indicative of a supratidal environment. Tourmaline has been reported to replace anhydrite in unmetamorphosed sedimentary rocks, and to display doubly terminated crystals in halite (Erd, 1980, cited in Henry and Dutrow, 1996, p. 529). Tourmaline requires that boron be present in the sediment. Ham and others (1961) reported borate minerals in gypsum and anhydrite of Permian formations in western Oklahoma, with the greatest concentration of boron in anhydrite deposited nearest the reconstructed shoreline, where evaporation probably was at a maximum. They found that conversion of anhydrite to gypsum resulted in segregation of nodules of calcium borate. All of the borate minerals are in massive gypsum beds, interstratified with marine dolomite, anhydrite, and shale. They determined that the anhydrite being converted to gypsum contained five times as much boron as the resulting gypsum, so that B of nearly 200 ppm is released into solution during the formation of gypsum, and available for the calcium borate minerals. Sodium cations were released by the dissolution of small amounts of halite contained in the anhydrite beds, and the sequence redeposited as $NaSO_4$.

Dolomite was not detected within the disrupted metalimestone lithofacies. However, it would be expected in a supratidal carbonate environment and could have been present and entirely consumed during metamorphism, thus could have supplied Mg for tourmaline.

SILTITE

Siltite is dark gray and is chiefly composed of quartz, albite, and biotite/phlogopite. It typically displays fine laminae, 1-3 mm thick, that are planar or very gently rippled to slightly undulatory. No flaser or lenticular bedding was observed. No climbing ripples, herringbone crosslamination, rip-up clasts, pebbles, mudcracks, or syneresis cracks were noted. No graded beds are present. Metalimestone forms 1-2 cm thick interbeds where the siltite is transitional into beds of metalimestone.

Marked compositional differences of laminae characterize some beds. Scapolite porphyroblasts occur along some 1-3 mm thick laminae and in beds up to 1 m thick. Porphyroblasts are as large as 1 cm in diameter, although generally smaller, with the largest elongate parallel to bedding. Scapolite comprises as much as 50 percent of some of the thicker beds. Thin sections reveal that optically continuous scapolite porphyryoblasts cut across layering and engulf grains of quartz, phlogopite, and calcite that now appear as inclusions. Scapolite crystals are unzoned.

The scapolite porphyroblasts indicate halite-rich precursor sediment. Halite may have precipitated from hypersaline brines of a body of water and settled to the floor beneath; or perhaps the halite formed originally as a crust on intertidal to supratidal flats, and then was reworked by waves and transported into a body of water and from where it settled out.

Phlogopite porphyryoblasts occur locally in the siltite. Magnesium was probably supplied by dolomite from closely associated scapolite-rich rocks, or perhaps the siltite contained dolomite cement. Potassium in the phologopite could have come from the detrital grains of granitic rocks--if crystalline rocks of southwestern Montana supplied detritus. Orthoclase ($KAlSi_3O_8$) is common there and K-feldspar is present in detrital rocks of the Lemhi Group in the Lemhi Range.

STRATIGRAPHIC SETTING

The stratigraphic sequence in the vicinity of the principal reference section of the Yellowjacket Formation and in the region to the south of the Moyer Creek area (fig. 2) is as follows:

ROCK UNIT	LITHOLOGY	INTERPRETATION
Unnamed unit (argillaceous quartzite of Ross, 1934)	siltite, meta-sandstone, orthoquartzite	intertidal
Hoodoo Quartzite	orthoquartzite	high-energy tidal
Yellowjacket Formation		
upper strata	siltite, argillite	intertidal
lower strata	metaevaporites	subtidal to supratidal

The Hoodoo strata of this sequence were deposited under high energy conditions and are interpreted as tidal deposits. The upper strata of the Yellowjacket Formation are conformable with the orthoquartzite of the Hoodoo, observed both in the vicinity of the principal reference sections of the formations and in the region southwest of Iron Lake. These upper Yellowjacket strata also are believed to be tidally controlled deposits (Tysdal, unpub. data). Metaevaporite strata of the principal reference section along Yellowjacket Creek occur within the lower part of the Yellowjacket Formation. (No pre-Yellowjacket strata are known, thus the "lower" strata of the formation are the lowest known rocks, but may not be the stratigraphically lowest rocks that would be assigned to the formation in a complete section.) It is reasonable to interpret the conformable evaporite-bearing strata of the lower part of the Yellowjacket as marginal marine strata because of the interpretation of the overlying rocks of the sequence. More specific interpretation of the regional and local depositional setting of the metaevaporites is necessarily speculative because of the occurrence of only isolated outcrops, the reconnaissance nature of our investigation, and the mask of metamorphism.

The above stratigraphic succession forms a transgressive sequence, indicating incursion of marine waters into the region, climaxing with deposition of orthoquarzite of the Hoodoo Quartzite. The sequence could represent deposits of a rift setting, with the marine strata deposited during initial flooding of an advancing sea. Such an interpretation is speculative. The measured section of Moyer Creek (fig. 3) shows repeated interbedding of metalimestone with metaevaporite rocks: (1) scapolite-rich strata indicative of halite-containing precursor strata, and (2) scapolite-bearing siltite. The repeated interbedding of limestone and strata of a restricted depositional setting suggests calcareous strata may have precipitated from sea water during repeated flooding. Such flooding could have taken place over a barrier into a previously restricted body of water--perhaps a lagoon or a large trough behind a sill threshhold. No barrier of any type is known in the limited area of examined metaevaporite strata, but the precipitation of halite from sea water requires the evaporation of about 90 percent of the water column before NaCl is sufficiently concentrated to cause direct precipitation (Warren, 1989). In the marginal marine lagoons of Australia where halite currently precipitates, Logan (1987) found complete surface disconnection of the restricted body of water before precipitation of halite could occur. Hence, interpretation of the scapolite-rich beds as subaqueous, as suggested above, would favor some type of a barrier system that separated a restricted body of water from the main source of marine water. Alternative scenarios call for the flooding to occur during a relative sea-level rise caused by faulting (rift-marginal?) accompanied by subsidence at the depositional site, or possibly by raised sea level during storm season as in the Ranns of Kutch, India (Glennie and Evans, 1976). By themselves, these scenarios fail to account for a restricted body of water for deposition of the salt that was metamorphosed to form the scapolite-rich rocks. However, the earthquake and storm-related concepts could enhance the barrier interpretation by providing a mechanism for periodic overflow of the barrier.

Silt grains now present within some metalimestone beds could have been transported by tidal currents and deposited as interbeds of siltite or locally mixed with calcareous rocks to yield silty limestone. Quartz silt grains observed in the metaevaporite beds may reflect a compound source, derived (1) subaerially, transported by wind and (or) periodic sheet flooding associated with rains, as in modern sabkhas; and by (2) marine flooding, forming laminae and thin beds. Halite, a source of Na and Cl for scapolite that is present within discrete siltite layers, could have been precipitated from stratabound brines concentrated by evaporative processes.

An alternative to the above interpretation of a marginal marine setting for the metaevaporite and associated strata of the Yellowjacket Formation is deposition in a lacustrine setting (for example, Hardie, 1984, 1990; Slack and others, 1993; Slack, 1996). Interpretation of the depositional environment for the upper strata of the Yellowjacket Formation would need to be changed--perhaps to a lake environment? But the orthoquartzite of the Hoodoo Formation, conformable above the Yellowjacket, is believed to be of marine origin, making the lacustrine interpretation less appropriate.

Boron that now occurs in tourmaline of the Moyer Creek strata may have been deposited originally in minerals formed in an evaporite setting. Borate minerals commonly occur in mudstones deposited in continental lakes fed by thermal springs or groundwater (Kyle, 1991). Commercially exploited borate deposits in the western United States and the World are stratigraphically associated with volcanic activity or inferred to be so. Many lie at least partly within lacustrine facies of their host formations, which implies closed basins created by contemporaneous tectonic activity (Smith and Medrano, 1996, p. 277). Within the Moyer Creek area, where the metaevaporite and associated rocks are best exposed, we found no volcanic rocks (such as tuffs, mafic or felsic intrusive or extrusive rocks), banded iron-formation, chert (indicating precursor magadiite--sodium silicate), manganiferous strata, or other metamorphic minerals suggestive of precursor minerals of, for example, trona (sodium carbonate) that would indicate a continental, lacustrine setting. The evidence presented suggests that a lacustrine setting is not the probable environment for the metaevaporites of the study area.

SPECULATION ON REGIONAL CORRELATION

We attribute scapolite in the Moyer and Yellowjacket Creek areas to the presence of halite precursor minerals in a metaevaporite sequence. Scapolitic rocks north of the northwest end of the Idaho batholith (fig. 1) were attributed to precursor halite in sediment, citing the occurrence of halite hoppers in the Wallace Formation several tens of kilometers to the east, in northwestern Montana (Hietenan, 1967; Mora and Valley, 1989). Formation of scapolite in the Skalkaho area was not attributed to specific precursor minerals, but the importance of dolomite and a source of Cl were mentioned (La Tour, 1974). In all of these areas, the scapolite is confined to specific thin beds or layers between scapolite-free layers.

It is tempting to speculate that the scapolitic rock of the three areas reflects metamorphism of evaporites that were deposited at the same time. But conversely, only the precursor sediment may be the same and the times of sediment deposition may differ. Nevertheless, metaevaporites are not a widespread feature of the Belt Supergroup, thus we speculate that the metaevaporites of the three areas may be time correlative. The thickness of the metaevaporite sequence and the repetition of differing rock types within the sequence of the Moyer-Yellowjacket Creek area do not fit the description of scapolitic rocks in the other two areas, but Hietenan (1967), La Tour (1974), and Mora and Valley (1989) did not focus on sedimentology, thus the differences may be more apparent than real. Further field examination of the strata in the three areas is needed to make sedimentologic comparisons, and an independent means of dating deposition of the (meta)evaporites is needed for more certain correlation.

SOME IMPLICATIONS FOR MINERALIZATION

The existence of (meta)evaporite deposits in the study region has implications for mineral deposits. Cu-Co-Au deposits of the Blackbird mining district (fig. 1) and contiguous terrane are stratabound Fe-silicate facies rocks that are rich in biotite, Fe, and Cl; some Fe-rich biotite contains as much as 1.87 percent Cl (Nash and Connor, 1993). These authors noted that associated scapolite also is Cl-rich, and that both the scapolite and biotite are very similar in composition to the same minerals in northern Idaho, described by Hietenan (1967) and Mora and Valley (1989). Nash and Connor (1993) stated that the strata of the Blackbird area resulted from deep-water sedimentation, not the shallow-water environment of the scapolitic strata described for northern Idaho and correlative halite hopper-bearing strata of northwestern Montana. They believed that the Cl of the scapolitic rocks of the Blackbird area must have come from a source other than shallow-water evaporites, but concluded that the possible residence of Cl [in the Blackbird strata] prior to metamorphism remains unresolved (Nash and Connor, 1993).

The sequence Yellowjacket-Hoodoo-unnamed unit of the principal reference section, and correlative strata southwest of Iron Lake (fig. 2), are interpreted as shallow-water, tidally controlled deposits (Tysdal, unpub. data) and the metaevaporite strata are marginal to the tidal setting. As noted in the introductory paragraphs of this report, all of these strata are interpreted as part of a thrust plate that is delimited by the northwest-trending Iron Lake fault, thus the strata are separate and distinct from the rocks of the Blackbird area (Tysdal, work in progress).

The east-central Idaho region of the study area is an overthrust terrane in which sheets of strata were transported eastward, including the metaevaporites of the Moyer-Yellowjacket Creek area. Nevertheless, prior to thrusting, evaporites may have existed within a sedimentary pile at the time of Proterozoic mineralization of the Blackbird area. Mineralizing fluids, whether of post-evaporite syndepositional exhalative deposits or later hydrothermal mineral deposits, likely would have moved upward through the evaporites, scavenging chemical elements. In addition, it is quite possible that the area of the Blackbird and vicinity could be underlain by a thrust fault(s) and that metaevaporites like those of the study area lie beneath the mining district. Hence, Cretaceous or older hydrothermal fluids that ascended through the sedimentary pile would have tapped the highly mobile halogen elements of the metaevaporites and incorporated them into new minerals. The Cl-rich biotites of the Blackbird mining district and vicinity, previously interpreted as metamorphosed exhalative mafic tuffs (Nash, 1989; Nash and Hahn, 1989; and Nash and others, 1990), may have derived their Cl from these evaporitic strata. The high salinities of fluid inclusions reported by these authors also may have their source in the evaporitic rocks.

REFERENCES CITED

Anderle, J.P., Crosby, K.S. and Waugh, D.C.E., 1979, Potash at Salt Springs, New Brunswick: Economic Geology, v. 74, p. 389-396.

Aitken, J.D., 1967, Classification and environmental significance of cryptalalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of southwestern Alberta: Journal of Sedimentary Petrology, v. 37, p. 1163-1178.

Blount, D.N., and Moore, C.H., Jr., 1969, Depositional and non-depositional carbonate breccias, Chiantla quadrangle, Guatemala: Geological Society of America Bulletin, v. 80, p. 429-442.

Burley, B.J., Freeman, E.B., and Shaw, D.M., 1961, Studies on scapolite: Canadian Mineralogist, v. 6, p. 665-674.

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

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

Survey Open-File Report 90-0234, 30 p.
Demicco, R.V., and Hardie, L.A., 1994, Sedimentary structures and early diagenetic features of shallow maine carbonate deposits: Society of Sedimentary Geology, SEPM Atlas Series No. 1, 265 p.
Ekren, E.B., 1988, Stratigraphic and structural relations of the Hoodoo Quartzite and Yellowjacket Formation of Middle Proterozoic age from Hoodoo Creek eastward to Mount Taylor, central Idaho: U.S. Geological Survey Bulletin 1570, 17 p.
Erd, R.C., 1980, Boron in metamorphic rocks: Longman, London, Mellor'sComprehensive Treatise on Inorganic and Theoretical Chemistry (Supplement), v. 5, Boron, p. 96-105.
Evans, B.W., Shaw, D.M., and Haughton, D.R., 1969, Scapolite stoichiometry: Contributions to Mineralogy and Petrology, v. 24, p. 293-305.
Fawcett, J.J., and Yoder, H.S., 1966, Phase relationships of chlorites in the system $MgO-Al_2O_3-SiO_2-H_2O$: American Mineralogist, v. 51, p. 353-380.
Fisher, F.S., McIntyre, D.H., and Johnson, K.M., 1992, Geologic map of the Challis 1° x 2° quadrangle, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1819, 39 p., 1 sheet, scale 1:250,000.
Glennie, K.W., and Evans, Graham, 1976, A reconnaissance of the Recent sediments of the Ranns of Kutch, India: Sedimentology, v. 23, p. 625-647.
Gordon, T.M., and Greenwood, H.J., 1970, The reaction: dolomite + quartz + water = talc + calcite + CO_2: American Journal of Science, v. 268, p. 255-242.
Ham, W.E., Mankin, C.J., and Schleicher, J.S., 1961, Borate minerals in Permian gypsum of west-central Oklahoma: Oklahoma Geological Survey Bulletin 92, 77 p.
Hardie, L.A., 1984, Evaporites--Marine or non-marine: American Journal of Science, v. 284, p. 1293-240.
______1990, The roles of rifting and hydrothermal $CaCl_2$ brines in the origin of potash evaporites--An hypothesis: American Journal of Science, v. 290, p. 43-106.
Henry, D.J., and Guidotti, C.V., 1985, Tourmaline as a petrogenetic indicator mineral--an example fron the staurolite grade metapelites of NW Maind: American Minealogist, v. 70, p. 1-15.
Henry, D.J., and Dutrow, B.L., 1996, Metamorphic tourmaline and its petrologic applications, *in* Grew, E.S., and Anovitz, L.M., eds., Boron--Mineralogy, petrology and geochemistry: Mineralogical Society of America, Reviews in Mineralogy, v. 33, p. 503-557.
Hietenan, Anna, 1967, Scapolite in the Belt Series in the St. Joe-Clear Water region, Idaho: Geological Society of America Special Paper 86, 56 p.
Holser, W.T., 1979, Trace elements and isotopes in evaporites, *in* Burns, R.G., ed., Marine minerals: Mineralogical Society of America, Reviews of Minerals, v.. 6, p. 295-346.
Kendall, C.G.St.C., 1992, Evaporites, *in* Walker, R.G., and James, N.P., Facies models--Respose to sea level change: Geological Association of Canada, 375-409.
Kendall, C.G.St.C., and Warren, John, 1987, A review and setting of tepees and their associated fabrics: Sedimentology, v. 34, p. 1007-1027.
Kyle, R.J., 1991, Evaporites, evaporitic processes, and mineral resources, *in* Melvin, J.L., ed., Evaporites, Petroleum, and Mineral Resoruces: New York, Elsevier, Inc., p. 477-533.
Kwak, T.A.P., 1977, Scapolite compositional change in a metamorphic gradient and its bearing on the identification of meta-evaporite sequences: Geological Magazine, v. 114, 343-354.
La Tour, T.E., 1974, An examination of metamorphism and scapolite in the Skalkaho region, southern Sapphire Range, Montana: Missoula, University of Montana M.S. thesis, 95 p.
Logan, B.W., 1987, The McCloud evaporite basin, western Australia: American Association of Petroleum Geologists Memoir 44, 140 p.
Middleton, G.V., 1961, Evaporite solution breccias from the Mississippian of southwest Montana: Journal of Sedimentary Petrology, v. 31, p. 189-195.
Moine, B., Sauvan, P., and Jarousse, J., 1981, Geochemistry of evaporite-bearing series--A tentative guide from the identification of metaevaporites: Contributions to Mineralogy and Petrology, v. 76, p. 401-412.
Mora, C.I., and Valley, J.W., 1989, Halogen-rich scapolite and biotite--implications for metamorphic fluid-rock interaction: American Mineralogist, v. 47, p. 721-737.
______1991, Prograde and retrograde fluid-rock interaction in calc-silicates northwest of the Idaho batholith--stable

saline hydrothermal brine: U.S. Geological Survey Open-File Report 89-445, 25 p.
Nash, J.T., and Hahn, G.A., 1989, Stratabound Cu-Co deposits and mafic volicaniclastic rocks in the Blackbird mining district, Lemhi County, Idaho, *in* Boyle, R.W., and others, eds., Sediment-hosted stratiform copper deposits: Geological Association of Canada Special Paper 36, p. 339-356.
Nash, J.T., Connor, J.J., Curry, K.J., and Papp, C.S., 1990, Anomalous chlorine in iron-rich strata Yellowjacket Formation, Lemhi County, Idaho: U.S. Geological Survey Open-File Report 90-721, 36 p.
Nash, J.T., and Connor, J.J., 1993, Iron and chlorine as guides to stratiformCu-Co-Au deposits, Idaho cobalt belt, USA: Mineralium Deposita, v. 28, p. 99-106.
North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bullletin, v. 67, p. 841-875.
Palmer, M.R., 1991, Boron isotope systematics of hydrothermal fluids and tourmalines--A synthesis: Chemical Geology, v. 94, p. 111-121.
Rember, W.C., and Bennett, E.H., compilers, 1979, Geologic map of the Challis quadrangle, Idaho: Idaho Bureau of Mines and Geology, Geologic Map Series, Challis 2° quadrangle, scale 1:250,000.
Ross, C.P, 1934, Geology and ore deposits of the Casto quadrangle, Idaho: U.S. Geological Survey Bulletin 854, 135 p.
Shinn, E.A., 1968, Practical significance of birdseye structures in carbonate rocks: Journal of Sedimentary Petrology, v. 38, p. 215-223.
Slack, J.R., 1996, Tourmaline associations with hydrothermal ore deposits, *in* Grew, E.S., and Anovitz, L.M., eds., Boron--Mineralogy, petrology and geochemistry: Mineralogical Society of America, Reviews in Mineralogy, v. 33, p. 579-343.
Slack, J.R., Palmer, M.R., Stevens, B.P.J., and Barnes, R.G., 1993, Origin and significance of tourmaline-rich rocks in the Broken Hill district, Australia: Economic Geology, v. 88, p. 505-541.
Smith, D.B., 1974a, Origin of tepees in Upper Permian shelf carbonate rocks of Guadalupe Mountains, New Mexico: American Association of Petroleum Geologists Bulletin, v. 58, p. 63-70.
______1974b, Sedimentation of Upper Artesia (Guadalupian) cyclic shelf deposits of northern Guadalupe Mountains, New Mexico: American Association of Petroleum Geologists Bulletin, v. 58, p. 1699-1730.
Smith, G.I., and Medrano, M.D., 1996, Continental borate depsits of Cenozoic age *in* Grew, E.S., and Anovitz, L.M., eds., Boron--Mineralogy, petrology and geochemistry: Mineralogical Society of America, Reviews in Mineraloby v. 33, p. 263-298.
Smoot, J.P., and Castens-Seidell, 1994, Sedimentary features produced by efflorescent salt crusts, Saline Valley and Death Valley, California, *in* Renaut, R.W., and Last, W.M., eds., Sedimentology and geochemistry of modern and ancient saline lakes: Society of Sedimentary Geology, Special Publication no. 50, p. 73-90.
Sonnenfeld, Peter, 1984, Brines and evaporites: New York, Academic Press, 613 p.
Tysdal, R.G., 1996a, Geologic map of adjacent parts of the Hayden Creek and Mogg Mountain quadrangles, Lemhi County, Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-2563, scale 1:24,000.
______1996b, Geologic map of the Lem Peak quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1777, scale 1:24,000.
Tysdal, R.G., and Moye, Falma, 1996, Geologic map of the Allison Creek quadrangle, Lemhi County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1778, scale 1:24,000.
Warren, J.K., 1982, The hydrological significance of Holocene tepees, stromatolites, and boxwork limestones in coastal salinas in south Australia: Journal of Sedimentary Petrology, v. 52, p. 1171-1201.
______1989, Evaporite sedimentology, importance in hydrocarbon accumulation: Englewood Cliffs, New Jersey, Prentice Hall, Inc., 285 p.
Wilson, J.L., 1975, Carbonate facies in geologic history: New York, Springer-Verlag, Inc., 470 p.
Yager, D.B., and Quick, J.W., 1992, SuperXap Manual: U.S. Geological Survey Open-File Report 92-13, 45 p.

Figure 3. Reconnaissance measured section of rocks interpreted as metaevaporites in lower strata of Yellowjacket Formation, along Moyer Creek, Salmon River Mountains, Salmon National Forest, Idaho. Section is in unsurveyed Opal Lake 7.5-minute quadrangle, north side of road, about 44° 57' 11" lat., 114° 17' 52" long.

UNIT NO.	THICKNESS (METERS)	DESCRIPTION
		Top of section
33	4.0	Metalimestone (marble), light-gray, coarsely crystalline; interlayered with siltite, dark-gray; cryptalgal structures?. Beds 5-10 cm thick, emphasized by differential weathering. Minor scapolite visible in unit. Crossbeds in sets up to 0.3 m high. Sample 96ITz2H.
32	8.0	Covered.
31	1.5	Scapolite-rich rock, light-gray.
30	0.5	Metalimestone (marble), light-gray, coarsely crystalline.
29	2.0	Siltite, dark-gray scapolitic.
28	1.0	Metalimestone (marble), light-gray, coarsely crystalline.
27	2.0	Siltite, dark-gray, scapolitic.
26	1.5	Metalimestone (marble), light-gray, coarsely crystalline
25	1.0	Siltite, dark-gray, finely laminated, scapolitic.
24	6.0	Metalimestone(marble), light-gray, about 75 % of unit; and scapolite-rich rock; siltite, dark-gray, in uppermost few cm of unit. Differential weathering reveals fine layers of differing composition.
23	3.0	Scapolite-rich rock, mainly; siltite, dark-gray, forms 1-3 mm thick layers about every 10 cm; sparse metalimestone, light-gray, in layers about 10 cm thick.
22	3.0	Metalimestone (marble), light-gray, coarsely crystalline.
21	7.5	Scapolite-rich rock, mainly; siltite, dark-gray, forms 1-3 mm thick layers about every 10 cm; sparse metalimestone, light-gray, in layers a few mm thick. Beds are discontinuous over 1-15 m; a dark-gray siltite unit 0.6 m thick tapers out laterally over 8 m down dip and over 5 m updip, thus is a lens about 13 m in length normal to strike. Beds of this unit truncate one another at very low angles. These strata are somewhat like a tidal flat sequence in this tapering-out pattern. Ledge, beneath cliff
20	3.5	Siltite, dark-gray; zones of scapolite. Spaced cleavage with calcite veins. Sample 96ITz2D.
19	1.5	Scapolite-rich rock, and minor interlayered metalimestone. Siltite, dark-gray, in laminae 1-3 mm thick; some laminae scapolite-rich; rippled. Are laminae cryptalgal structures? Beds taper and pinch out laterally over 1-3 m. Sample 96ITz2C.
18	7.5	Covered.
17	1.0	Siltite, dark-gray, and scapolite-rich rock; finely interlaminated.
16	1.0	Metalimestone (marble), light-gray, coarsely crystalline. Some thin discontinuous 1-2 cm thick interbeds of siltite, dark-gray. Sparse scapolite-rich interbeds.

Figure 3. continued

UNIT NO.	THICKNESS (METERS)	DESCRIPTION
15	1.5	Metalimestone (marble), pale brown, altered.
14	0.5	Siltite, dark-gray, finely laminated. Small fault (~ 1 m) at top.
13	2.5	Metalimestone (marble), pale brown, limonitic. Trace of sphalerite, specular hematite. Breccia, tectonic; displays spaced cleavage.
12	1.5	Covered. Float of siltite, dark-gray.
11	2.0	Metalimestone (marble), light-gray, coarsely crystalline; some biotite (phlogopite?). Bench at top of unit.
10	1.0	Siltite, dark-gray, finely laminated to massive. Some layers are scapolitic, with local scapolite "spots" up to 5 mm in diameter.
9	1.0	Metalimestone (marble), light-gray, coarsely crystalline; local 1-2 cm thick interbeds of siltite, dark-gray. Siltite beds are gently ripple crosslaminated, and are discontinuous over several meters. Very sharp planar contacts of layers. No scapolite visible in metalimestones. Scapolite "spots" up to 5 mm in diameter in siltite. Sample 96ITz2G.
8	2.0	Siltite, dark-gray, and scapolite-rich rock, interbedded. Upper 0.3 m is all siltite. Sample 96ITz2F from topmost layer.
7	2.0	Metalimestone (marble), light-gray, coarsely crystalline; and siltite, dark-gray, in discontinuous beds 2-3 cm thick, forms less than 10 % of unit.
6	1.5	Siltite, dark-gray; scapolite-rich rock, light-gray; and minor metalimestone, light-gray; all rock types form thin interbeds. Unit forms ledge.
5	3.7	Siltite, dark-gray; scapolite-rich rock, light-gray; and minor metalimestone, light-gray; all rock types form thin interbeds. Each rock type has sharp, planar contacts. All units are finely planar laminated, especially the dark-gray siltite. Unit is recessive in ledge face. Sample 96ITz2E.
4	2.0	Metalimestone (marble), light-gray, very calcareous, coarsely crystalline, finely laminated; some small ripples (wave length--1-2 cm), crosslaminated; differential weathering enhances compositional variation; almost no scapolite visible. Minor dark-gray siltite in lower part of unit. Sharp lower contact. Irregular fold, about 1.5 m high, present and is overlain and underlain by horizontal strata. Sample 96ITz2B.
3	2.3	Siltite, dark-gray, finely laminated, noncalcareous, dense; siliceous? Less scapolite-rich than light-colored rocks of section. Sample 96ITz2A.
2	1.5	Metalimestone (marble), light-gray, very calcareous, coarsely crystalline.
1	100 est.	Mostly covered; uppermost part is siltite, dark-gray, finely laminated to "massive;" poorly exposed; contains sparse interbeds 0.3-0.5 m thick of light-gray metalimestone; scapolite in both rock types.

Figure 4a. Syngenetic fold structure in metalimestone of unit 4, Moyer Creek measured section (fig. 3).

Figure 4b. Tracing from photograph of figure 4a. Hammer for scale--handle is 24 cm long.

Figure 5. Scapolite-rich beds along Moyer Creek, showing fine laminae at top of each bed.

Figure 4a

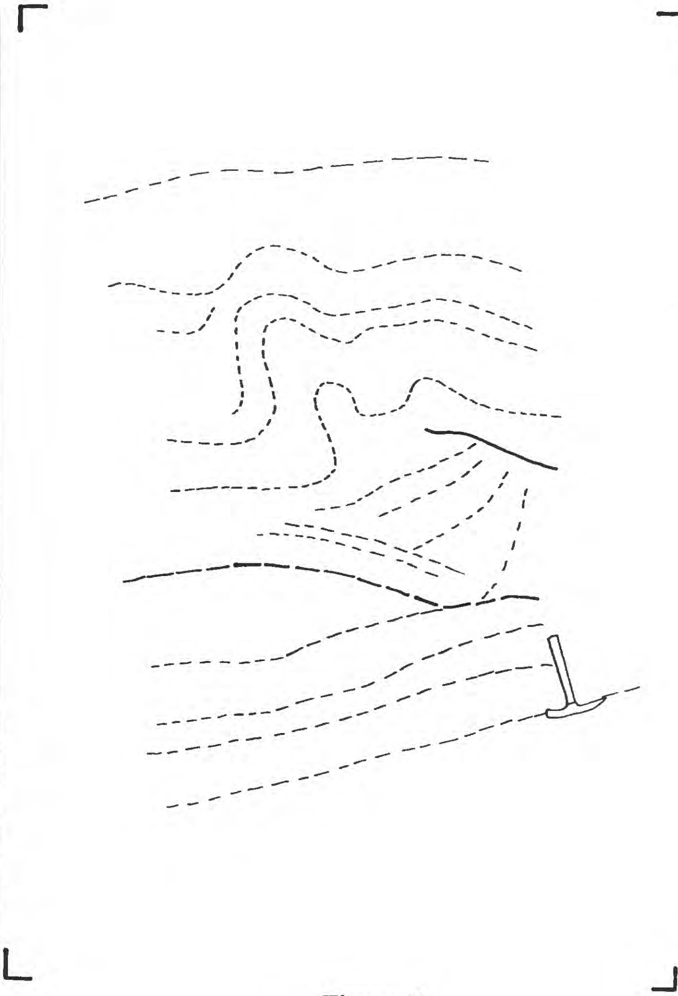


Figure 4b

Figure 5

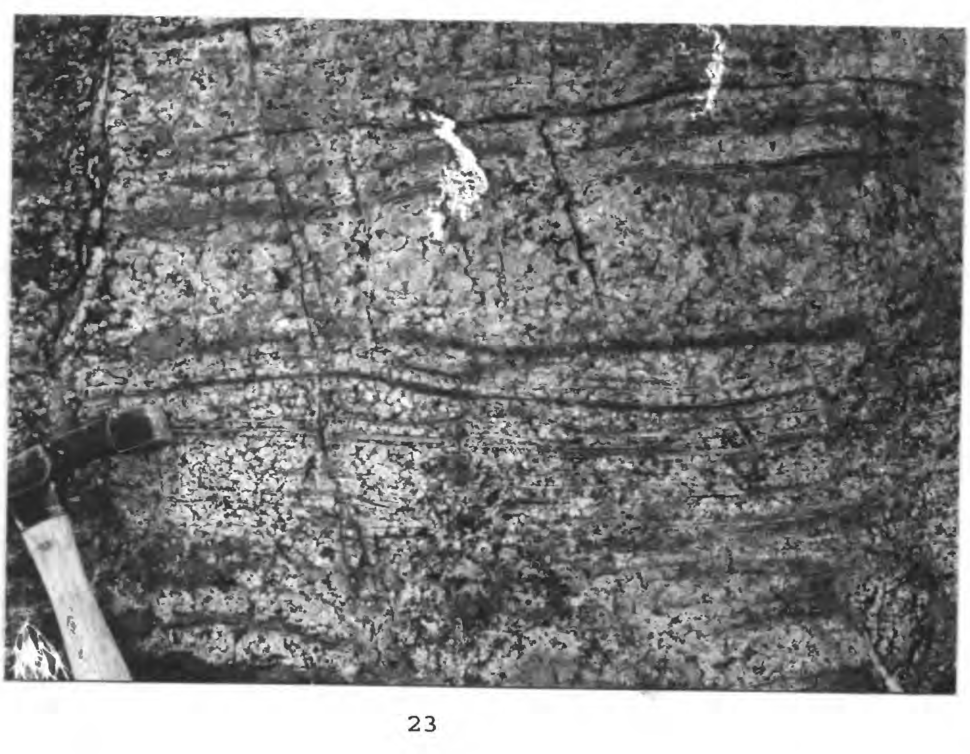


Table 1. Major and minor minerals of the scapolite-bearing strata of the lower part of the Yellowjacket Formation along Yellowjacket Creek and Moyer Creek, Salmon River Mountains, Idaho. Stratigraphic positions of 96ITz2A-H, from measured section at Moyer Creek, are shown in figure 3. [Minerals determined by X-ray diffraction and listed in order of decreasing abundance.]

SAMPLE NO.	LAT.	LONG.	"ROCK NAME"	MINERALS
				Yellowjacket Creek
93ITz103	44-58-40	114-31-14	"scapolite"	quartz, microcline, scapolite, calcite, trace mica
96ITz103	44-58-46	114-30-43	"scapolite"	quartz, scapolite (30% meionite), phlogopite
96ITz104A	44-58-41	114-31-12	"siltite"	albite, quartz
96ITz104B	do	do	"siltite"	quartz, muscovite, phlogopite, albite, microcline(?)
93ITz106A	44-59-22	114-29-25	"siltite"	quartz, albite, muscovite, phlogopite
93ITz106B	do	do	"micaceous scapolite"	quartz, phlogopite, scapolite (50% meionite), muscovite
96ITz106	44-59-17	114-29-40	"siltite"	quartz, albite, phlogopite
				Moyer Creek
93ITz108	44-57-10	114-16-44	"scapolite"	scapolite (30% meionite), quartz, microcline, calcite, trace mica
93ITz109	44-58-01	114-17-48	"metalimestone"	calcite, quartz, phlogopite, minor tourmaline, fluorite(?)
96ITz2A	44-57-11	114-17-52	"siltite"	quartz, scapolite (25% meionite), phlogopite, trace microcline
96ITz2B	do	do	"metalimestone"	calcite, quartz, microcline, scapolite (30% meionite), minor albite, trace mica
			top 6 cm (dk gray)	quartz, calcite, albite, microcline, trace mica
			bottom 10 cm (lt gray)	calcite, quartz, microcline, minor scapolite, trace mica
96ITz2C	do	do	"metalimestone"	calcite, scapolite (50% meionite), quartz, trace mica
96ITz2D	do	do	"siltite"	quartz, scapolite (30% meionite), phlogopite, microcline
96ITz2E	do	do	"metalimestone"	calcite, quartz, scapolite, trace microcline, trace mica
96ITz2F	do	do	"micaceous scapolite"	phlogopite, microcline, scapolite, quartz, albite
96ITz2G	do	do	"siltite"	quartz, scapolite (40% meionite), microcline
96ITz2H	do	do	"scapolite"	quartz, scapolite (45% meionite), microcline, minor mica

Table 2. Concentrations of selected elements in samples of scapolite-bearing rocks in lower strata of the Yellowjacket Formation along Yellowjacket Creek and Moyer Creek, Salmon River Mountains, Idaho.
[Analysis by ACTLABS, Inc., Wheat Ridge, Colo., except Cu, Zn, Rb, Nb, Ce, Nd, and La determined by energy dispersive radioisotope analysis (Yager and Quick, 1992)]

	Scapolite-rich rocks				Scapolite-rich Siltites		Siltites				
Sample Number	93ITZ 103	93ITZ 108	96ITZ 103	96ITZ 2H	96ITZ 2D	96ITZ 2G	93ITZ 106A	96ITZ 104A	96ITZ 104B	96ITZ 106	96ITZ 2A
	weight percent										
SiO_2	64.3	61.5	68.3	65.7	63.4	69.8	76.6	78.9	75.6	76.5	71.2
Al_2O_3	11.2	11.5	14.2	12.7	14.8	10.9	10.4	10.6	12.3	11.5	11.4
Fe_2O_3	2.6	2.7	4.8	4.2	6.0	3.0	4.6	0.4	4.2	4.7	4.2
MgO	1.6	1.9	2.2	2.2	2.8	2.0	1.4	0.1	1.8	0.8	3.2
MnO	0.03	0.04	0.02	0.05	0.02	0.02	<0.01	<0.01	<0.01	<0.01	0.02
CaO	11.2	11.5	4.8	6.0	2.5	5.8	0.2	1.7	0.4	0.2	3.7
Na_2O	2.9	3.3	3.5	2.4	3.2	2.8	2.7	7.0	2.2	2.9	3.2
K_2O	3.5	2.4	2.5	4.5	5.2	3.0	3.1	0.05	4.0	2.1	2.6
TiO_2	0.03	0.04	0.02	0.05	0.02	0.02	<0.01	<0.01	<0.01	<0.01	0.02
P_2O_5	0.07	0.10	0.10	0.09	0.12	0.11	0.10	0.09	0.12	0.11	0.08
LOI	4.3	5.0	1.5	2.1	2.9	2.4	1.1	1.3	1.5	0.9	2.3
Total	101.6	99.6	102.0	100.0	101.0	99.8	100.2	100.2	102.1	99.7	101.9
	Minor and trace elements in parts per million										
Cl	5590	8590	10600	5260	10900	6060	<500	<500	<500	<500	9200
Br	15	10	15	10	15	10	10	5	10	10	25
F	800	640	1300	1800	1500	860	620	300	1100	380	1600
Cu	40	<40	<40	55	<40	<40	<40	<40	<40	<40	<40
Zn	<40	<40	<40	<40	<40	<40	<40	<40	<40	<40	45
Rb	60	80	150	150	245	90	120	<10	160	60	150
Sr	110	150	130	140	160	80	40	25	60	55	145
Zr	280	235	250	260	380	330	200	270	420	1130	410
Y	40	30	45	25	25	25	25	10	45	120	40
Nb	10	10	10	<10	<10	<10	<10	<10	<10	<10	<10
Ce	85	55	100	70	55	100	40	<20	80	160	45
Nd	20	20	40	50	40	<20	<20	25	40	120	<20
La	45	50	50	45	55	20	<20	<20	40	95	50
Ba	670	430	320	680	1070	490	510	10	635	345	425

Table 2. continued

	Micaceous scapolites		Metalimestones			
	93ITZ 106B	96ITZ 2F	93ITZ 109	96ITZ 2B	96ITZ 2C	96ITZ 2E
	weight percent					
SiO_2	69.5	59.7	38.9	47.3	52.8	48.7
Al_2O_3	11.6	17.1	8.1	6.0	8.0	5.4
Fe_2O_3	4.9	6.4	6.0	0.9	1.9	1.5
MgO	3.1	3.6	7.6	0.5	0.9	1.1
MnO	0.03	0.03	0.16	0.07	0.07	0.07
CaO	2.8	2.1	19.3	24.6	20.4	26.7
Na_2O	1.4	3.6	0.2	1.5	2.7	1.8
K_2O	3.7	6.8	3.7	2.1	0.6	1.0
TiO_2	0.03	0.03	0.16	0.07	0.07	0.07
P_2O_5	0.13	0.08	0.07	0.04	0.07	0.03
LOI	2.2	2.4	15.5	18.8	14.1	18.1
Total	99.4	101.8	99.7	101.9	101.6	104.5
	Minor and trace elements in parts per million					
Cl	1180	8030	640	2490	7960	3060
Br	20	15	10	10	10	10
F	1000	2100	3200	300	420	520
Cu	<40	<40	45	<40	<40	45
Zn	<40	<40	110	<40	<40	<40
Rb	170	310	200	40	<10	45
Sr	65	95	60	270	120	105
Zr	380	200	140	165	235	280
Y	65	25	20	25	35	30
Nb	<10	10	10	<10	10	<10
Ce	75	40	25	30	75	70
Nd	35	35	25	<20	<20	55
La	50	40	20	20	30	30
Ba	580	1380	50	660	70	200
B*	n.d.#	n.d.	1500	n.d.	n.d.	n.d.

* = boron determined by DC-ARC atomic emission spectroscopy (R.T. Hopkins)
# = not determined