UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geochemical stratigraphy of the Yellowjacket Formation (Middle Proterozoic) in the area of the Idaho Cobalt Belt, Lemhi County, Idaho

Part A. Discussion

By

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ABSTRACT

The Middle Proterozoic Yellowjacket Formation in the area of the Idaho Cobalt Belt (ICB) of east-central Idaho consists of as much as 13,000 m of biotite-grade impure quartzite, siltite, argillite, and marble. The formation is roughly divisible into three lithostratigraphic subunits of varying thickness, here called the lower, middle and upper subunits. The generally coarsening- and thickening-upward nature of the succession suggests that the Yellowjacket represents a basin-filling prograding wedge. The formation contains two locally mineralized but regionally extensive zones called the Blackbird zone (BZ) and the Jackass zone (JZ). The BZ lies near the top of the middle subunit and contains the Co reserves of the Blackbird mining district; it is marked regionally by the presence of "biotitite", a rock containing abundant Fe-rich biotite. The JZ lies near the top of the lower subunit and contains minor deposits of banded iron-formation and cobaltian pyrite. The common Fe mineral in the lower subunit is magnetite; pyrite and magnetite are common in the JZ. Ilmenite is the typical iron mineral in the middle subunit and Fe-silicate (in biotitite) is abundant in the BZ. Fe-rich strata throughout the formation were likely derived at least in part from sea-floor, geothermal exhalations.

The lower subunit (and the JZ) is locally enriched in Cu and Sb, and the middle subunit (and the JZ) is locally enriched in As, Mo, and Se. Biotitite (in the BZ) is enriched in Fe, Li, P, Ti, and V. These stratigraphically controlled geochemical features may mirror chemical changes associated with geothermal activity through time. Anomalous Cu in the lower part of the succession displays itself in both anomalously high and anomalously low concentrations. About one-fourth of the samples collected from the lower subunit contained ppm Cu. A similar Cu phenomenon in Belt Supergroup argillitic strata of northwestern Montana was attributed to post-depositional leaching and it's possible that such leaching has occurred in the lower subunit of the Yellowjacket as well.

The strongly linear ICB is thought by some to mark the axis of a middle Proterozoic intracratonic rift, along which sea-floor venting produced synsedimentary mineralization. This mineralization is in fact virtually restricted to two stratigraphic horizons (BZ and JZ) whose surface traces diverge from the line of the ICB (and the rift axis). This divergence raises the possibility that the axis, if it exists, lies elsewhere. In addition, both the JZ and the BZ have been tentatively identified in the Lemhi Range to the southeast, suggesting that the ICB is a larger and more diffuse feature than heretofore thought.

INTRODUCTION

This report describes a geochemical study of the Yellowjacket Formation (Middle Proterozoic) in and around the southeastern half of the Idaho Cobalt Belt (ICB) of east-central Idaho during the years 1983-1986 (fig. 1). Interest in the ICB arises primarily because it contains, in the Blackbird mining district (fig. 2), one of the largest reserves of cobalt in the United States (Hughes, 1983). This work has focused on the host rocks (Yellowjacket) south and east of the district because the effects of metamorphism and mineralization, with its attendant alteration, are less pronounced there than inside the district.

Yellowjacket rocks southeast of the district are crucial to an understanding of mineralization in the ICB for three reasons; 1) they display more fully than rocks inside the district the essential nature of the host stratigraphy, 2) they demonstrate that the mineralized strata in the district continue outside as a mappable but largely unmineralized zone (the Blackbird zone), and 3) they indicate that the ICB includes at least two stratigraphically separated episodes of mineralization.

In this report the use of the term mineralization (or mineralized) refers specifically to the anomalous occurrence of precious or base metals, commonly as sulfides, in the rocks of this study.

I thank Karl Evans, George Desborough, and J.T. Nash, all of the U.S. Geological Survey, for use of unpublished mapping, assistance in opaque mineral identification, and a stimulating review of an early draft, respectively.

GEOLOGIC SETTING

Structure

The barest outline of the geologic setting of the Idaho Cobalt Belt suggests a long and complicated tectonic history:

1) crustal instability during sedimentation (growth faults and synsedimentary mineralization of Hughes, 1983)

2) biotite-grade metamorphism and folding prior to Precambrian intrusion at 1.37 ga (Evans and Zartman, 1990)

3) Cambro-Ordovician syenitic intrusion at about 490 ma (Evans and Zartman, 1988)

4) Sevier-type (Cretaceous) thrusting

5) Late Cretaceous (Idaho Batholith) and Tertiary intrusions (Kiilsgaard and Lewis, 1985), and

6) Tertiary volcanism, caldera formation (Ekren, 1985) and subsequent crustal extension.

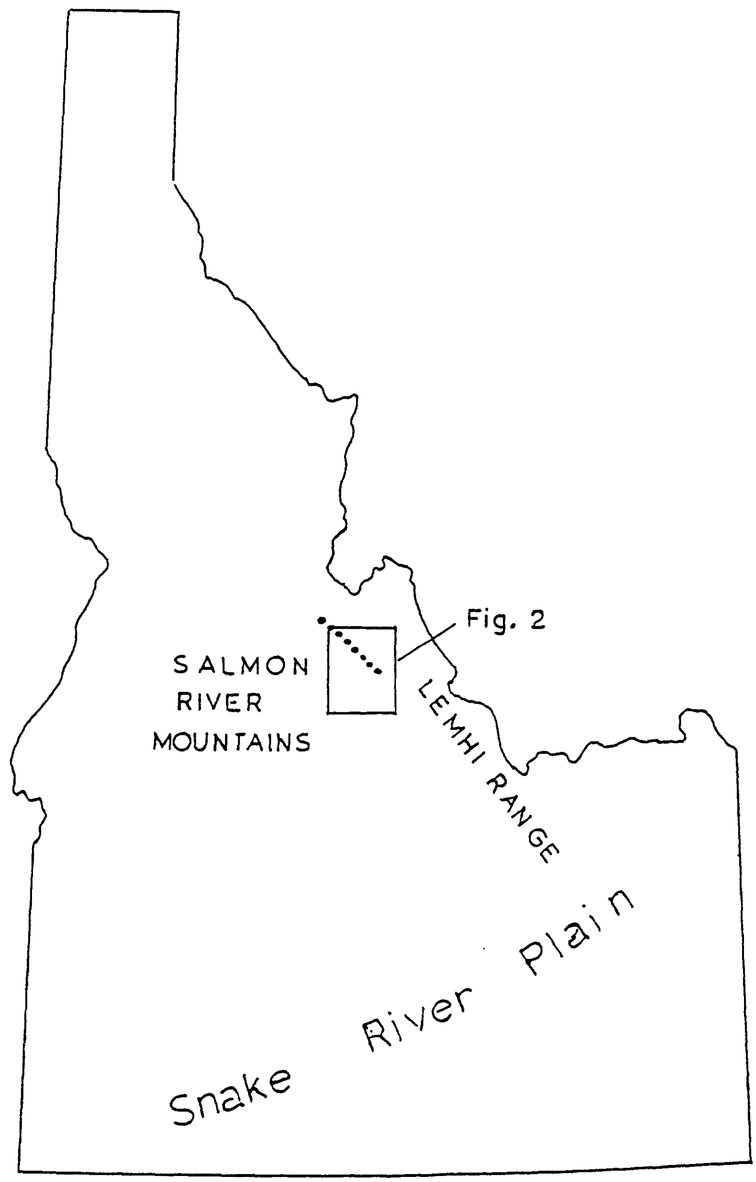

Figure 1.--Index to geologic map and location of Idaho Cobalt Belt (dotted line), east-central Idaho.

In spite of this tectonic complexity, the gross regional structure across the southeastern end of the ICB is rather simple (fig. 3), consisting primarily of an enormously thick (13,000 m) sedimentary succession thrown into large, more or less open folds (structures to the northwest are more complex).

Jumbled bedding in Moyer Creek, including a major dip reversal, indicate the presence of an important fault, herein called the Moyer Creek Fault. Topographic expression requires that it be high-angle, and compressional features suggest it is a thrust, as indicated on figure 3. The Moyer Creek fault separates Yellowjacket rocks of contrasting lithology. To the south and west of the fault, the Yellowjacket contains prominent impure scapolitic marble and thick-bedded white quartzite (the Hoodoo Quartzite of Ross, 1934), neither of which is known to the north or east.

A somewhat similar jumbled zone to the northwest, though poorly exposed and hence much less well-defined, probably reflects a similar high-angle, reverse fault (the Leesburg fault of Shockey, 1957, p. 16). The Leesburg fault is shown in figure 3 as a subsurface thrust. Southeastward this fault breaks the surface near the Twin Peaks Mine (fig. 2a) as a a high-angle, west-dipping reverse fault (Modreski, 1985, p. 214). Throw across both the Moyer Creek and Leesburg faults is probably not large (as suggested on fig. 3), although both faults presumably reflect Sevier-type compression.

The footwall of the Leesburg fault is occupied locally by the Big Creek Quartzite (mid-Proterozoic Lemhi Group), but a sliver of Ordovician strata also crops out in the footwall at the Twin Peaks Mine (Modreski, 1985). The Big Creek apparently sits here as a detached block (Connor and Evans, 1986), but because its regional structural relations are unknown, I show the block as a grossly conformable part of the stratigraphic section (fig. 3).

Cenozoic extensional faults in the southeastern half of the ICB exhibit two major orientations (fig. 2a); roughly north-south and roughly northeast-southwest. The north-south system commonly displays west-side down movement. This system may have Precambrian antecedents (Hughes, 1983). The Panther Creek graben is part of the northeast-oriented trans-Challis fault system of Kiilsgaard, Fisher, and Bennett (1986) but presumably reflects the same geologically late extension that the north-south system does.

Stratigraphy

The Yellowjacket Formation in the ICB consists of metamorphosed (biotite-grade), mostly dark, generally fine-grained, thinly-bedded to laminated, impure argillite, siltite, quartzite, and marble. Dark, impure quartzite is widely viewed as characteristic of the formation and mid-Proterozoic strata containing prominent amounts of this lithology crop out over an area of some 20,000 square kilometers in east-central Idaho and southwestern Montana (Lopez, 1981, fig. 1). The formation may be most complete, however, in the area shown in figure 2a.

The Yellowjacket Formation was named by Ross in 1934 (p. 16) for outcrops of thin-bedded quartzite and minor impure marble in Yellowjacket Creek (fig. 2b). Bennett, in 1977 (p. 10), extended the name to rocks northwest of the (then unknown) Moyer Creek Fault. Connor and Evans (1986) mapped three lithic subunits in the Leesburg quadrangle, and these are here extended throughout the area of figure 2a. These units are equivalent in part to three units defined earlier by Hughes (1983) and in part to the middle three (of five) units defined even earlier by Lopez (1981). The stratigraphic succession along the line of the cross-section (fig. 3) is diagrammatically summarized in figure 4, where I suggest it consists of three lithostratigraphic units (four, if the Hoodoo Quartzite is counted separately) and two locally mineralized but regionally extensive zones. Neither a bottom nor a top has yet been described for the Yellowjacket Formation.

Every worker in the Yellowjacket has found that subdivisions of whatever kind become diffuse at regional scales, and the lower, middle, and upper subunits used here are no exception. The contacts are gradational over hundreds of meters and the subunits are in part laterally equivalent. The Jackass (JZ) and Blackbird (BZ) zones are not lithic units, strictly speaking, although both contain distinctive lithic types; rather they are zones characterized by diagnostic Fe minerals. Although the JZ in places lies at the top of the lower subunit, and the BZ in places lies at the top of the middle subunit, both zones wander through the local lithostratigraphy to an extent that they cannot be placed on the same stratigraphic footing as the subunits. Nonetheless these zones appear to constitute two of the most important stratigraphic markers in the formation.

The lower subunit of the Yellowjacket is the finest-grained part of the formation and characteristically consists of interlaminated to thinly interbedded, gray to dark grayish-green argillitic siltite and very fine-grained quartzite. Layering is generally planar parallel to subparallel with local, finely-scaled cross-lamination. Locally, the lower subunit coarsens downward. South of the Moyer Creek fault, characteristic lithologies include fine-grained, impure scapolite-bearing marble, and medium-grained, thick-bedded, clean, white quartzite (the Hoodoo Quartzite, described by Evans and Ekren in 1985 as a lens in the Yellowjacket). The stratigraphic position of the

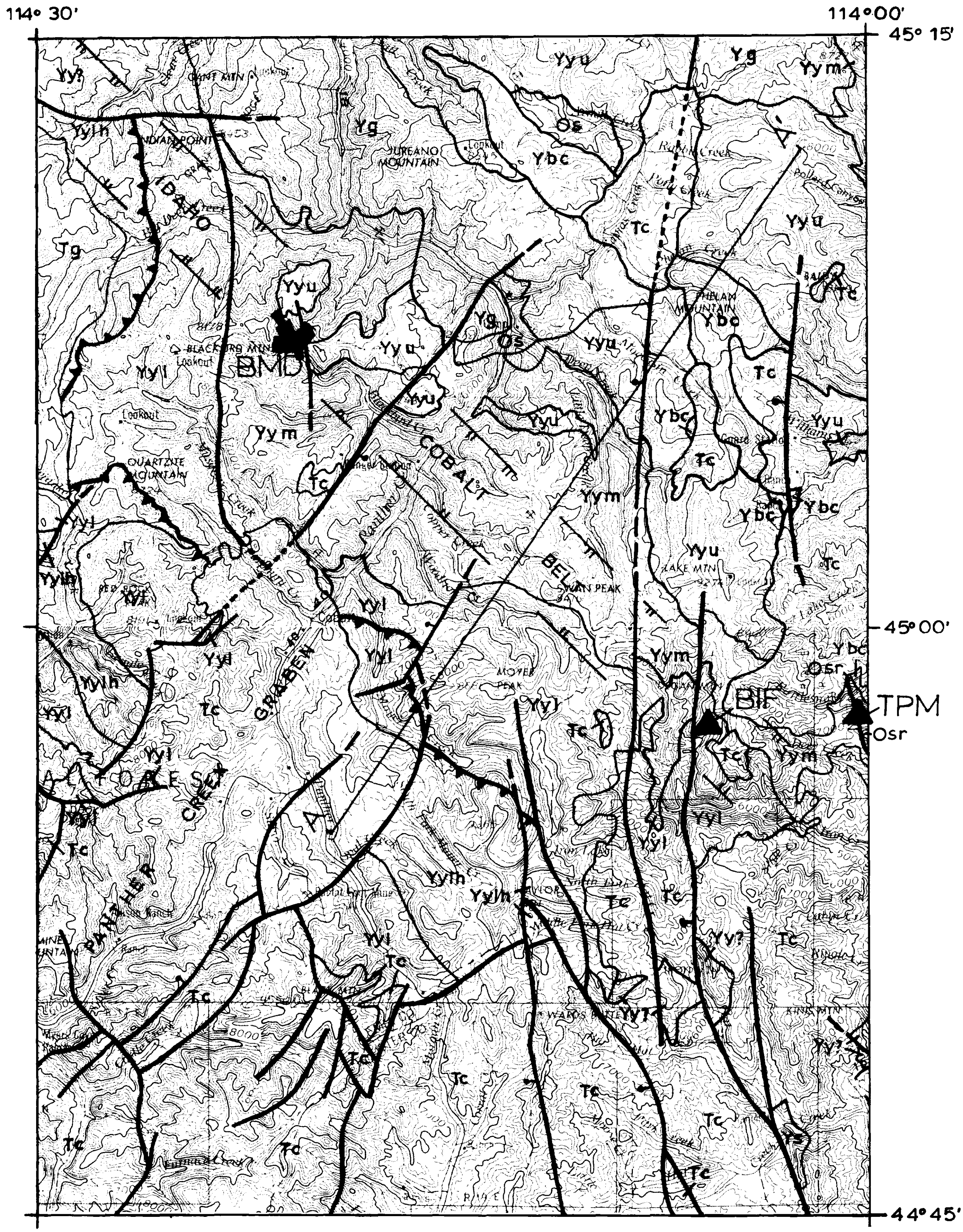

Figure 2a.--Geologic map of area in and around Idaho Cobalt Belt. Adapted from Fisher, McIntyre, and Johnson (1983), Connor and Evans (1986), and K.V. Evans, unpublished mapping. [BMD, Blackbird Mining District; BIF, Jackass Creek banded-iron formation; TPM, Twin Peaks mine]

CORRELATION OF MAP UNITS

	Tg		TERTIARY
	Tc		
Unconformity			
	Osr	Ordovician	
	Os	Ordovician and Ordovician (?)	PALEOZOIC
Unconformity			
	Ys		
	Ybc		
	Yg		
	Yyu	Middle Proterozoic	PROTEROZOIC
	Ym Yy?		
	Yyl		
	Yylh		
	Yyl		

LIST OF MAP UNITS

Tg	Tertiary granitic rocks
Tc	Tertiary volcanic rocks (Challis)
Osr	Ordovician sedimentary rocks
Os	Ordovician and Ordovician(?) syenitic rocks
Ys	Middle Proterozoic Swauger Quartzite
Ybc	Middle Proterozoic Big Creek Quartzite
Yg	Middle Proterozoic granite
Yy?	Middle Proterozoic rocks of uncertain affinity
Yyu	Upper unit of Middle Proterozoic Yellowjacket Formation
Yym	Middle unit of Middle Proterozoic Yellowjacket Formation
Yyl	Lower unit of Middle Proterozoic Yellowjacket Formation
Yylh	Hoodoo Quartzite of Middle Proterozoic Yellowjacket Formation

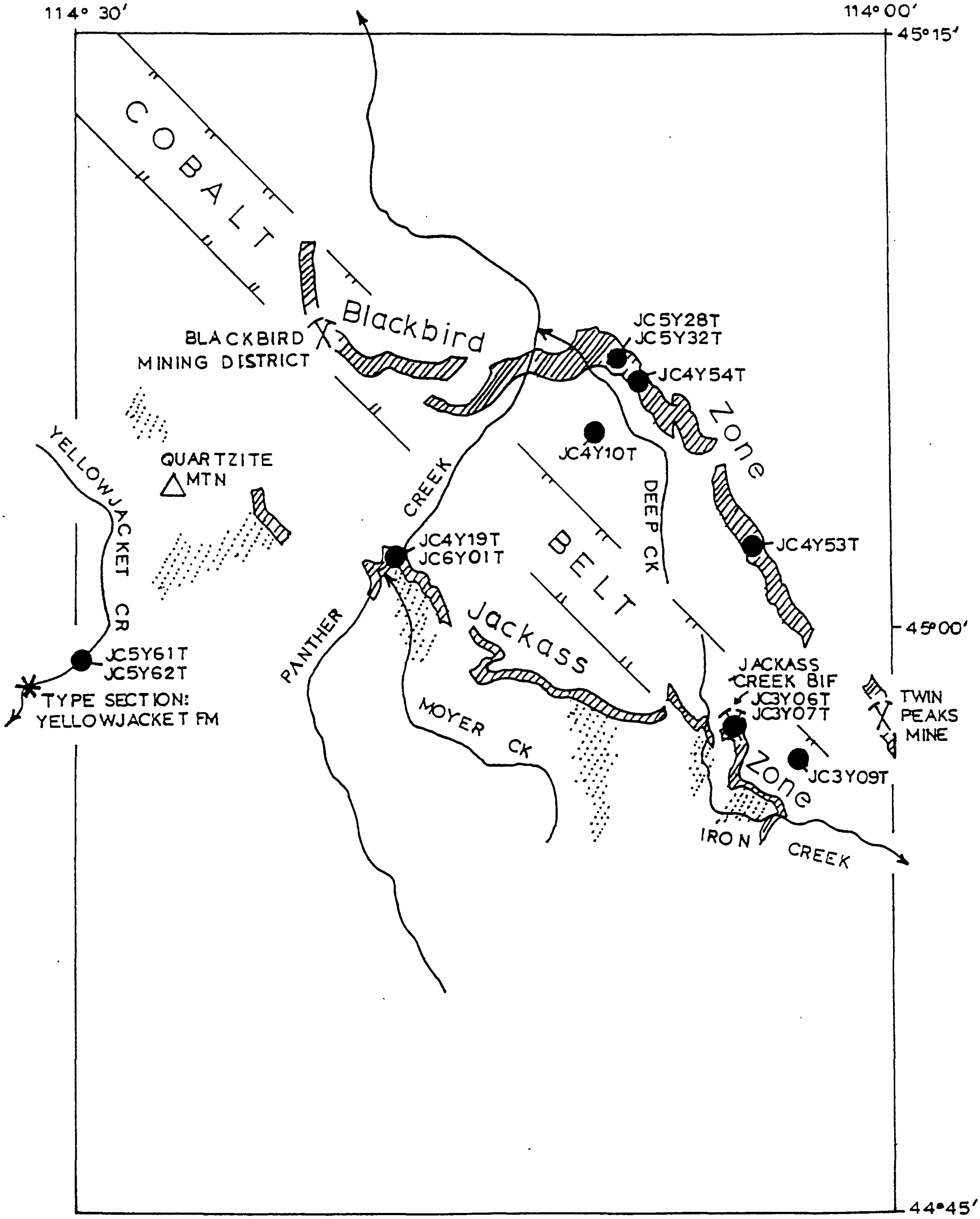

Figure 2b.--Map showing place names and sample locations mentioned in text and showing relation of Blackbird and Jackass zones to Idaho Cobalt Belt. [Outcrop of magnetically susceptible Yellowjacket strata is dotted]

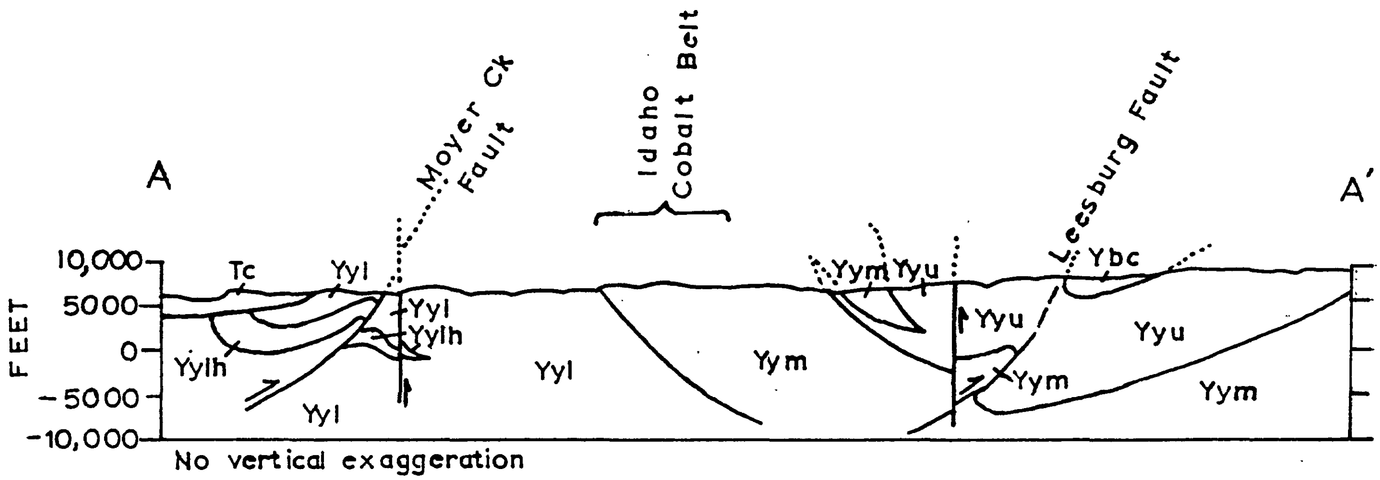

Figure 3.--Geologic section across southeastern end of the Idaho Cobalt Belt. Symbols as in figure 1.

SUBUNIT (Thickness, m)	STRATIGRAPHY West — East	IDENTIFYING CHARACTERISTICS: LITHOLOGY	MINERALS	FE-FACIES	MS?
Upper (3000 min)		Thick-bedded, hummocky X-stratified, impure quartzite	Well-rounded tourmaline	?	No
	BZ	"Biotitite"; Diamictite	Fe-rich biotite; Scapolite	Silicate	No
Middle (5000 max)		Thin-bedded, black & white banded, graded couplets; "Dikelets"	Blebby ilmenite?		No
	JZ	Sand-poor, laminated, argillitic siltite	Magnetite; Pyrite	Oxide/ Sulfide	Yes
Lower (5000 min)		Thin-bedded to laminated, argillitic siltite and impure quartzite; Impure marble near base	Green biotite; Scapolite	Oxide/ Sulfide	Yes — ? —
Hoodoo Qtzite		Thick-bedded, clean, white quartzite		?	No

Figure 4.--Summary character of the Yellowjacket Formation in the area of the Idaho Cobalt Belt. [BZ = Blackbird zone (circle locates Blackbird mining district), dashed line represents eastward extension of BZ; JZ = Jackass zone (circle locates Jackass Creek BIF), middle-lower contact represents westward extension of Jackass zone; MS = magnetic susceptibility; see text for definition of "Biotitite" and "Dikelets"]

marble beds and the Hoodoo is uncertain but both probably lie low in the subunit.

Additional diagnostic features of the lower subunit include abundant green biotite (rather than the brown biotite common to the middle and upper subunits), mud chips and polygonal mud cracks, and rare but widespread microscopic occurrences of cherty(?) texture in otherwise clastic siltite. This chert, if that is what it is, occurs neither as clasts nor as cement; possibly it represents relicts of siliceous exhalite.

The Jackass zone (JZ) roughly follows the top of the lower subunit from Panther Creek northwest to near Quartzite Mountain (fig. 2b). East of Panther Creek the JZ drops further into the lower subunit (more likely, the lower-middle contact rises) and includes banded iron-formation (BIF) in Jackass and Iron Creeks. More widespread are sparse occurrences of magnetite- and pyrite-rich laminae. The JZ is locally sand-poor (sediment-starved). Most important, the JZ sits in or atop a sequence of variably magnetic strata in the lower subunit.

The middle subunit of the Yellowjacket formation characteristically contains plane parallel, laminated to thin-bedded siltite-argillite couplets. These couplets produce an eye-catching, black-and-white banded appearance in outcrop; the white beds are composed of quartz-rich siltite and the black beds are composed largely of mica (argillite). Locally, the planar bedding is strongly disrupted by soft-sediment flow. Bedding in the middle subunit thickens upwards. The middle subunit thins rapidly to the east, probably to extinction. Thinning takes place by interfingering at both the top and bottom of the subunit, with loss of characteristic strata eastward.

A diagnostic feature of the subunit is the presence of "dikelets"; slanting, mm-sized, silt penetrations into the argillite layers. The origin of the dikelets is obscure. The common opaque mineral of the middle subunit characteristically occurs in the argillitic (black) parts of the black-and-white couplets as disseminated blebby or tabular grains a few microns across. These grains are probably ilmenite according to George Desborough of the U.S. Geological Survey, rather than the magnetite/pyrite of the lower subunit.

The Blackbird zone (BZ) lies at the top of the middle subunit in and near the Blackbird mining district. Southeastward the BZ rises into the upper subunit (more likely, the middle-upper contact drops). The definitive rock type in the BZ is "biotitite", a rock composed largely of Fe-rich brown biotite. Inside the district biotitite is the common ore host (ore is also hosted by siliceous exhalite according to Nash and Hahn, 1986, p. 11); east of the district, biotitite layers maintain their unusual chemistry but are unmineralized. Locally, the biotitite contains Na-scapolite porphyroblasts.

The BZ also contains sparse, scattered lenses of interstratified matrix-supported conglomerate (diamictite) composed of small to large (1 m), unsorted and angular, locally derived clasts. Rarely, the clasts are slightly "smeared out", indicating that they were soft during deposition.

The upper subunit of the Yellowjacket Formation characteristically contains light- to dark-gray, thin- to thick-bedded (up to a 1 m), very fine to fine-grained, flat laminated, locally ripple-marked, hummocky cross-stratified, impure quartzite. The upper subunit is the coarsest (sandiest) on average of the three subunits.

Tourmaline is ubiquitous in the Yellowjacket, and in rocks below the upper subunit it occurs everywhere as disseminated, finely tabular, locally euhedral, sometimes broken, blue-green crystals. A distinctive tourmaline, however, appears in the upper subunit; tourmaline there is coarse, well-rounded (multi-cycle), light blue and, locally, pink-cored.

Deposition

The Yellowjacket Formation from the upper part of the lower subunit (approximately the Jackass zone) to the top of the exposed section is a coarsening- and thickening-upward sequence with a locally sand-starved base and a locally hummocky cross-stratified top, and as such apparently represents a basin-filling, prograding wedge. The common occurrence of planar laminations and graded bedding, and an overall lack of shallow-water features suggests an environment generally below wave base. The hummocky cross-stratification in the upper subunit presumably relects late-stage shelf deposition.

Neither the size nor shape of the basin is known; Hughes (1983, p.27) suggested that it may have been quite large, extending even to the Snake River Plain. He suggested that the deepest and most tectonically active part of the basin lay under the ICB. The diamictite lenses, apparently constrained to the BZ and emplaced by gravity-flow mechanisms, indicate local over-steepening of the sea-floor, a situation consistent with a slope-rise or basin margin. Such a margin would perhaps have roughly paralleled the contact between the middle and upper subunits (fig. 2a).

Strata below the Jackass zone locally fine and thin upward, although exact relations among the sandy components of this part of the Yellowjacket are hazy. Rare polygonal mud cracks and mud chips in the lower subunit and the JZ suggest intermittent subaerial conditions (tidal flats?) prior to the basin-filling episode described above. Redbeds, however, are notably lacking throughout the Yellowjacket.

Biotitite in the BZ and BIF in the JZ represent intrabasinally generated sediment (Hughes, 1983; Hahn and Hughes, 1984; Nash and Hahn, 1986, Modreski, 1985), probably mostly by sea-floor, hydrothermal exhalation, although some workers view the biotitite as altered mafic volcaniclastic sediment. Anomalous concentrations of "exhalative"-type trace elements (As, B, Cu, Mo, Sb, Se) appear in other parts of the Yellowjacket as well, suggesting that such emissions may have occurred episodically during accumulation of much of the formation. NaCl-rich scapolite (in biotitite) suggests the local presence of brine in these sediments (Hietanen, 1967, p. 49). A northeastern (cratonic) source for most of the extrabasinal sediment has been advocated by Hughes (1983) and Lopez (1981).

GEOCHEMISTRY

All of the geochemical analyses performed for this study were done in the Denver laboratories of the U.S. Geological Survey. Reproducibility of the analytical methods are given in table 1, and sample locations mentioned in this report are shown in figure 2b. A listing of sample locations, analyses and methods of analysis are available in computer-readable form as Part B of this report (Connor, 1990).

A statistical summary of geochemical variability in the Yellowjacket Formation appears in table 2. I exclude from this summary atypically pure (for Yellowjacket) quartzite samples collected from the Hoodoo. The field collections on which this summary is based had no formal underlying design and summary statistics are somewhat hazardous; nevertheless, I believe that the data in table 2 reasonably represent the geochemical variability of the formation in the area of the ICB. The 50th percentile constitutes a "best guess" of the average composition of the formation and the 10th and 90th percentiles similarly constitute a best guess of the limits of likely range in composition for typical Yellowjacket rocks.

Maximum values listed in table 2 demonstrate the local presence of geochemically unusual rock within the stratigraphic succession. Maximum concentrations exceed the 50th percentile by 5 times or more for the following constituents:

Constituent	Maximum concentration	50th percentile (table 2)	Sample number	Stratigraphic location (lithology)
As ppm	40	2.7	JC3Y06T	JZ (BIF)
B ppm	1000	40	JC3Y07T	JZ (BIF)
CaO %	5.8	.30	JC5Y61T	Subunit 1 (marble)
Co ppm	1100	8.0	JC3Y07T	JZ (BIF)
Cu ppm	1100	6.5	JC4Y19T	JZ (siltite)
$FeTO_3$ %	24	4.3	JC5Y28T	BZ (biotitite)
Li ppm	110	20	JC5Y32T	BZ (biotitite)
Mn ppm	1700	220	JC5Y32T	BZ (biotitite)
Mo ppm	41	<2.0	JC3Y07T	JZ (BIF)
P ppm	3200	400	JC5Y32T	BZ (biotitite)
Pb ppm	130	5.0	JC3Y09T	Subunit 2 (siltite)
Sb ppm	4.8	.40	JC3Y07T	JZ (BIF)
Se ppm	7.8	<.10	JC3Y07T	JZ (BIF)
TiO_2 %	7.6	.47	JC5Y32T	BZ (biotitite)
V ppm	410	50	JC5Y32T	BZ (biotitite)
Y ppm	81	13	JC5Y62T	Subunit 1 (marble)
Zn ppm	240	30	JC3Y09T	Subunit 2 (siltite)

Not surprisingly, nearly all of these high concentrations occur in either the Blackbird or Jackass zones. Samples JC3Y06T and JC3Y07T are Fe-oxide-rich samples from the BIF in Jackass Creek; JC4Y19T is also from the JZ but is siltite rather than BIF. Samples JC5Y28T and JC5Y32T are biotitites from the BZ. JC5Y61T and JC5Y62T are samples of impure marble from the lower subunit. JC3Y09T was collected from an altered (faulted?) siltite in the middle subunit. The high Pb and Zn is unusual for Yellowjacket rocks (this is the only anomalous Pb-Zn sample in this study), although mineralization at the nearby Twin Peaks mine (which lies in the BZ; see fig. 2b) includes galena.

The BIF, biotitite, and impure marble are all atypical lithologies in the Yellowjacket succession, as is quartzite of the Hoodoo, and samples of each are listed in table 3 suggesting the degree of geochemical atypicality for these rocks when compared to the 50th percentiles in table 2.

Overview

Histograms of 13 of the anomalous constituents listed above are shown in figure 5; CaO, Y, Pb, and Zn are not shown. The histograms clearly demonstrate stratigraphic control on element distribution. Six samples of biotitite from the BZ and four samples collected from or marginal to the BIF in Jackass Creek provide most of the higher concentrations, but even if these ten samples are excluded, many elements still exhibit anomalously high concentrations in those two zones. The data in figure 5 suggest that, overall, the JZ tends to be high in Cu, Mo, Sb, and Se when compared to the BZ, and the BZ tends to be high in Fe, Li, P, Ti, and V when compared to the JZ.

Elemental comparisons among the three subunits, but excluding the BZ and JZ, suggest that Cu and Sb, and possibly Se, tend to be anomalously high in the lower subunit and As, Mo, and Se tend to be anomalously high in the middle subunit. If these highs reflect sea-floor venting, they suggest that the syn-sedimentary hydrothermal activity invoked for the origin of the BIF in the JZ and the biotitite in the BZ, was not restricted to the JZ or BZ, but may have occurred throughout deposition of the lower and middle subunits.

Geochemical differences among the three subunits (again excluding samples from the BZ and JZ) was examined by multiple-group discriminant function analysis (Dixon, 1968). Two geochemical indices useful in distinguishing among the three subunits are:

Z_1 = 0.0446-3.4445(Log P)-2.5409(Log Sr)-1.5215(Log As)-0.9076(Log Sb)

Z_2 = 5.2066+2.2189(Log P)+0.3389(Log Sr)-3.0333(Log As)+3.2043(Log Sb)

An XY plot of the samples (and the subunit averages) based on these indices is shown in figure 6. This plot visually enhances the geochemical differences among the subunits indicated in the histograms of figure 5.

The discrimination relies on the stratigraphic distribution of two "exhalative" elements, As and Sb, plus the distribution of P and Sr, and reflects the fact that the upper subunit is low in P (apatite) and Sr (albite) compared to the middle and lower subunits. The high As in the middle subunit and the high Sb in the lower subunit may, as previously suggested, represent sea-floor venting.

The geochemical separation shown among subunit averages in figure 6 is statistically significant. Thus, the two equations (above) permit geochemical assignment of a Yellowjacket sample to a subunit provided a suitable chemical analysis is available. Once a sample is plotted on figure 6, the subunit average closest to the plotted point represents the subunit to which the sample most likely belongs. On average such an allocation should result in the correct stratigraphic assignment 3 out of 4 times.

Blackbird zone (BZ)

The Blackbird zone consists of as much as 1000? m of interbedded quartzite, siltite, and argillite anchored on the Blackbird mining district (fig. 2b). In and near the district, the BZ lies mostly in the upper part of the middle subunit; southeastward it rises into the the upper subunit. The zone is characterized by the presence of intercalated "biotitite", a rock type dominated by Fe-rich biotite, but it is also spatially associated with two other rock types: diamictite (described above) and cross-cutting tourmalinized breccia.

I have traced the BZ from the Blackbird district southeastward to the Twin Peaks mine (fig. 2b); the zone apparently continues to the northwest past Blackbird (Lund and others, 1983, p. 4), and has been tentatively identified in the Lemhi Range to the east as well (Connor and Evans, 1990). Inside the Blackbird district, individual biotitite beds are as much as 20 cm thick and "packages" of biotitite are as much as 10 m thick (Nash and Hahn, 1986). The abundance and thickness of individual biotitite layers decrease southeastward. In Deep Creek, biotitite beds rarely exceed 15 cm thickness, and still farther east they are even thinner, although scarcity of outcrop could easily mask the true situation. The thickness of the BZ may similarly decrease southeastward.

Mineralization in the BZ in the Blackbird District is principally cobaltite, chalcopyrite, pyrite, and native gold. Nash and Hahn (1986) provide an extended discussion of mineralization in the district. Between the district and the Twin Peaks mine, the zone is virtually unmineralized. At the Twin Peaks mine, the mineralization is largely galena, chalcopyrite, pyrite, and trace Au, but no Co (Modreski, 1985, p. 214).

Biotitite

Biotitite rock is relatively non-descript in outcrop, being generally the blacker, more biotite-rich layers of a generally dark and micaceous section. The most biotite-rich samples generally display a characteristic sheen or sparkle. Texture in thin section is more diagnostic. Sample JC5Y32T (table 3), for example, consists of interlocking, coarse flakes of light yellow-brown to dark brown biotite (78%) in a schistose fabric. Common acessory minerals in biotitite are disseminated quartz, opaque minerals, and coarse, recrystallized apatite. Locally, biotitite contains porphyroblasts of muscovite or Na-rich scapolite; an analysis of hand-picked crystals of scapolite from a sample collected in Deep Creek appears in table 4.

The analysis of sample JC5Y32T (table 3) suggests the extraordinary chemical character of this rock type (and of its contained biotite). Specifically, the high Fe and Ti seem characteristic; the Ti here resides largely in coarse, euhedral ilmenite, but ilmenite-poor samples still commonly contain as much as 1 percent TiO2 or more (presumably in the biotite). The characteristic geochemistry of biotitite is akin to alkali basalt according to Nash and Hahn (1986, p. 18).

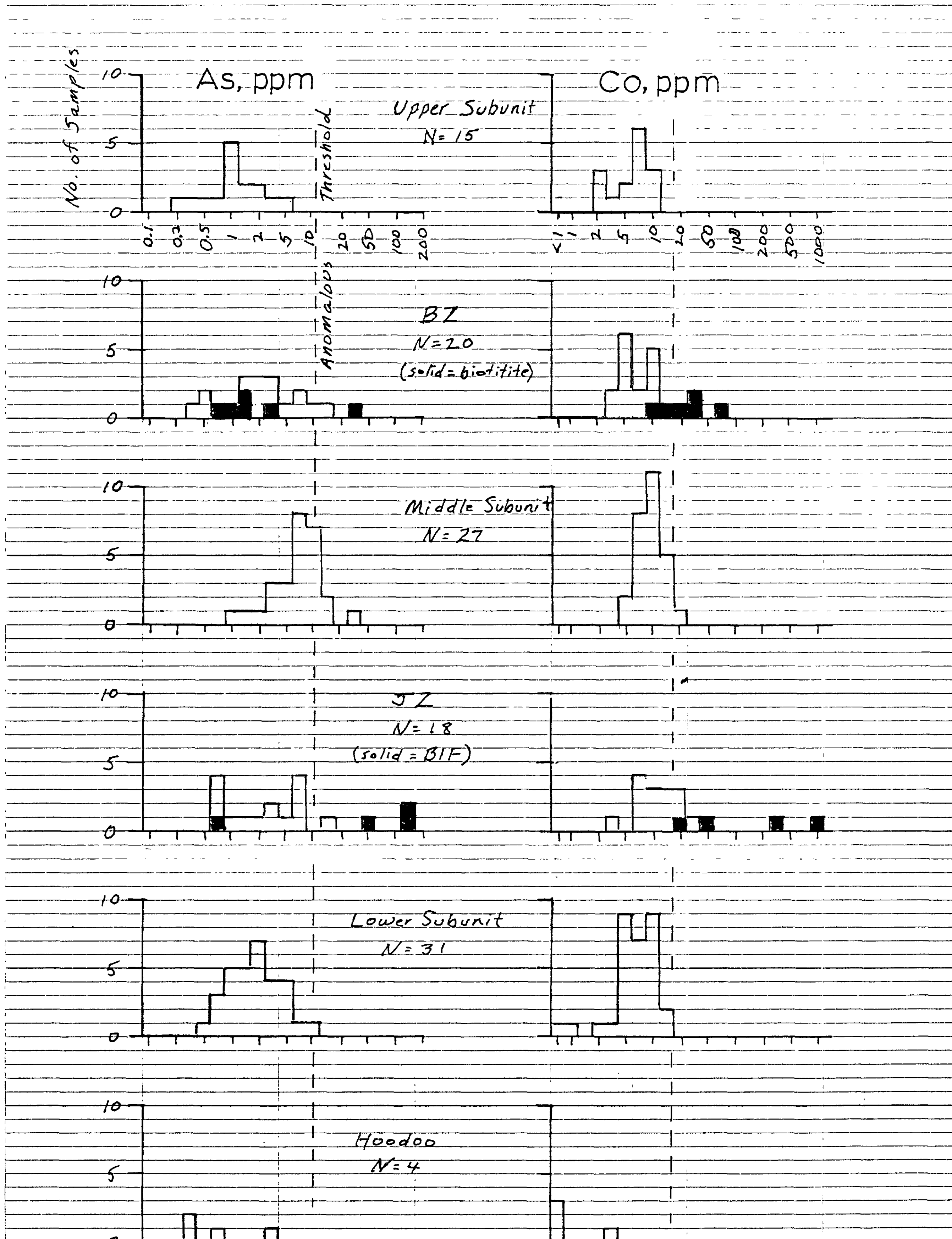

Figure 5.--Histograms of selected elements in the Yellowjacket Formation. [Dashed vertical line is 90th percentile (from table 2); vertical scale same for all histograms; horizontal scale same in each column; stratigraphic subdivisions same for all histograms; solid areas represent samples of biotitite in BZ and samples of BIF in JZ]

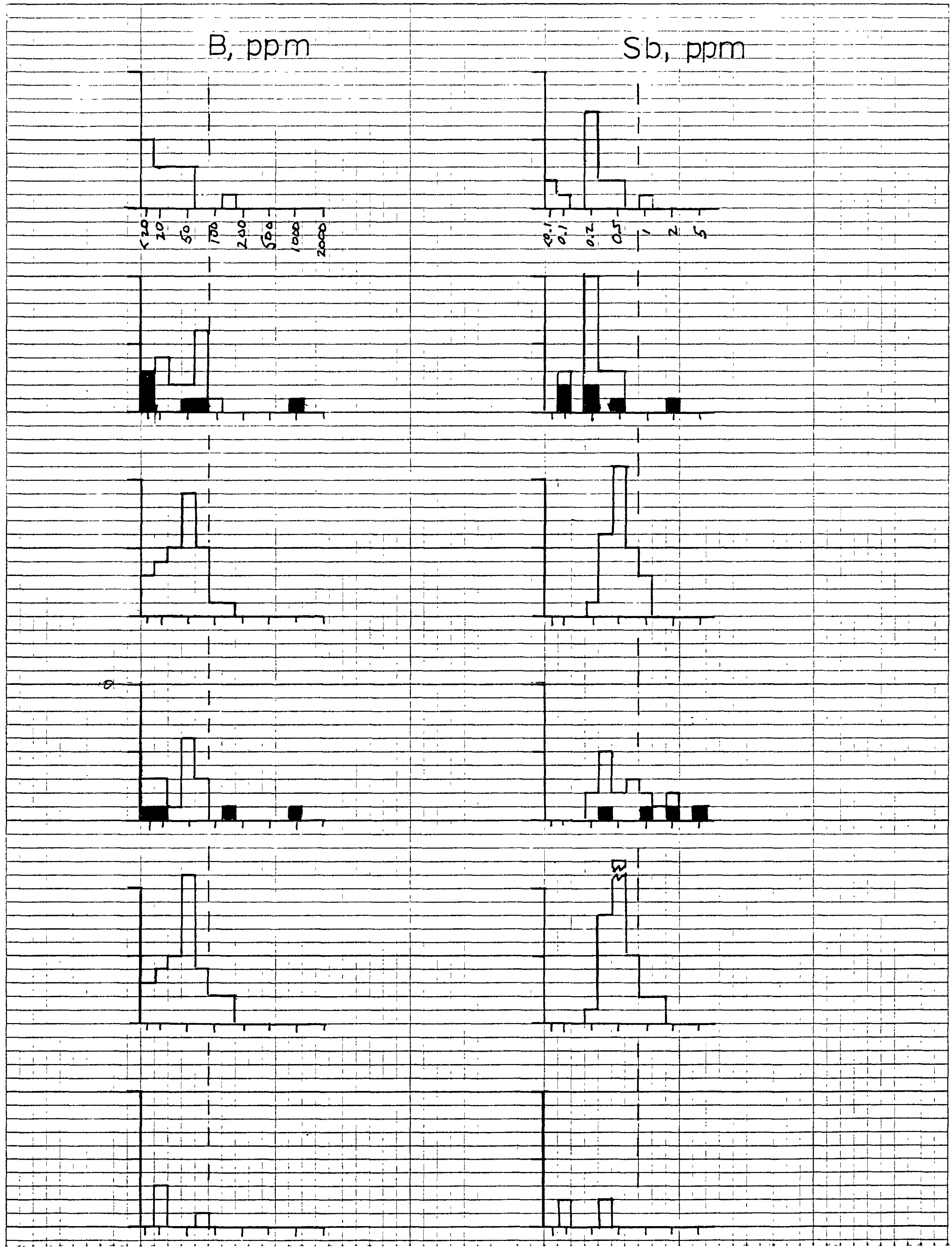

Figure 5.--Continued

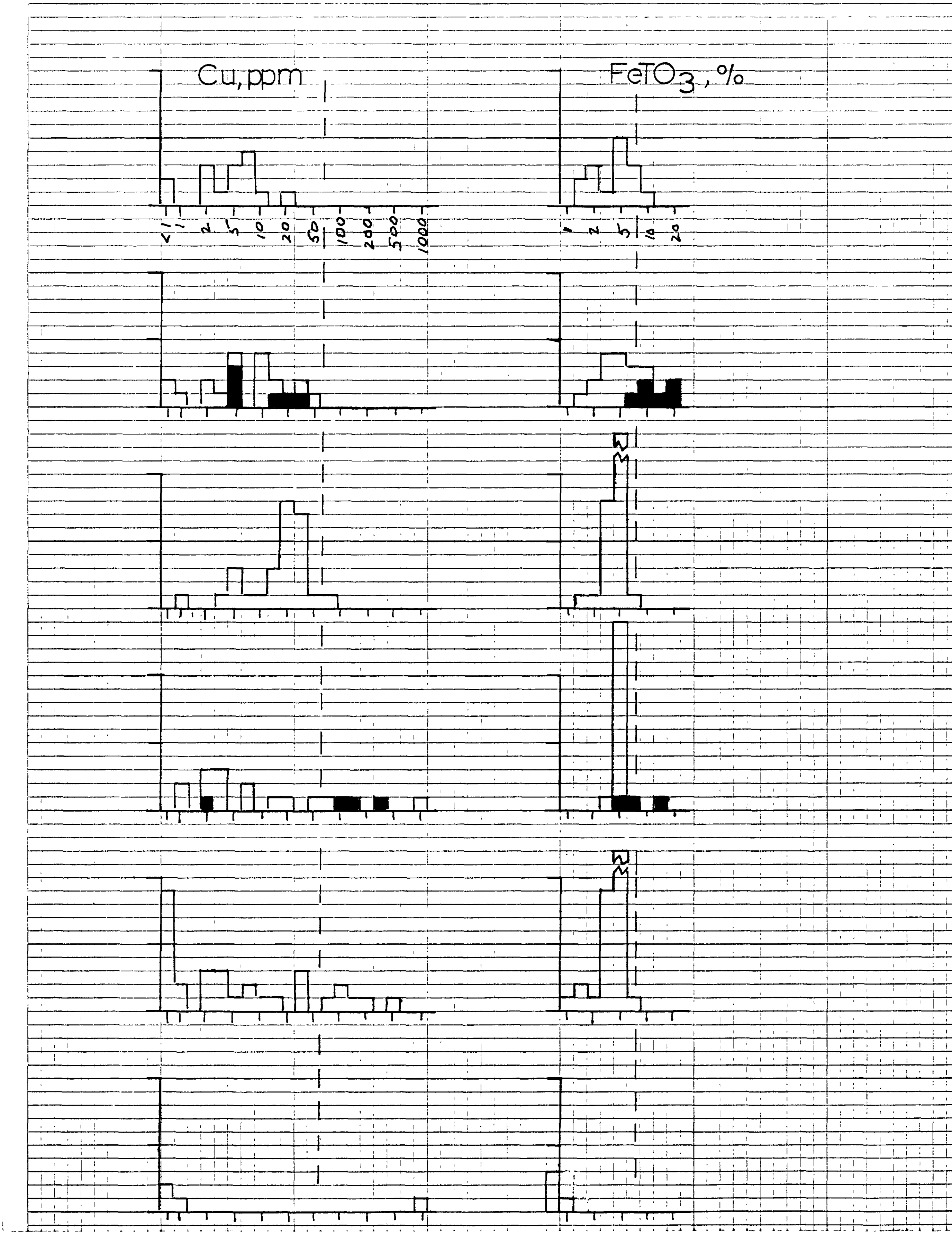

Figure 5.--Continued

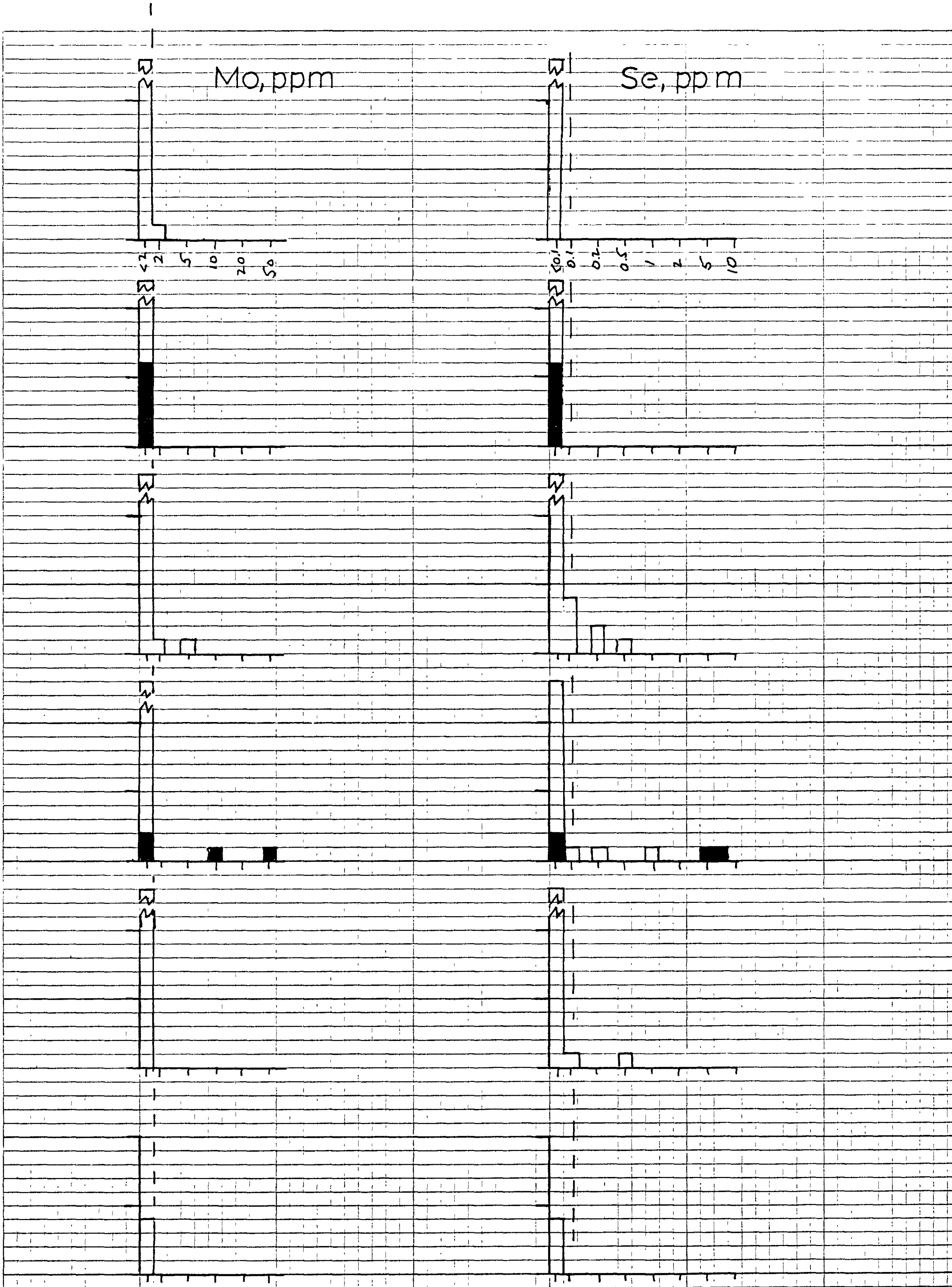

Figure 5.--Continued

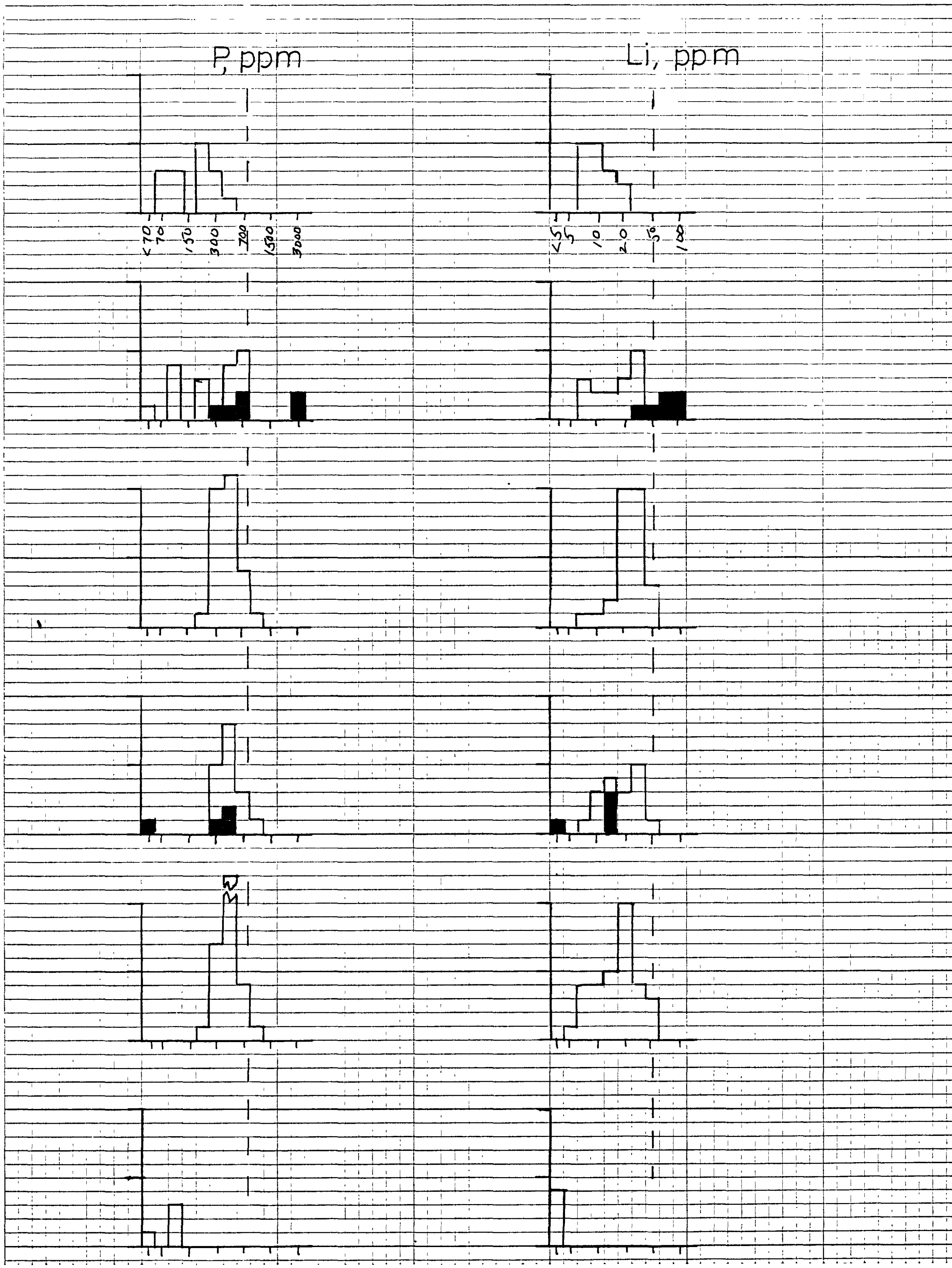

Figure 5.--Continued

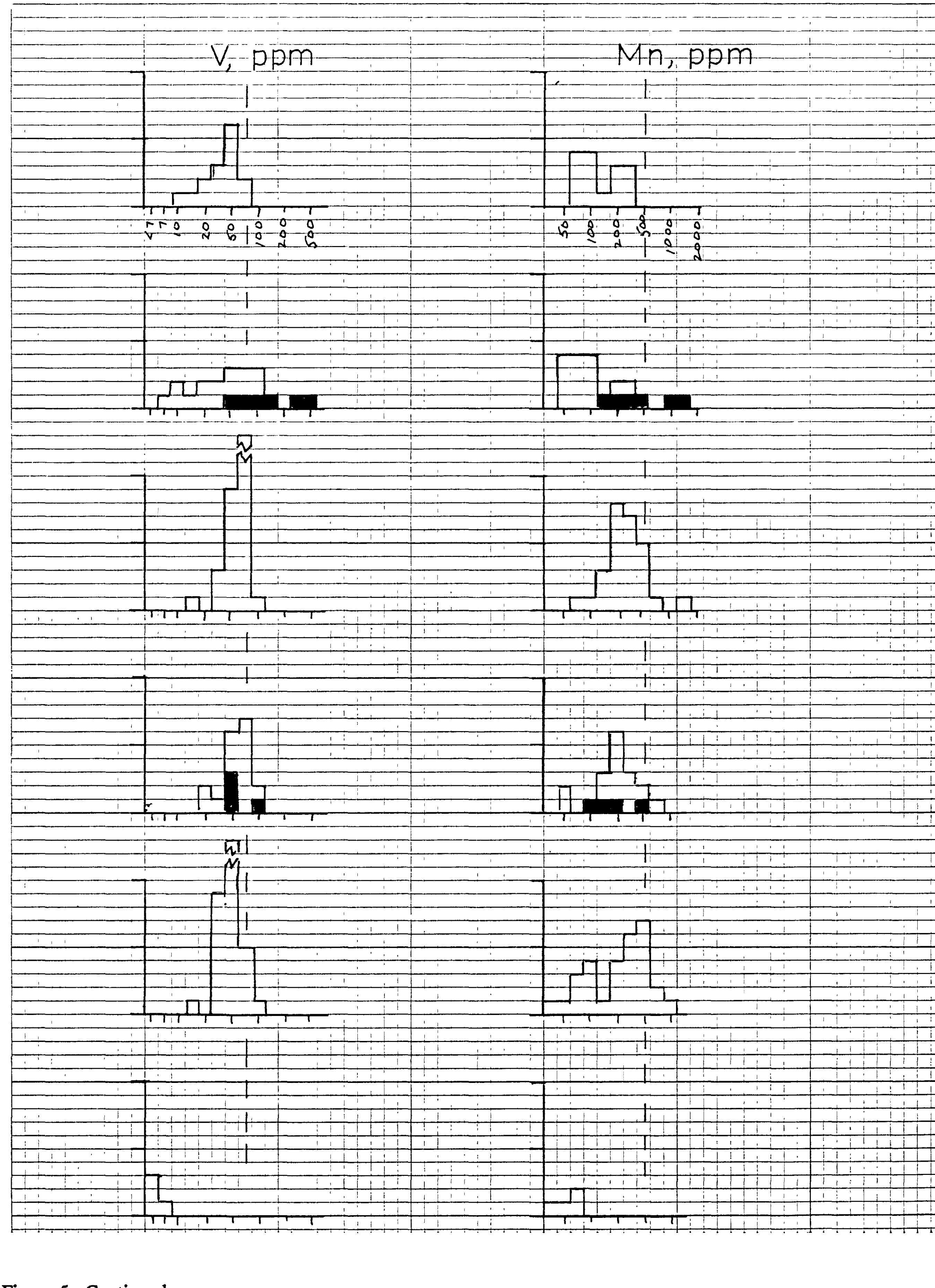

Figure 5.--Continued

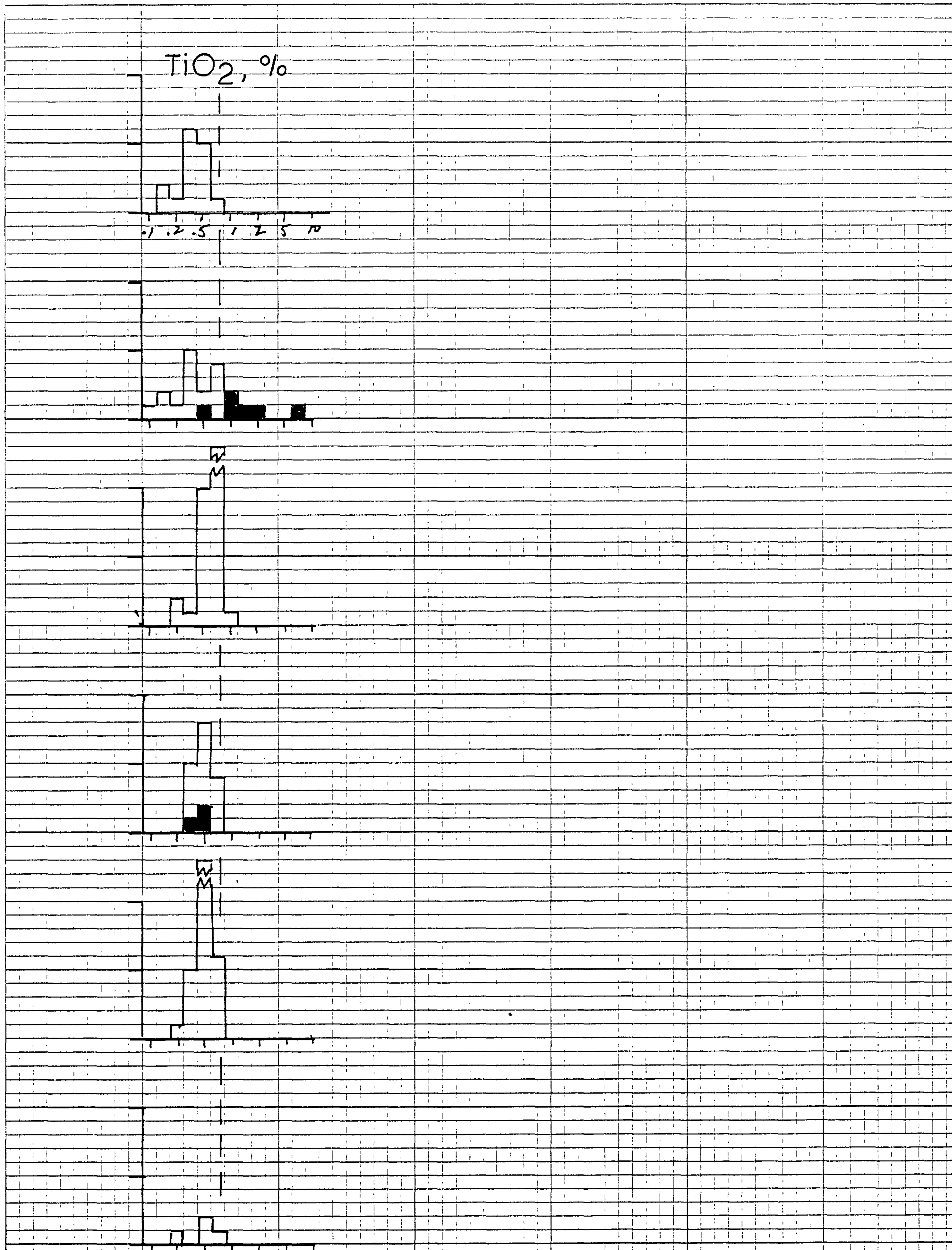

Figure 5.--Continued

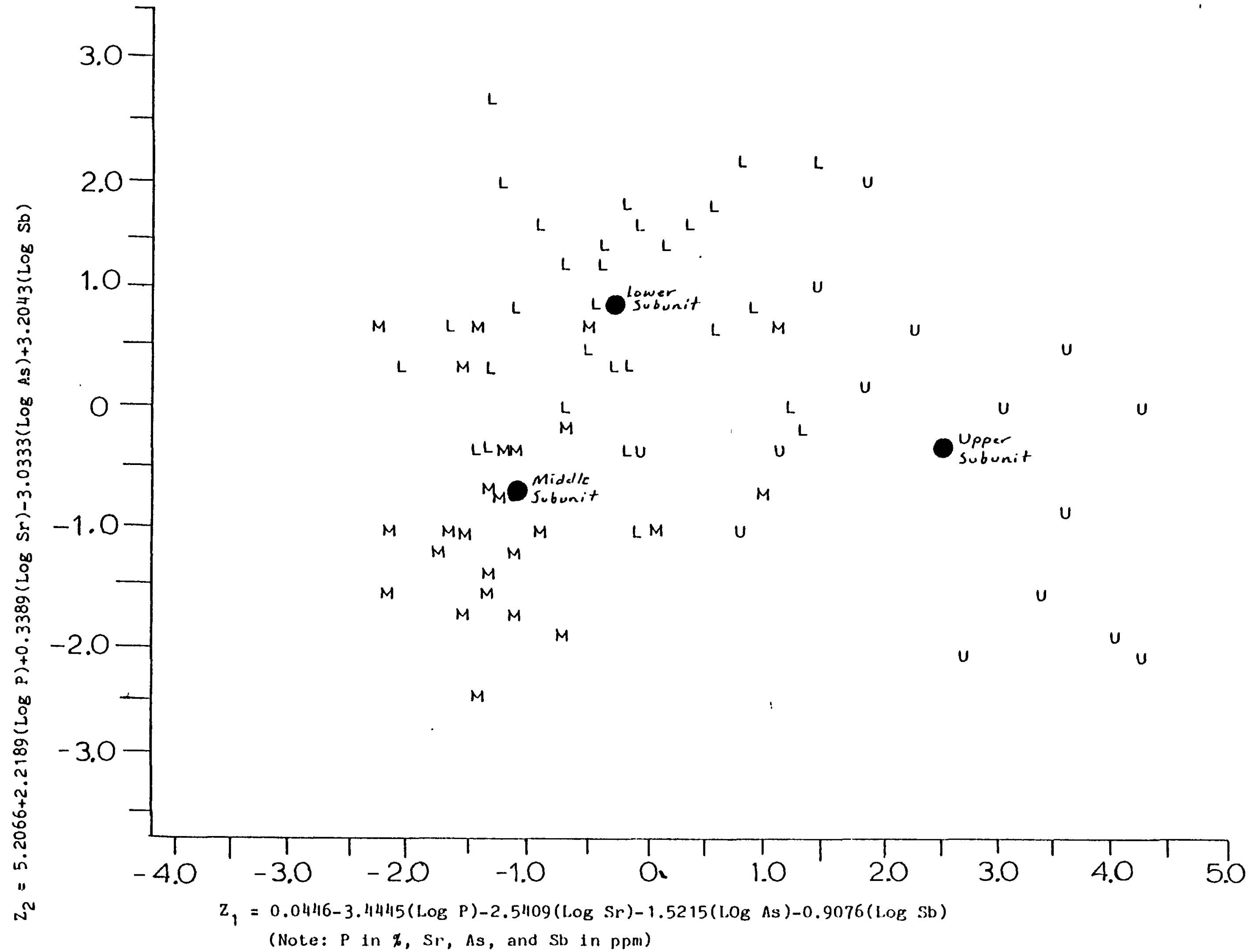

Figure 6.--XY plot showing geochemical differences among subunits of the Yellowjacket Formation. [Letters represent samples; L = lower subunit, M = middle subunit, U = upper subunit. Solid dots are subunit averages]

Hughes (1983, p. 25) suggested that biotitite is a product of submarine volcanism ("aquagene tuff"). Nash and Hahn (1986, p. 4) suggested that biotitite may have been deposited at least partly as an Fe-rich "gelatinous chemical sediment". Throughout the Yellowjacket generally, Fe-rich strata seems to be related to sea-floor venting (e.g., the Jackass Creek BIF), and biotitite may likewise reflect in part complex Fe-rich sea-floor exhalation.

Tourmalinized breccia

Small, intrusive quartz-tourmaline breccia bodies crop out in a wide zone roughly parallel to, but mostly south of, the Blackbird zone. Tourmalinized breccia is also found in or near the Jackass zone (Modreski, 1985), but not in the quantity seen near the BZ. The breccia bodies are generally cross-cutting (many are dike-like) and most appear to be shattered Yellowjacket cemented by fine-grained, black tourmaline. However, quartz in the breccia tends to be a recrystallized mosaic and probably much of the quartz, like the tourmaline, has been introduced. Accessory minerals include both K- and Na-feldspar, white mica and biotite, apatite, and opaque minerals. In the Blackbird mining district, some of the breccias are mineralized (Nash and Hahn, 1986); they lack sulfides away from the district.

Tourmaline in the breccia occurs as mats of fine-grained, stubby, barrel-shaped crystals with a pale pink to blue-green pleochroism. Samples of relatively pure quartz-tourmaline indicate a Mg:Fe atomic ratio in the tourmaline of about 1:1 suggesting a tourmaline of intermediate composition.

Maximum element concentrations observed in 17 samples of tourmalinized breccia, excluding B, Al, Mg, and Fe (necessary for tourmaline), were:

As ppm	330	Cu ppm	36	P ppm	900
Au ppm	<.1	Ga ppm	50	Sc ppm	71
Ba ppm	630	K %	1.8	Sr ppm	290
Be ppm	4	La ppm	220	Th ppm	30
Ca %	.39	Li ppm	20	Ti %	.37
Ce ppm	480	Mn ppm	80	V ppm	170
Co ppm	28	Nd ppm	220	Y ppm	170
Cr ppm	76	Ni ppm	19	Yb ppm	18
				Zr ppm	500

Elements As (sample JC4Y10T) and Ce and Y (samples JC4Y53T and JC4Y54T) are high enough to attract the eye, but none of the elements exhibit discernible spatial patterns. The breccia bodies apparently formed late, following lithification of the host, and the shattered texture indicates explosive emplacement. Because they are B-rich, the breccias may be related to (final?) expulsion of basin fluids.

Jackass zone (JZ)

The Jackass zone consists of a few hundred m in the upper part of the lower subunit of the Yellowjacket Formation. It is in general more sand-poor than the rest of the Yellowjacket, particularly in the western part of the study area, and it appears to be pervasively though weakly pyritized. It locally exhibits small, apparently stratabound shows of Cu, mostly as malachite but also as chalcopyrite.

The JZ lies at the top of a thick sequence of magnetically susceptible strata, and contains banded iron-formation (BIF) in Iron and Jackass Creeks. I have traced the JZ from lower Iron Creek northwestward almost to Quartzite Mountain (fig. 2b). Like the BZ, the lateral limits of the JZ are not known but the zone probably continues in both directions.

The BIF in Jackass and Iron Creeks consists principally of magnetite, pyrite, and chalcopyrite and apparently resulted from sea-floor geothermal activity (see Nash, 1989, and Modreski, 1985, for details of these deposits). The BIF is geochemically anomalous in many trace metals including As, B, Co, Cu, Mo, Sb, and Se (sample JC3Y06T, table 3). Sample JC6Y01T (table 4) was a 2-cm cube of Co-bearing pyrite (3000 ppm Co) collected from the JZ at the mouth of Moyer Creek (fig. 2b). Stratabound trace magnetite and anomalous Cu was found in the same outcrop, and it's probable that the Cu, Co, and magnetite in Moyer Creek reflect the same kind of mineralizing processes as those envisioned at Jackass Creek. According to Nash (1989) the cobaltiferous pyrite in the JZ in Iron Creek was early diagenetic.

Magnetic susceptibility

A hand-held susceptibility-meter survey along roads in the ICB showed that strata in the Jackass zone and below are magnetically susceptible to a marked degree (fig. 2b). Readings in the susceptible area commonly ranged from 2000-5000 relative units, in sharp contrast to uniform readings of 2 relative units in strata lying higher in the Yellowjacket. The lateral limits of susceptible strata are unknown but, like the JZ, such strata likely occur both northwest and southeast of the limits shown in figure 2b. Mabey (1982) spoke of a "large magnetic high" in the Precambrian here of several km width and 100 km length.

The magnetic susceptibility reflects disseminated magnetite in the lower subunit. This magnetite commonly occurs in coarse, euhedral grains, and tends to be more abundant in the siltitic (rather than the argillitic) parts of the host rock; that is, it is stratabound. Modreski (1985, p. 211) remarked on the chemical purity of this magnetite, which is consistent with a relatively low temperature of formation.

There is no marked change in Fe concentration from the lower to the middle to the upper subunit; all contain about 5% total Fe as Fe_2O_3 (see Fe histogram, fig. 5). Thus, the magnetism in the lower subunit does not represent simple enrichment in Fe. Rather, the Fe mineralogy changes upward through the Yellowjacket. In the lower subunit magnetite is a typical Fe mineral, and magnetite and pyrite are common in the JZ. Above the JZ, the common Fe mineral appears to be ilmenite (middle subunit) and, higher yet, Fe-biotite and ilmenite (BZ).

This change in Fe mineralogy upward is summarized in figure 4, where I suggest that the distribution resembles facies of iron-formation (James, 1964). In this sense, then, the Yellowjacket might be viewed as an iron-formation, albeit an Fe-poor one. Failure to develop more fully presumably reflects a terrigenous sedimentation rate too great to have permitted significant chemical (Fe) accumulation. Chemical sedimentation was locally important, however, as suggested by the JZ and BZ and their contained mineralization.

The euhedral form of the magnetite in the lower subunit suggests diagenetic or metamorphic crystallization, and the Fe-biotite in biotitite (BZ) is also metamorphic. But the origin of the ilmenite in the middle subunit is more puzzling. Fine-grained, blebby ilmenite occurs, among other places, in locally-derived framework clasts, some of which were soft when deposited. This occurrence indicates that the ilmenite was introduced early (synsedimentational?), which in turn suggests that the observed upward change from one Fe mineral to another in the succession is probably not a metamorphic effect. Possibly, the upward change in Fe mineralogy reflects time-dependent change in the geochemical conditions of exhalation.

And an odd copper distribution

The Yellowjacket Formation hosts numerous Cu deposits and prospects but the distribution of this Cu (see Cu histogram, fig. 5) is decidedly more variable in the lower part of the formation. In the lower subunit and the JZ Cu highs occur in widely dispersed but small, apparently stratabound, accumulations. Nash (1989) invoked early diagenetic Cu-bearing fluids to account for some of the Cu (and Co) mineralization in the JZ, and the Cu highs of figure 5 possibly reflect rather widespread movement of such fluids.

Cu lows are an equally intriguing feature in figure 5, and there appears to be a large amount of copper-poor rock in the lower subunit. Over a fourth of the samples (9 of 31) from this subunit contained less than 1 ppm Cu; it is of more than passing interest that the lowest Co values in the study, if the quartzose Hoodoo is excluded, also appear in the lower subunit. Similar Cu lows in argillitic rocks of the Belt Supergroup (middle Proterozoic) to the north was ascribed to post-depositional, probably diagenetic, leaching (Connor and others, 1981). Possibly, the low-Cu rock in the lower subunit of the Yellowjacket represents a similar kind of post-depositional leaching. If so, this (now) low-Cu rock constitutes a plausible source for the Cu (and Co) in Nash's fluids.

There are two important differences between the Cu anomalies in the Belt and in the lower Yellowjacket, however. In the Belt, argillitic rocks with anomalously high Cu consistently displayed anomalously high Ag as well (3-5 ppm Ag); the lower Yellowjacket does not, apparently, contain anomalous Ag in its Cu-rich parts. Also, the Belt Cu anomalies occur in thick redbed sequences; the lower Yellowjacket is nowhere red, although a redbed heritage is conceivable.

The Idaho Cobalt Belt

The Idaho Cobalt Belt (ICB) was defined by Hughes (1983) as a narrow, northwest-trending zone of Co occurrences of about 50 km length centered on the Blackbird Mine (fig. 2b). Hughes and co-workers (Hahn and Hughes, 1984) interpreted the mineralization in the ICB to be the result of submarine volcanism along the axis of an intracratonic rift.

This work bears only marginally on Hughes' volcanic-rift concept. The biotitite and the stratabound magnetite in the Yellowjacket support the concept of sea-floor geothermal venting during basin evolution. Any such geothermal fluids would presumably be driven in a convective cell by an underlying volcanogenic heat-source. More, abundant mafic dikes cut the formation which, if of the proper age, would conveniently provide not only the heat-transfer mechanism to drive convection but could also constitute "feeders" for the submarine volcanism postulated by Hughes (1983).

The suggestion, however, of a major tectonic linear (rift axis) at an angle to the regional stratigraphic grain (fig. 2b) gives me pause. The JZ and BZ, as primary loci of mineralization in the Yellowjacket, are important elements of the ICB, but both diverge widely from the ICB in plan view. If the ICB is genetically related to a rift axis, that axis does not, apparently, directly underlie the ICB. Moreover, the JZ and BZ, as regionally extensive zones of spotty mineralization, need not necessarily represent venting from a single narrow linear. Possibly, sea-floor venting during deposition of the Yellowjacket was distributed more widely in both space and time than implied by Hughes' model.

A southeastward extension?

The Idaho Cobalt Belt points southeastward towards the Lemhi Range (fig. 1). Does the ICB in fact extend to the southeast? There is evidence that it does in the sense that field evidence indicates that both the JZ and the BZ crop out in the northern half of the Lemhi Range.

Tietbohl (1986) mapped a large submarine debris flow (diamictite) in the Lemhi Range about 35 km directly along a southeastern projection of the ICB. Because diamictite is known in the Yellowjacket, Tietbohl's diamictite suggests (weakly) a Yellowjacket equivalency for his rocks. Of more importance here, however, is that his diamictite interfingers with large amounts of argillitic siltite remarkably similar to that in the JZ (and the lower Yellowjacket generally) in its color, lithology, bedding style, polygonal mud cracks, local Cu accumulations, and magnetic susceptibility. Most importantly, I noted (above) the existence of a linear magnetic anomaly associated with the trace of the JZ, and Tietbohl's rocks are a part of that magnetic anomaly.

Tietbohl called his rocks Lemhi Group (as did Ruppel before him in 1975). I prefer, however, to equate these Yellowjacket-like strata, at least in part, with the magnetic, argillitic beds of the JZ and the lower subunit of the Yellowjacket in the area of the ICB.

As for the BZ, recent work (Connor and Evans, 1990) in the northern tip of the Lemhi Range demonstrated the presence there of both biotitite and anomalously high Co (up to 2000 ppm). This area has a long history of Cu mining (see Ross, 1925), and this new information now strongly suggests that the mineralization there represents a southeastward or, more accurately, an eastward extension of the BZ.

CONCLUSIONS

1. The Middle Proterozoic Yellowjacket Formation in the area of the Idaho Cobalt Belt (ICB) of east-central Idaho consists of as much as 13,000 m of biotite-grade impure quartzite, siltite, argillite, and marble. The formation can be divided into three lithic subunits. The lower subunit (5000 m?) contains abundant laminated, greenish-gray siltite with local lenses of scapolitic marble and white, thickbedded quartzite (Hoodoo Quartzite). The middle subunit (5000 m maximum) contains abundant, thin, argillite-siltite couplets with diagnostic cross-cutting silt "dikelets". The upper subunit (3000 m) contains abundant thick-bedded, hummocky cross-stratified, impure quartzite. The generally coarsening and thickening upward nature of the succession suggests that the Yellowjacket represents a basin-filling prograding wedge.

2. The Yellowjacket contains two locally mineralized but regionally extensive zones, one near the top of the lower subunit (the Jackass zone or JZ) and the other near the top of the middle subunit (the Blackbird zone or BZ). The BZ contains the Co reserves of the Blackbird mining district. Both in the district and elsewhere the BZ is characterized by intercalated layers of "biotitite", a rock rich in Fe-biotite. The JZ contains minor deposits of banded iron-formation, which is locally Co-bearing. The Fe-rich strata in both zones was likely derived at least in part from sea-floor, geothermal exhalations.

3. The common Fe mineral in the lower subunit is magnetite; pyrite and magnetite are common in the JZ; ilmenite is the typical Fe mineral in the middle subunit and Fe-silicate (in biotitite) is abundant in the BZ. In addition, Cu and Sb are locally high in the lower subunit and the JZ, whereas As, Mo, and Se are locally high in the JZ and the middle subunit. In the BZ, biotitite has its own suite of anomalous elements (Li, Mg, Sc, Ti, V). These stratigraphically controlled geochemical changes may mirror chemical change in geothermal activity through time.

4. Cu in the lower subunit (and the JZ) displays both anomalously high and anomalously low concentrations. Over one-fourth of the samples collected from the lower subunit contained ppm Cu. A similar Cu phenomenon in Belt Supergroup argillitic strata of northwestern Montana was attributed to post-depositional leaching and it's possible that such leaching has occurred in the Yellowjacket as well. Such widespread leaching could have provided the Cu (and Co) for the diagenetic(?) stratiform mineralization postulated by Nash (1986) in the JZ at Iron Creek.

5. Small cross-cutting bodies of tourmalinized quartz breccia crop out in the BZ and JZ and in the middle subunit; they are most concentrated in strata below the BZ. They appear to have been emplaced explosively, apparently following lithification of the host.

6. Mineralization in the ICB is largely restricted to the JZ and BZ of the Yellowjacket Formation. Regionally, however, the surface traces of these zones diverge from the strongly linear ICB, whose locus is thought by some to mark the axis of a middle Proterozoic intracratonic rift. This divergence raises the possibility that the axis, if it exists, lies elsewhere. In addition, both the JZ and the BZ have been tentatively identified in the Lemhi Range to the southeast, suggesting that the ICB is a larger and more diffuse feature than heretofore thought.

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Table 1.--*Estimates of analytical error in the geochemical study of the Yellowjacket Formation*

[Methods of chemical analysis given in Connor (1990); LEV, logarithmic error variance; GE, geometric error; %, error as percent of total observed variance; N, number of analyses above lower limit of analytical determination]

Constituent	LEV	GE	%	N
Al	0.0004	1.05	2.7	50
Al_2O_3	<.0001	<1.03	<.1	50
As	.1130	2.17	52.9	50
B	.0013	1.09	3.1	43
Ba	.0004	1.05	.2	50
Be	.0062	1.20	20.1	37
Ca	.0006	1.06	.1	50
CaO	.0006	1.06	.1	47
Ce	.0034	1.14	2.3	47
Co	.0033	1.13	2.8	50
Cr	.0009	1.07	1.7	50
Cu	.0175	1.36	7.3	46
Fe	.0005	1.05	.7	50
FeO_3*	<.0001	<1.03	<.1	50
Ga	.0009	1.07	2.6	50
K	.0004	1.05	.3	50
K_2O	.0001	1.02	<.1	50
La	.0037	1.15	2.5	47
Li	.0004	1.05	.4	50
LOI**	.0022	1.11	2.7	50
Mg	.0008	1.07	1.3	50
MgO	.0001	1.02	.1	50
Mn	.0020	1.11	1.8	50
MnO	.0021	1.11	4.8	25
Na	.0008	1.07	.3	50
Na_2O	.0023	1.12	2.2	45
Nd	.0014	1.09	1.7	46
Ni	.0027	1.13	3.7	50
P	.0021	1.11	2.0	50
P_2O_5	.0003	1.04	2.4	34
Pb	.0235	1.42	23.8	26
Sb	.0076	1.22	10.3	48
Sc	.0011	1.08	1.6	50
Se	.0113	1.28	42.9	8
SiO_2***	<.0001	<1.03	<.1	50

Table 1.--Continued

Constituent	LEV	GE	%	N
Sr	.0004	1.05	<.1	50
Th	.0021	1.11	5.4	48
Th	.0043	1.16	2.2	48
Ti	.0008	1.07	1.3	50
TiO_2	<.0001	<1.03	<.1	50
U	.0011	1.08	2.2	50
V	.0005	1.05	.6	50
Y	.0017	1.10	1.1	41
Yb	.0064	1.20	10.9	31
Zn	.0111	1.27	6.2	44
Zr	.0034	1.14	11.4	50

* Total Fe as Fe_2O_3.

** Loss-on-ignition at 900 degrees C.

*** The distribution of SiO_2 is negatively rather than positively skewed; non-logarithmic statistics for this oxide are: error variance, 0.0498; standard error, 0.22; percent error, <.1.

Table 2.--*Geochemical summary of the Yellowjacket Formation*

[Methods of chemical analysis given in Connor (1990); data given as parts per million except where noted as percent (%); N, number of samples analyzed]

Element	N	Minimum	Percentiles 10	50	90	Maximum
Ag	111	<2.0	<2.0	<2.0	<2.0	2.0
Al_2O_3 %	110	4.7	9.4	14	17	26
As	111	.20	.60	2.7	11	140
Au	111	All samples	<10			
B	111	<20	20	40	89	1000
Ba	111	10	280	670	1000	2200
Be	111	<1.0	1.0	2.0	3.0	4.0
Bi	111	<10	<10	<10	<10	10
CaO %	110	<.020	.070	.30	1.1	5.8
Cd	111	All samples	<2.0			
Ce	111	<4.0	17	66	100	200
Co	111	<1.0	3.1	8.0	18	1100
Cr	111	4.0	20	48	70	230
Cu	111	<1.0	1.0	6.5	58	1100
Eu	111	<2.0	<2.0	<2.0	<2.0	3.0
$FeTO_3$* %	110	1.1	2.0	4.3	6.8	24
FeO %	44	.28	.87	2.5	4.6	13
Ga	111	5.0	10	17	27	47
Ho	111	All samples	<4.0			
K_20 %	110	.090	1.8	3.8	6.2	8.6
La	111	<2.0	9.1	33	57	82
Li	111	<2.0	7.1	20	39	110
LOI** %	110	.24	.61	1.6	2.7	5.1
MgO %	110	.21	.57	1.2	2.0	5.7
Mn	111	27	60	220	510	1700
Mo	111	<2.0	<2.0	<2.0	<2.0	41
Na %	111	.040	.15	1.8	2.9	5.0
Nb	21	<4.0	<4.0	5.0	11	23
Nd	111	<4.0	8.1	31	49	65
Ni	111	3.0	6.1	16	26	78
P	111	<50	100	400	600	3200
Pb	111	<4.0	<4.0	5.0	16	130
Sb	111	<.10	.20	.40	1.0	4.8
Sc	111	<2.0	5.0	10	15	40
Se	111	<.10	<.10	<.10	10	7.8

Table 2.--Continued

Element	N	Minimum	Percentiles 10	50	90	Maximum
SiO_2 %	110	41	63	71	78	89
Sn	111	All samples	<20			
Sr	111	9.0	31	71	160	270
Ta	111	<40	<40	<40	<40	60
Th	111	1.6	7.3	12	18	40
TiO_2 %	110	.11	.27	.47	.72	7.6
U	111	.88	1.8	3.4	5.2	6.9
V	111	8.0	22	50	77	410
Y	111	<2.0	3.1	13	33	81
Yb	111	<1.0	<1.0	2.0	3.0	8.0
Zn	111	<4.0	4.0	30	74	240
Zr	111	31	110	210	280	910

* Total Fe as Fe_2O_3.
** Loss on ignition at 900 degrees C.

Table 3.--*Geochemical analyses of compositionally atypical rock in the Yellowjacket Formation*

[Methods of chemical analysis are given in Connor (1990); data are in percent (%) or parts per million (ppm); sample numbers in parentheses. <, Concentration less than stated value. --, No data]

	Biotitite (JC5Y32T)	Banded iron-fm (JC3Y06T)	Marble (JC5Y62T)	Hoodoo Qtzite (JC5Y66T)
Ag ppm	2	<2	<2	<2
Al_2O_3 %	11.8	7.95	10.9	3.75
As ppm	32	140	.6	.6
B ppm	<20	130	<20	60
Ba ppm	460	280	240	270
Be ppm	3	2	2	<1
Bi ppm	10	<10	<10	<10
CaO %	1.07	<.02	4.09	.06
Ce ppm	62	100	92	40
Co ppm	64	270	10	2
Cr ppm	100	34	62	10
Cu ppm	35	270	3	2
Eu ppm	3	<2	<2	<2
$FeTO_3$ % *	23.2	16.7	3.03	1.14
FeO %	--	.93	--	--
Ga ppm	28	25	14	<4
K_2O %	5.82	2.22	1.65	1.87
La ppm	60	47	52	22
Li ppm	110	13	6	4
MgO %	5.71	.83	2.25	.21
Mn ppm	1700	130	490	61
Mo ppm	<2.0	9	<2	<2
Na %	.24	.05	1.4	.16
Nb ppm	--	<4	--	--
Nd ppm	65	40	44	18
Ni ppm	46	25	17	5
P ppm	3200	400	400	100
Pb ppm	4	<4	<4	<4
Sb ppm	2.5	2.1	.4	.1
Sc ppm	23	7	9	<2
Se ppm	<.1	4.6	<.1	<.1
SiO_2 %	41.4	65.7	74.2	92.1
Sr ppm	38	9	74	16
Th ppm	10.2	11.5	33.4	3.1
TiO_2 %	7.59	.35	.38	.08

Table 3.--Continued

	Biotitite (JC5Y32T)	Banded iron-fm (JC3Y06T)	Marble (JC5Y62T)	Hoodoo Qtzite (JC5Y66T)
U ppm	5.21	3.87	5.06	1.01
V ppm	410	39	31	6
Y ppm	16	6	81	<2
Yb ppm	3	<1	8	<1
Zn ppm	32	60	<4	<4
Zr ppm	423	240	273	60

* Total Fe as Fe_2O_3.

Table 4.--*Geochemical analyses of scapolite and pyrite from the Yellowjacket Formation*

[Methods of chemical analysis are given in Connor (1990); data are in percent (%) or parts per million (ppm). <, Concentration less than stated value. --, No data]

	Scapolite (JC5Y20T)	Pyrite (JC6Y01T)
Al_2O_3 %	23.2	--
As ppm	<10	40
Ba ppm	90	40
Be ppm	11	<2
CaO %	9.66	--
Ce ppm	69	33
Co ppm	9	3300
Cr ppm	6	23
Cu ppm	37	2
$FeTO_3$ %*	1.64	--
Ga ppm	13	<8
K_2O %	1.01	--
La ppm	33	17
Li ppm	14	<4
MgO %	.54	--
Mn ppm	680	41
Mo ppm	<2	<4
Na_2O %	6.31	--
Nd ppm	45	15
Ni ppm	7	120
P ppm	1600	<100
Pb ppm	17	9
Sc ppm	4	<4
SiO_2 %	52.1	--
Sr ppm	200	11
TiO_2 %	.66	--
V ppm	29	<4
Y ppm	49	13
Yb ppm	4	<2
Zn ppm	5	<4

* Total Fe as Fe_2O_3.