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Some geochemical features of the Blackbird and Jackass zones of the Yellowjacket Formation (Middle Proterozoic) in east-central Idaho

Part A. Discussion

By

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CONTENTS

TABLES

ILLUSTRATIONS

ABSTRACT

The Blackbird and Jackass zones are the most highly mineralized parts of the 13-km(?)- thick Yellowjacket Formation (Middle Proterozoic) in east-central Idaho. Mineralization in both zones has been interpreted as syndepositional, involving sea-floor venting of hydrothermal (hot-spring) brines.

The 1,000-m-thick Blackbird zone hosts the world-class Cu-Co-Au deposits of the Blackbird Mining District. In addition to Co, this zone is marked by locally abundant, Fe- and Ti-rich (more than 20 percent Fe-oxide, more than 1 percent Ti-oxide), biotitic strata, or "biotitite." Biotitite is composed largely of biotite, muscovite, and quartz. It is characteristically high in Fe and Ti and compared to average Yellowjacket it also contains elevated MgO, K_2O, Co, Li, V, Y, and Yb. Biotitite in the Blackbird district was called aquagene tuff by previous workers who believed it to be a product of submarine volcanism. Most of the biotitite examined in this work is viewed as a mixture of such tuff and more ordinary sediment.

The Jackass zone lies as much as 5,000 m below the Blackbird zone, but like the Blackbird, the Jackass is also diagnostically marked by Fe-rich strata. The Fe in the Jackass zone, however, is largely in magnetite, rather than biotitite. The Jackass zone is provisionally defined here as a westward-thinning wedge of variably magnetic, Cu-anomalous strata. The magnetism in the zone results from pervasively disseminated magnetite at concentrations of 3-5 percent, and the local presence of banded-iron formation. The anomalous Cu is discontinuous but widely distributed and apparently occurs in small stratabound layers. The zone is as much as 600 m thick.

In addition to Cu and magnetite, the Jackass zone is also marked by slightly anomalous shows of As, Au, Sb, Se, and Pb. A startling aspect of the geochemistry of the Jackass and its associated strata, however, is the local presence of exceptionally low-Cu (less than 5 ppm) and low-Zn (less than 8 ppm) rocks. Such metal-deficient rock suggests the possibility of post-depositional element rearrangement, with the Cu (at least) having been moved (diagenetically?) from low-Cu strata to high-Cu strata, resulting in "green-bed Cu" mineralization like that in the coeval classic Belt rocks of western Montana.

INTRODUCTION

The Yellowjacket Formation was named by Ross (1934) for exposures of thin-bedded, calcareous, impure quartzite (lithic arkose) in Yellowjacket Creek in the eastern Salmon River Mountains of Idaho (fig. 1). As the term is currently used, however, the formation includes virtually all of the dark-colored, quartz-rich metasedimentary rocks of Middle Proterozoic age in east-central Idaho (see, for example, Lopez, 1981). The formation is best known as host to the stratiform Co deposits of the Blackbird Mining District.

In the area around the Blackbird District, the Yellowjacket is an upward-thickening, upward-coarsening sequence of as much as 13,000 m and represents an important basin-filling episode in the Middle Proterozoic (Hughes, 1983; Connor, 1990). In describing the geochemical stratigraphy of the Yellowjacket, Connor (1990) briefly discussed two geochemically distinct zones in the formation, called (informally) the Blackbird and the Jackass zones (fig. 2). This report continues that discussion.

The Blackbird and Jackass zones are the main mineralized parts of the Yellowjacket. The Blackbird zone lies near the contact of the middle and upper subunits of the Yellowjacket. The Jackass zone lies near the top of the lower subunit of the formation, as much as 5,000 m stratigraphically below the Blackbird zone (fig. 2). Because the middle subunit of the Yellowjacket thins eastward, the zones pass to the east into the upper and the lower subunits of the formation, respectively (fig. 2). Both the Blackbird and the Jackass zones are handily traced in the field by the presence of characteristic rock types, even where visible mineralization is absent.

Mineralization in the Blackbird District and at Jackass Creek has been interpreted as syndepositional, involving sea-floor venting of hydrothermal brines (Nash and Hahn, 1986; Nash, 1989a). The presence of widespread possibly volcaniclastic rocks (biotitite) in the Blackbird zone and small but scattered banded-iron formation (BIF) in the Jackass zone, suggests that such venting was regional in nature and occurred in at least two major pulses. Each pulse, then, presumably represents a quasi-timeline in the Middle Proterozoic of east-central Idaho.

SAMPLING

Most of the rocks on which this report is based were collected in the summers of 1987-89. Chemical analyses appear in Part B of the report. Analytical work generated in related Yellowjacket studies appears in Nash (1989a, 1989b), Connor (1990, part B), and Connor and others (1990).

Sampling in this work focused on areas where the Blackbird or Jackass zones were exposed, or thought to be exposed. Limited outcrop and locally complicated structure in many exposures of the Blackbird zone precluded the use of a formal sampling design in examination of that zone, and samples were collected as exposure permitted. In the examination of the Jackass zone, however, more complete exposures and simpler structure permitted sampling across four widely separated sections believed to contain the zone.

In these sections, samples were taken at each 100 m mark, outcrop permitting; at each mark, two samples were collected in a random fashion from a 10 m interval.

Sampling over and above that needed specifically for examination of the two zones included collection of sample suites from reference sections of three Lemhi Group formations in the Lemhi Range, and miscellaneous sampling of widely scattered exposures of Middle Proterozoic rocks throughout east-central Idaho and southwesternmost Montana. All samples consisted of about 250-500 g of rock collected from layers 5-10 cm thick.

BLACKBIRD ZONE

Description

The Blackbird zone was named by Connor (1990) for an interval of variable thickness containing "biotitite" near the contact of the middle and upper subunits of the Yellowjacket (fig. 2). Biotitite is a dark, biotitic, Fe-and Ti-rich schistose rock, and a major Co host inside the Blackbird mining district. Although biotitite has been found outside the limits of the Blackbird zone, the trace of the zone (fig. 3) is the locus of the bulk of the biotitite in the study area.

Nash and Hahn (1986) estimated the zone's thickness in the Blackbird District at about 1,000 m, and it is probably at least that thick in both Deep Creek (fig. 3) and in the Lemhi Range (fig. 1). In places, the zone is tightly folded or sheared and the zone's thickness is not everywhere accurately determined. The percentage of biotitite in the zone is variable, but in most places probably does not exceed a few percent.

The geographic limit of the zone has yet to be established; it has been traced from the Blackbird District eastward into the northern tip of the Lemhi Range. Important Co mineralization north of the Blackbird district in the Clear Creek area (fig. 1) suggests that the zone crops out there (Lund and others, 1983).

Biotitite

Mineralogy.--Biotitite is the defining rock type of the Blackbird zone. In many places biotitite is unremarkable in outcrop and consists simply of the darker and more micaceous parts of the local sequence. It is a metasedimentary rock containing substantial amounts of brown biotite. Where particularly rich in biotite, the rock in hand specimen tends to be black and lustrous. The rock fabric is recrystallized and strongly schistose.

Biotitite is typically composed of biotite, muscovite, and quartz (table 2). Some samples in this work contained mm-sized porphyroblasts of scapolite or muscovite, and coarse (0.2 mm) anhedral apatite or coarse (0.2 mm) euhedral ilmenite. Quartz was generally clear and locally displayed an interlocking mosaic pattern, uncommon in more ordinary Yellowjacket rocks. Biotite flakes were well formed and ranged up to 0.3 mm long. Pleochroism in the biotite is light yellow-brown to dark brown or, locally, dark red-brown. In hand sample, biotitite may resemble altered mafic dikes and sills of possibly contemporaneous age. In thin section, however, the dikes and sills generally exhibit clear relict igneous fabric whereas the biotitite fabric is strongly metamorphic.

Minor but ubiquitous components included albite, microcline, zoisite, tourmaline, and non-opaque minerals. Rarely, rounded to subrounded, sand-sized quartz-feldspar-mica clots and coarse (0.5 mm) poikiloblastic chlorite oriented at large angles to the schistosity were seen in thin section. The clots, which may be retrograded garnets, and the poikiloblastic chlorite possibly reflect thermal events in the Late Cretaceous or early Tertiary.

Geochemistry.--Biotitite in the Blackbird district was called aquagene tuff by Hughes (1983) and Hahn and Hughes (1984), who believed it to be products of submarine volcanism. Nash and Hahn (1986) provided an average chemistry for such tuff and suggested further that at least some tuff may have originated as accumulations of "Fe-rich, gelatinous ooze" from sea floor hot-spring activity. Whatever its origin, Nash and Hahn's tuff (biotitite) is compared to the biotitite of this work in figure 4 and table 1. On average, the biotitite of figure 4 has about half the Fe and Ti of the Nash and Hahn's tuff. Clearly, if the biotitite contains a tuff component, that component was strongly diluted by more ordinary sediment during deposition.

Biotitite is characteristically high in Fe and Ti (fig. 4). Twenty-seven biotitite samples above and right of the solid semi-circle in figure 4 (sample sets 1 and 2) contain about twice as much Fe or Ti as average Yellowjacket (table 1). These 27 samples are here taken as representative of biotitite. All 27 samples were collected outside of the Blackbird district, most of them from exposures in Deep Creek, about 15 km east of Blackbird. Unlike biotitite at Blackbird, the samples of this study were not visibly mineralized by base or precious metals.

Set 1 biotitite samples average 10 percent Fe_2O_3 and almost 1 percent TiO_2; set 2 samples, a smaller, Ti-rich set, average 22 percent Fe_2O_3 and 4.9 percent TiO_2. The geochemistry of both sets is summarized in table 1 where they are compared to average Yellowjacket and to the tuff of Nash and Hahn (1986).

Set 1 biotitite contains about twice as much or more of $FeTO_3$, FeO, MgO, K_2O, TiO_2, Co, Li, V, Y, and Yb than does average Yellowjacket (table 1). Except for the Fe and Ti oxides (and B?), however, the geochemistry of Set 1 is not all that different from ordinary shale (see, for example, the shale chemistry of Turekian and Wedepohl, 1961). Maximum concentrations recorded in Set 1, however, indicate a rock locally enriched in Ce, Cr, Nd, Pb, V, Y, Yb, and perhaps Co, Cu, Ni, and Zn.

Compared to Nash and Hahn's (1986) tuff, Set 1 biotitite is higher in SiO_2 and lower in $FeTO_3$ and TiO_2. The maximum observed concentrations of $FeTO_3$, TiO_2, and P_2O_5 and minimum observed SiO_2 (see footnote 3, table 1) in Set 1 biotitite, however, compare favorably with tuff, and it is clear that Set 1 biotitite and tuff could be viewed as compositional variants of a common rock. Trace element comparisons are less favorable; the relatively high As, Co, and Cu in tuff likely reflects the pervasive effects of sulfide mineralization inside the Blackbird district.

Set 2 biotitite is also anomalously high in many constituents compared to average Yellowjacket. The exceptionally high TiO_2 in fact appears to be the defining character of the set, although both Nb and V are also quite high. The high TiO_2 reflects an abundance of ilmenite. Set 2 is similar to the tuff of Nash and Hahn (1986), at least in its major oxide chemistry.

The chemistry of Set 2 biotitite also compares favorably with the chemistry of mafic dikes and sills in the Yellowjacket. Conceivably, Set 2 biotitite represents recrystallized sill material although a hallmark of the dikes and sills is their relict igneous fabric in thin section. Set 2 biotitite exhibits no such fabric. The 4 samples of Set 2 were all collected within a km or so of each other in Deep Creek and possibly represent a single, Ti-enriched layer.

JACKASS ZONE

Description

Nash (1989a) named the Jackass zone for exposures of cupriferous banded-iron formation (BIF) in Jackass Creek (fig. 3). The zone was sampled in four stratigraphic sections (PC, SM, SC, HC, fig. 5) and found to be a westward-thinning wedge of variably magnetic, Cu-anomalous strata (fig. 6) The magnetism in the zone results from stratiform disseminations of magnetite at concentrations of 3-5 percent, and the local presence of BIF. The anomalous Cu is discontinuous but widely distributed and also apparently stratabound. Anomalous magnetite and Cu both occur outside the boundaries of the zone (fig. 6) but, as drawn (arbitrarily), the zone includes most of the anomalous strata in the four sampled sections.

The positive Cu anomaly at Squawboard Meadows (15 ppm, fig. 6) is disappointingly low, but it is nonetheless legitimate inasmuch as that particular section is low in Cu overall. Similarly, the data of this study failed to reveal the zone in Panther Creek, although Connor (1990) demonstrated the presence there of the zone with anomalous Cu (at 1,100 ppm), Co (at 3,000 ppm), and magnetite. The Jackass zone may wedge out northwest of Panther Creek, where it is at most a few tens of meters thick; in Hayden Creek (50 km to the southeast) some 600 m of strata are included in the zone. Like the Blackbird zone, the geographic limits of the Jackass zone remain unknown.

Also like the Blackbird zone, the Jackass apparently developed in part as a result of sea-floor hot spring activity. The Jackass Creek BIF (and some nearby cobaltiferous pyrite deposits) were attributed by Nash (1989a) to sea-floor venting in a hydrothermal system. A smaller BIF exposed in Hayden Creek includes a 3 m layer of magnetite-cemented chert breccia suggesting possible origination as an Fe-rich siliceous exhalite. Tietbohl (1986) noted an abundance of chert clasts in the Hayden Creek diamictite and likely derivation might be from intrabasinal venting of siliceous exhalative materials. More, Tietbohl (1986) viewed the diamictitic strata as originating in gravity-induced debris flows, which suggests tectonic instability during deposition of the Jackass zone. Such tectonism perhaps provided the conduits (growth faults?) for upward transport of hot spring solutions thought to be responsible for mineralization in the zone.

Mineralogy

The characteristic rock of the Jackass zone is poorly sorted, dark-gray to greenish-gray, laminated argillitic siltite. The relatively clay-rich nature of these (and adjacent) strata is apparent in the average modes of the four sampled sections (table 4).

Samples from the Jackass zone generally exhibited maximum grain sizes of a few tenths mm, generally as floating sand; below this maximum, the fabric was commonly unsorted. Southeastward, the zone lies near the top of a 1,000-m sequence containing abundant, thin to thick deposits of coarse, unsorted, gravity-driven debris flows (the Hayden Creek Diamictite of Tietbohl, 1986). Clasts in these beds ranged up to half a m in diameter and included fragments of siltite or silty quartzite (abundant), orthoquartzite, granite, and magnetite-chert (less common).

Detrital quartz varieties in the Jackass and its enclosing strata included clear to cloudy, single and polycrystalline (quartzite and chert) grains; some grains locally showed moderate or better rounding and some exhibited authigenic overgrowths. White mica occurred both in long (0.3 mm) flakes and in a very fine grained matrix, much of which may have been deposited as mud chips. Green biotite was common in the Squawboard Meadows section and the lower half of the Salmon River section, but rare in the Panther Creek and Hayden Creek sections. Matrix chlorite was sporadically present as was a late-stage, coarse, poikilitic chlorite.

Carbonate occurred largely in disseminated, anhedral crystals replacing earlier fabric. Calcite was the common carbonate except in the Hayden Creek section where much was probably ankerite. Trace zoisite was widespread in the Squawboard Meadows and Salmon Canyon sections but was rare in Hayden Creek and absent in Panther Creek. It occurred mostly as disseminated, finely crystalline clumps of aggregates as much as 0.05 mm across; near the bottom of Squawboard Meadows it occurred as well-crystallized laths up to 0.2 mm long.

Common accessory minerals included apatite, magnetite, tourmaline, and zircon. Apatite occurred as anhedral to euhedral grains up to 0.05 mm across. Magnetite commonly formed disseminated euhedra as much as 0.1 mm across. Zircon occurred as locally rounded (and overgrown), crystals of various size (to 0.03 mm), and tourmaline as subhedral to anhedral needles of 0.1 mm length or less, commonly with overgrowths. Other opaque minerals included hematite (after pyrite or chalcopyrite?), and small (less than 10 microns) anhedral blebs, probably ilmenite. Locally high Y and Ce suggested the presence of monazite or xenotime, respectively.

Geochemistry

Summary.--The average geochemistry of the Jackass zone and maximum recorded element concentrations within it are listed in table 3, along with average element levels in the Yellowjacket as a whole.

The Jackass zone is geochemically similar to the Yellowjacket, except for Cu, Sb, and Y whose medians in the zone are at least twice those of average Yellowjacket (table 3). Cu, of course, is diagnostic of the zone, but high concentrations of Sb also locally mark it (fig. 7). In fact, the zone and its enclosing strata consistently exhibit Sb concentrations higher than average Yellowjacket (the right-hand border of each column represents average Sb in the Yellowjacket). Connor (1990) previously noted that high Sb was characteristic of the Lower Yellowjacket, perhaps reflecting something in the geochemistry of sea floor emanations during deposition. The relatively high Y in these same strata (table 3), however, remains unexplained.

Maximum recorded element concentrations in the Jackass zone of As, Ba, Ca, Cu, Pb, Sb, and Zn are five times or more that in average Yellowjacket (table 3). The stratigraphic distribution of these elements (excluding Cu, shown in fig. 6) plus Au and Se is depicted in figures 7 and 8. As, Au, Se, Pb, and Sb, along with Cu, exhibit their highest concentrations inside the zone (fig. 7); these six elements, thus, collectively constitute a provisional geochemical signature marking the Jackass zone.

The data on Au in the Jackass zone is severely limited. In the four sampled sections, Au was detected overall in only three of 14 analyses (21 percent), but all three came from within the zone (fig. 7). At 4 ppb maximum, however, Au is awkwardly low in these rocks. Nonetheless, like the unimpressive Cu anomaly at Squawboard Meadows, 4 ppb Au appears to be a legitimate positive anomaly when compared to a Jackass background of about 1 ppb Au. (A 4 ppb maximum coupled with 21 percent sample detection in a lognormal distribution indicates a mode (average) of about one ppb).

Data on Se and Pb are also limited but, like Au, the highest concentrations of each occur within the zone. Overall, 12 of 96 analyses contained detectable Se (0.1 ppm or more), and 10 of the those 12 came from the zone. With respect to Pb, one analysis inside the zone in Hayden Creek contained 260 ppm Pb.

The data for As (fig. 7), Ba, Ca, and Zn (fig. 8) exhibit equivocal patterns with respect to the Jackass zone. The element As marks the zone in Hayden Creek, but in Salmon Canyon As is higher above the zone and in Squawboard Meadows it is higher below the zone. Ba, like As, marks the zone best in Hayden Creek where high concentrations straddle the lower contact. The distribution of Ca reflects the distribution of (mostly) trace calcite, and is not spatially related to the Jackass zone.

Zn weakly marks the zone in the Salmon Canyon section although the highest concentrations of Zn were found at the base of the Squawboard Meadows section. An impressive Zn pattern appears in Hayden Creek where exceptionally low Zn (less than 8 ppm) below the zone strongly highlights the more ordinary Zn levels in the zone.

Metal depletion(?) and "green-bed Cu".--The markedly low Zn below the zone in the Hayden Creek section points to a geochemical peculiarity in the rocks of this study that was touched on above; that is, the presence of unexpectedly low concentrations, even concentrations typifying "geochemically anomalous" rock. Note the anomalous Cu at 15 ppm maximum in the Squawboard Meadows section (fig. 6) and anomalous Au at 4 ppb maximum overall (fig. 7). Add to these "highs", anomalous Se at 0.2 ppm and anomalous As at 7.5 ppm (fig. 7) and the peculiarity of the Jackass zone becomes apparent. Such concentrations are more comparable to crustal abundance levels than to mineral anomalies; yet they clearly help to define a geochemically anomalous zone. These anomalous but in fact rather ordinary element levels stand out in part because adjacent strata exhibit subordinary element concentrations.

Geologic processes of some kind have produced in the host strata of the Jackass zone erratic element distributions for Cu and Zn (fig. 9). These histograms contrast rather with the more uniform distributions of the rock-forming elements K and Al in the same strata. Cu in these rocks is clearly polymodal and is dominated by a population of low concentrations centered below 5 ppm; nearly half (45 of 96, or 47 percent) of the Cu analyses fall into this population. Zn is distinctly bimodal with a secondary but nonetheless prominent mode centered below 8 ppm; about 17 percent of the Zn analyses fall into this population.

The low Zn and Cu cannot be attributed to local intercalations of quartz-rich (metal-poor) strata in these rocks, as neither the K nor the Al distributions are multimodal (as would be required if inclusion of such strata were skewing the base metal distributions). The erratic Cu and Zn can be explained as (1) original deposition of metal-poor mud or (2) post-depositional metal removal. Connor (1991), in a study of an Upper Ravalli (Belt Supergroup) Cu-bearing redbed sequence in western Montana, found a Cu depletion similar to that seen here. This similarity is apparent in figure 9, where Cu distributions in both the Jackass host and the Ravalli show primary modes near or below 5 ppm Cu.

In the Ravalli study, Connor (1991) concluded that the Cu had undergone severe post-depositional rearrangement, probably as part of the same process that produced myriad small Cu accumulations in nearby strata ("green-bed occurrences" of Harrison and Reynolds, 1979). In a similar fashion, it is possible that the erratic Cu and Zn distributions associated with the Jackass zone demonstrate the effects of some kind of post-depositional metal rearrangement.

Anomalous Cu in the Jackass zone resembles the green-bed Cu of Harrison and Reynolds to the extent that enrichment occurs in small, apparently stratabound, deposits spatially associated with low-Cu (depleted) rock. The Jackass mineralizing process(es), however, was likely more complicated than that underlying formation of green-bed Cu, primarily because of the possibility of synsedimentary metal exhalation during deposition of the Jackass. Such a process is unthinkable for green-bed Cu, which many believe is related to de-watering processes (see Connor and others, 1983).

In addition, green-bed Cu apparently requires a redbed host; a preferred locus for such Cu according to Harrison and Reynolds (1979) are green strata intercalated with red strata. The Jackass and its enclosing strata are not red, although a redbed heritage is possible. A m or so of pale-lavender siltite was observed high in the Salmon River section, and a few red mud clasts were seen low in the Hayden Creek section during sampling. Nonetheless, the greenish and purplish hues so ubiquitous in Ravalli strata, even where metamorphically washed out, are lacking in the Jackass. Conceivably, Cu enrichment in the Jackass involved both exhalative processes and post-depositional rearrangement.

Comparison with the Lemhi Group.--The Jackass zone constitutes a variably magnetic, Cu-anomalous sequence in the Middle Proterozoic of east-central Idaho. In the Salmon River Mountains, the Jackass lies near the top of the lower subunit of the Yellowjacket Formation (Connor, 1990); southeastward in the Lemhi Range, strata assigned to the Jackass have been mapped as Lemhi Group (the Hayden Creek Diamictite and Apple Creek Formation of Tietbohl, 1986).

The Yellowjacket Formation and the Lemhi Group both consist of enormously thick sequences of metasedimentary rock, and the relation of one to the other is currently in dispute. Insufficient data precludes an attempt at resolution of so large a problem here, but the lithic, mineral, and geochemical similarities of strata in and along the Jackass zone are sufficiently strong to support lateral equivalence of at least those rocks. (Previous work has proposed such equivalence; Ekren, for example, in 1988 mapped selected exposures of the lower Yellowjacket in the Salmon River Mountains as Apple Creek Formation.)

Originally, the Apple Creek Formation was defined by Anderson (1961) as the Apple Creek Phyllite for exposures in Apple Creek, a tributary of Hayden Creek. The formation was redefined by Ruppel in 1975 in a new reference section located some 20 km south of Hayden Creek (AC, fig. 1). Whereas Anderson's phyllite (or at least part of it) is here included in the Jackass, the relation of Ruppel's redefined Apple Creek to the Jackass remains unclear.

Ruppel's Apple Creek was sampled during this work in order to compare it with the sections used to study the Jackass, and it is so compared in tables 4 and 5. The Apple Creek was sampled in exposures immediately west of Golden Trout Lake about one km northwest of and on strike with Ruppel's reference section. Samples were taken in the same manner as in the Jackass study; that is, two random samples at every 100-m mark. Differences between the Apple Creek and the other sections are few; the Apple Creek lacks chlorite and biotite (table 4), contains nearly twice the B and Ca, marginally more Cr, Li, and Zr, and less Ce than the Jackass (table 5). The Apple Creek also lacks banded-iron formation and is non-magnetic, but then so are parts of the Jackass. More compelling differences between the two units are seen in outcrop and include, in the Apple Creek, the presence of multiple, thick (tens of m) carbonate layers, and a thick top containing abundant purple quartzite and siltite.

In spite of these differences, much of the Apple Creek is a greenish-gray shaley interval indistinguishable, at least in small exposures, from the Jackass. The Apple Creek even contains the same astonishingly low concentrations of Cu and Zn (table 5) as the Jackass and associated strata. Nonetheless, equivalence, even partial equivalence, of Ruppel's Apple Creek with the Jackass zone is not warranted on these points; detailed mapping will be required to prove (or disprove) equivalence.

Also sampled, somewhat as an afterthought, were the type sections of the Inyo Creek and West Fork Formations (IW, fig. 1) in the base of the Lemhi Group (Ruppel, 1975). These formations were sampled, in the same manner as the previous sections, by Karl Evans and Russ Tysdal, U.S. Geological Survey.

The Inyo Creek and West Fork Formations, like the Jackass and the Apple Creek, are relatively clay-rich metasedimentary rocks. The fabric and mineralogy of these rocks in thin section was similar to that seen in the Jackass and Apple Creek, including the presence of disrupted bedding, abundant floating sand, and an identical accessory mineral suite. Like the Jackass, but unlike the Apple Creek, the Inyo Creek and West Fork contained green biotite.

The only real similarity to the Jackass strata lay in the lower half of the West Fork Formation. Samples collected there were generally unsorted and reminiscent of the finer grained parts of the Hayden Creek Diamictite (they lacked material coarser than about one mm). Also, coarse, disseminated euhedral magnetite was found in a sample (sample 8KE006A) taken from the base of the West Fork. Like the Apple Creek, these two formations are for all practical purposes geochemically indistinguishable from the rocks containing the Jackass zone (table 5) although, like the Apple Creek, they are distinctly high in B, Li and Cr when compared to the Jackass. Clearly, the finer grained intervals in the Yellowjacket (Jackass zone) and the Lemhi Group (Apple Creek, Inyo Creek, and West Fork) are geochemically alike.

All geochemical data collected from the Lemhi Group are included in part B of this report.

CONCLUSIONS

1. The Blackbird and Jackass zones of the 13-km(?)-thick Yellowjacket Formation are the most highly mineralized parts of the formation. Mineralization in both zones is spotty but widespread and apparently stratabound, and has been attributed at least in part to sea-floor venting of hydrothermal (hot-spring) brines. The geographic extent of such venting was apparently larger by far than previously suspected, inasmuch as both zones have now been traced in outcrop for some 50 km. The Blackbird zone is as much as 1,000 m thick; the Jackass zone, which lies as much as 5,000 m below the Blackbird, is as much as 600 m thick. The geographic limits of either zone are unknown.

2. The characteristic rock of the Blackbird zone is biotitite, a dark, micaceous Fe- and Ti-rich schist typically composed of biotite, muscovite, and quartz. Biotitite in the Blackbird District has been viewed as volcaniclastic (aquagene tuff) by previous workers. Biotitite outside the district, where it is unmineralized, is clearly a mixture of ordinary sediment and some kind of Fe-rich material, possibly tuff. Four samples of exceptionally Ti-rich biotitite (as much as 7 percent TiO_2) collected from Deep Creek may represent a single depositional event there.

3. The Jackass zone is a variably magnetic, Cu-anomalous interval exposed in the lower Yellowjacket Formation of the eastern Salmon River Mountains and in the Lemhi Group of the northern Lemhi Range. The relation of the Yellowjacket Formation to the Lemhi Group is incompletely understood, but the lithic similarities of the strata exposed along the trace of the Jackass zone are sufficient to indicate the equivalence of at least those strata. The Jackass zone exhibits slightly elevated As, Au, Sb, Se, and Pb; together with Cu, these elements constitute a geochemical signature of the zone.

4. The Jackass zone and enclosing strata may have undergone element depletion as well as element enrichment. Exceptionally low concentrations locally of Cu and Zn cannot be explained in terms of intercalated quartzite-rich (element-poor) beds, which the interval lacks, and instead are believed to reflect post-depositional element rearrangement.

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Table 1.--*Summary geochemistry of biotitite and comparison with other rocks*

[N, number of analyses; %, percent; ppm, parts per million; ppb, parts per billion; --, no data]

	Yellowjacket	Biotitite					Mafic tuff
		Set 1			Set 2		
	Median[1]	N	Median	Max.	N	Median	Geom. mean[2]
Oxides							
SiO_2 %	71	23	55	61[3]	4	44	48
Al_2O_3 %	14	23	19	24	4	13	15
$FeTO_3$ %[4]	4.3	23	10	20	4	22	22
FeO %	2.5	3	8.3	13	0	--	17
MgO %	1.2	23	2.4	4.3	4	5.7	7.0
CaO %	.30	23	.26	4.9	4	1.0	.59
Na_2O %	2.4	23	.77	4.6	4	.40	.15
K_2O %	3.8	23	7.1	11	4	5.9	6.5
TiO_2 %	.47	23	.93	1.5	4	4.9	2.2
P_2O5 %	.092	23	.12	.51	4	.73	.40
Elements							
As ppm	2.7	24	1.7	23	4	32	56
Au ppb	--	20	<2.0	4.0	2	<2	--
B ppm	40	24	57	1600	4	<20	--
Ba ppm	670	24	950	3100	4	680	--
Be ppm	2.0	24	<4.0	5.0	4	<4	--
Cd ppm	<2.0	20	<8.0	9.0	2	<8	--
Ce ppm	66	24	27	150	4	40	55
Co ppm	8.0	24	19	90	4	44	206
Cr ppm	48	24	77	130	4	81[5]	304
Cu ppm	6.5	24	5.0	86	4	38	333
Ga ppm	17	24	30	50	4	<24	--
La ppm	33	24	28	71	4	56	31
Li ppm	20	24	43	91	4	96	--
Mn ppm	220	24	260	2300	4	730	460
Mo ppm	<2.0	24	<8	14	4	<8	--
Nb ppm	5.0	21	<20	23	2	75	27
Nd ppm	31	24	30	80	4	55	--
Ni ppm	16	24	19	63	4	42	161
Pb ppm	5.0	24	<20	340	4	<20	--
Sb ppm	.40	18	.20	1.4	4	1.1	--

Table 1.--*Summary geochemistry of biotitite and comparison with other rocks*--Continued

	Yellowjacket	Biotitite					Mafic tuff
		Set 1			Set 2		
	Median[1]	N	Median	Max.	N	Median	Geom. mean[2]
Elements							
Sc ppm	10	24	19	28	4	21	--
Sr ppm	71	24	47	190	4	40	--
Th ppm	12	24	20	30	4	<20	--
U ppm	3.4	4	5.1	6.9	2	4.7	--
V ppm	50	24	100	160	4	350	--
Y ppm	13	24	39	84	4	20	14
Yb ppm	2.0	24	5.5	11	4	<4	--
Zn ppm	30	24	25	260	4	29	--
Zr ppm	210	24	300	560	4	400	154

[1]From Connor (1990, table 2, 50th percentile).

[2]From Nash and Hahn (1986, table 2). In much geochemical work, the geometric mean is about nine-tenths of the median.

[3]The minimum for SiO_2 is 47%.

[4]Total Fe as Fe_2O_3.

[5]Maximum observed Cr was 230 ppm.

Table 2.--*Average biotitite modes*

[All data in percent]

	Set 1 (N=24)	Set 2 (N=4)
Mineral		
Quartz	20.1	12.0
Albite	1.1	1.0
Microcline	.3	<.1
Mica		
Biotite	36.1	78.5
Muscovite	35.7	1.5
Chlorite	.9	<.1
Scapolite	2.3	<.1
Carbonate	.3	<.1
Zoisite	<.1	.0
Heavy minerals		
Opaque[1]	1.3	6.0
Tourmaline	.3	<.1
Apatite	.4	1.0
Other[2]	.4	<.1

[1]Mostly ilmenite.
[2]Mostly(?) zircon.

Table 3.--*Summary geochemistry of the Jackass zone and comparison with average Yellowjacket*

[N, number of analyses; %, percent; ppm, parts per million; ppb, parts per billion; --, no data]

Element	Jackass zone			Yellowjacket
	N	Median	Max.	Median[1]
Ag ppm	24	<8.0	<8.0	<2.0
Al %	24	7.3	9.1	7.4
As ppm	24	2.4	13	2.7
Au ppb	5	2.0	4.0	--
B ppm	24	50	90	40
Ba ppm	24	730	4800	670
Be ppm	24	<4.0	<4.0	2.0
Bi ppm	24	<40	<40	<10
Ca %	24	.20	1.6	.21
Ce ppm	24	40	230	66
Co ppm	24	9.0	24	8.0
Cr ppm	24	47	63	48
Cu ppm	24	21	640	6.5
Fe %	24	3.5	7.3	3.0
Ga ppm	24	20	30	17
K %	24	3.0	4.5	3.2
La ppm	24	39	120	33
Li ppm	24	16	33	20
Mg %	24	.80	1.7	.72
Mn ppm	24	230	810	220
Mo ppm	24	<8.0	<8.0	<2.0
Nb ppm	24	<20	<20	5.0
Nd ppm	24	40	100	31
Ni ppm	24	21	39	16
Pb ppm	24	<20	260	5.0
P ppm	24	500	700	400
Sb ppm	16	1.1	5.4	.40
Sc ppm	24	10	15	10
Se ppm	24	<.10	.20	<.10
Sr ppm	24	40	130	71

Table 3.--*Summary geochemistry of the Jackass zone and comparison with average Yellowjacket*--Continued

Element	Jackass zone N	Jackass zone Median	Jackass zone Max.	Yellowjacket Median[1]
Th ppm	24	<20	20	12
Ti %	24	.30	.40	.41
U ppm	24	<400	<400	3.4
V ppm	24	56	78	50
Y ppm	24	28	58	13
Yb ppm	24	<4.0	7.0	2.0
Zn ppm	24	21	170	30
Zr ppm	24	210	440	210

[1]From Connor (1990, table 2, 50th percentile).

Table 4.--*Average modes of sections sampled in study of Jackass zone*

[All data in percent; N, number of samples]

Mineral	Sections containing Jackass zone: Panther Creek (N=8)	Squawboard Meadows (N=21)	Salmon Canyon (N=27)	Hayden Creek (N=23)	Apple Creek: Golden Trout Lake (N=15)
Quartz	47.5	38.3	37.0	31.9	31.7
Chert	.0	.4	.0	.0	.3
Albite	4.0	9.1	8.5	2.7	9.1
Microcline	.0	.0	.2	.0	.5
Mica					
Illite	34.8	36.7	41.9	53.8	52.4
Chlorite	8.3	2.6*	4.0*	6.2	<.1
Biotite	.5	6.0	2.2	<.1	<.1
Carbonate	4.5	.3	.1	2.4	3.9
Zoisite	.0	4.1	2.2	<.1	<.1
Heavy minerals					
Opaque	.5	1.6	3.5	3.0	2.7
Tourmaline	<.1	.7	.2	.1	.3
Apatite	<.1	.1	.1	.1	<.1
Other**	<.1	.5	.1	.1	<.1

* Includes late poikiloblastic chlorite.
** Mostly(?) zircon.

Table 5.--*Geochemical averages (as geometric means) of sections sampled in study of Jackass zone*

[ppm, parts per million; %, percent]

Element	Sections containing Jackass zone				Lemhi Group formations		
	Panther Creek	Squawboard Meadows	Salmon Canyon	Hayden Creek	Apple Creek	Inyo Creek	West Fork
Al %	6.3	6.4	6.8	7.0	6.4	6.1	5.8
As ppm	1.5	2.5	3.1	1.9	1.8	1.4	1.2
Au ppm	<.002	<.002	<.002	.004	<.002	<.002	<.002
B ppm	37	38	35	56	92	57	73
Ba ppm	300	550	670	950	410	580	510
Ca %	.22	.39	.25	.24	.49	.42	.29
Ce ppm	32	44	44	36	22	47	22
Co ppm	6.8	7.3	7.9	10	7.2	10	8.4
Cr ppm	39	44	41	42	62	47	49
Cu ppm	10	6.5	4.2	4.1	3.2	4.2	4.2
Fe %	3.4	2.9	3.0	3.9	2.5	2.3	2.4
Ga ppm	20	21?	22	20	20	20	20
K %	1.7	2.1	2.1	2.8	2.3	2.7	2.4
La ppm	35	39	36	33	34	34	25
Li ppm	23	19	16	16	27	28	27
Mg %	.92	.67	.66	.84	1.1	1.2	.82
Mn ppm	310	310	180	190	230	230	180
Nd ppm	29	34	36	31	33	36	24
Ni ppm	17	17	18	18	22	17	18
P %	.036	.048	.050	.049	.068	.051	.053
Pb ppm	20	14	<20	<20	<20	<20	<20
Sb ppm	.59	.63	1.2	1.9	.60	.67	.63
Sc ppm	9.0	9.4	9.0	9.9	10	9.5	8.7
Se ppm	.079	.14	<.10	.068	<.10	<.10	<.10
Sr ppm	48	120	75	21	50	57	51
Th ppm	20	20	20	20	18	<20	20
Ti %	.24	.29	.26	.28	.32	.26	.28
V ppm	41	47	42	49	52	44	47
Y ppm	27	26	29	30	29	27	24
Yb ppm	<4.0	3.4	3.7	3.6	3.6	<4.0	4.0
Zn ppm	33	43	23	11	19	20	20
Zr ppm	210	240	210	210	320	300	310

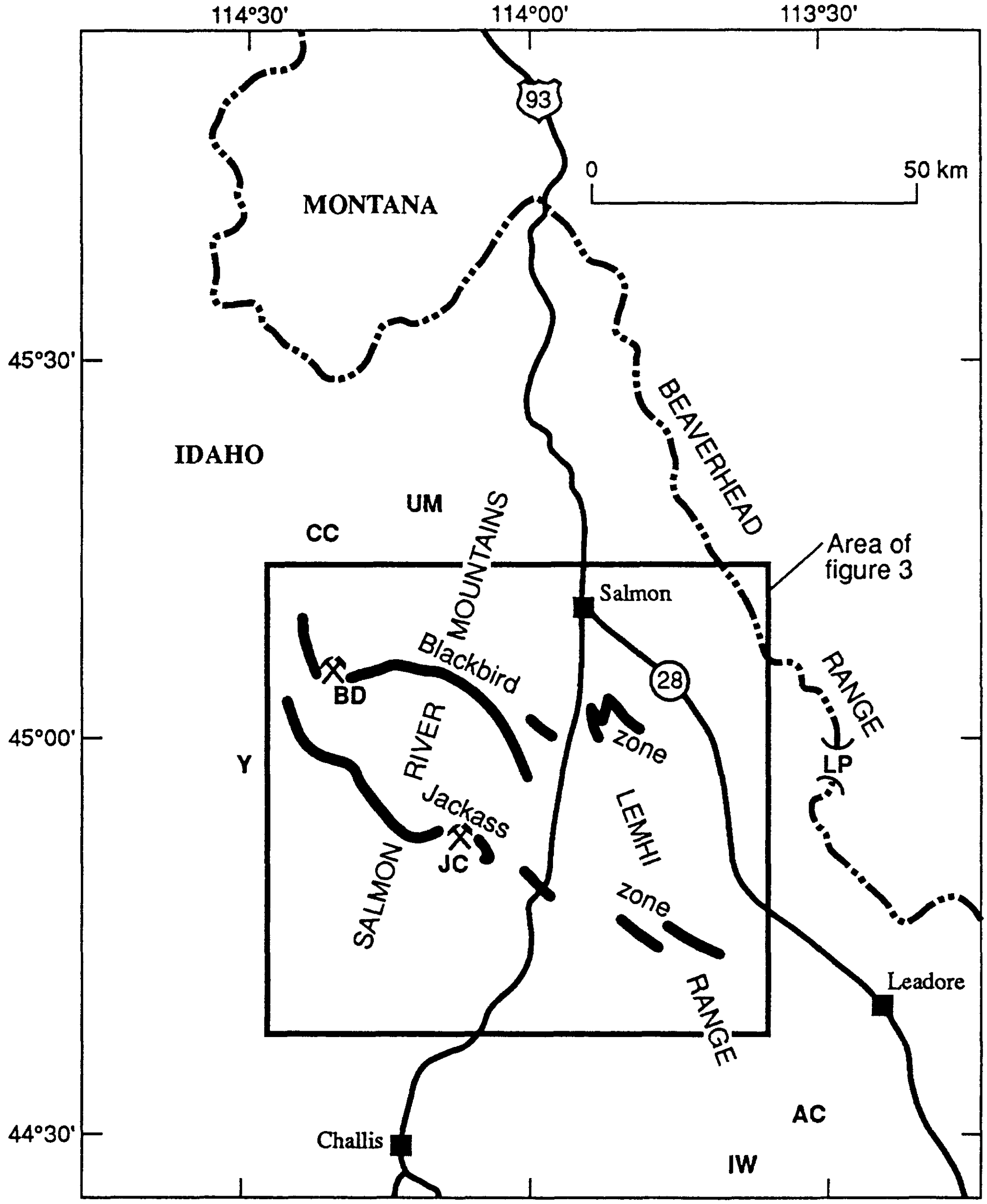

Figure 1.--Index map showing trace of Blackbird and Jackass zones.

AC	Reference section, Apple Creek Formation
BD	Blackbird mining district
CC	Clear Creek
JC	Jackass Creek
IW	Type sections, Inyo Creek and West Fork Formations
LP	Lemhi Pass
UM	Ulysses Mountain
Y	Type section, Yellowjacket Formation

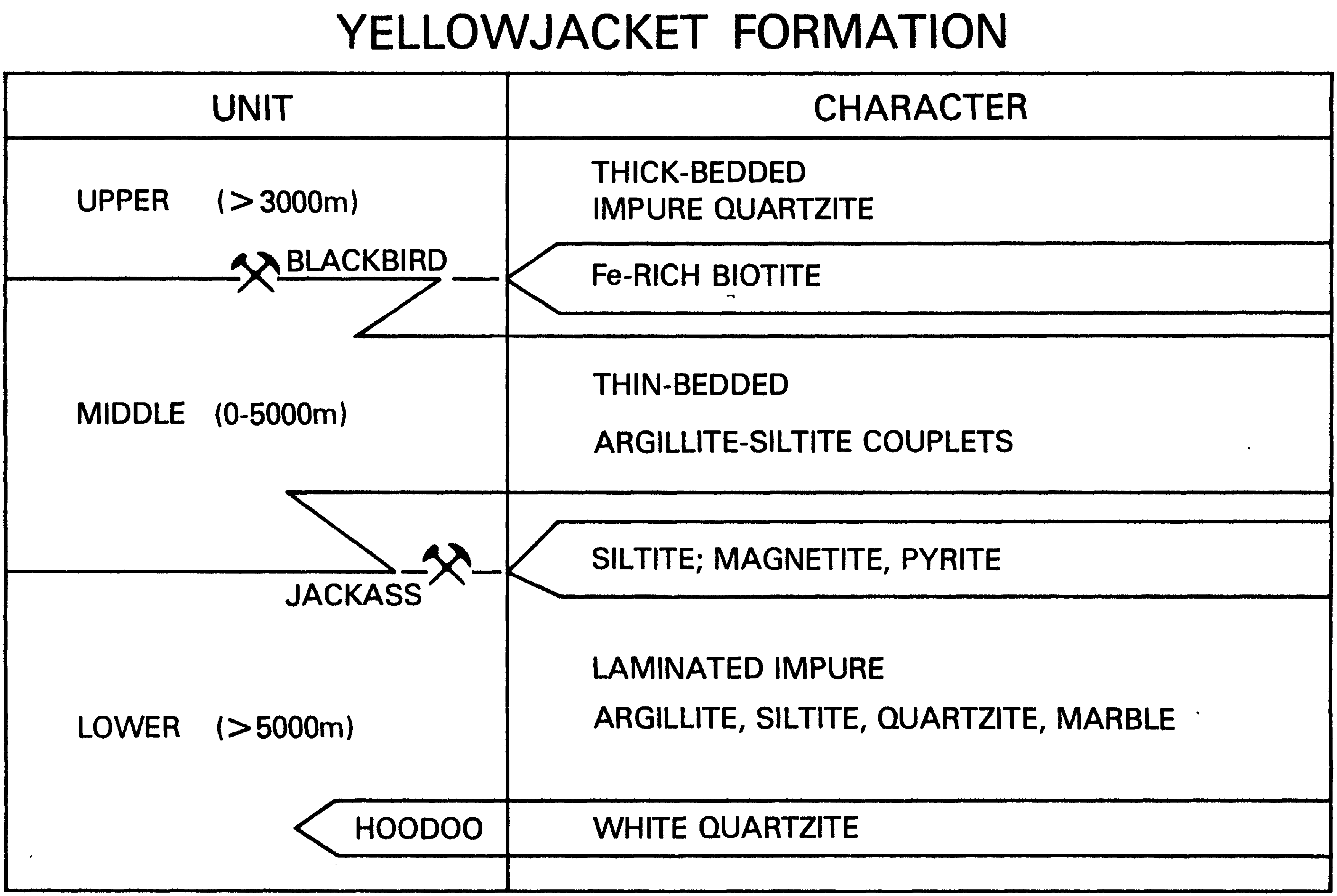

Figure 2.--Summary character of the Yellowjacket Formation. Blackbird and Jackass zones are located by pick and hammer symbols.

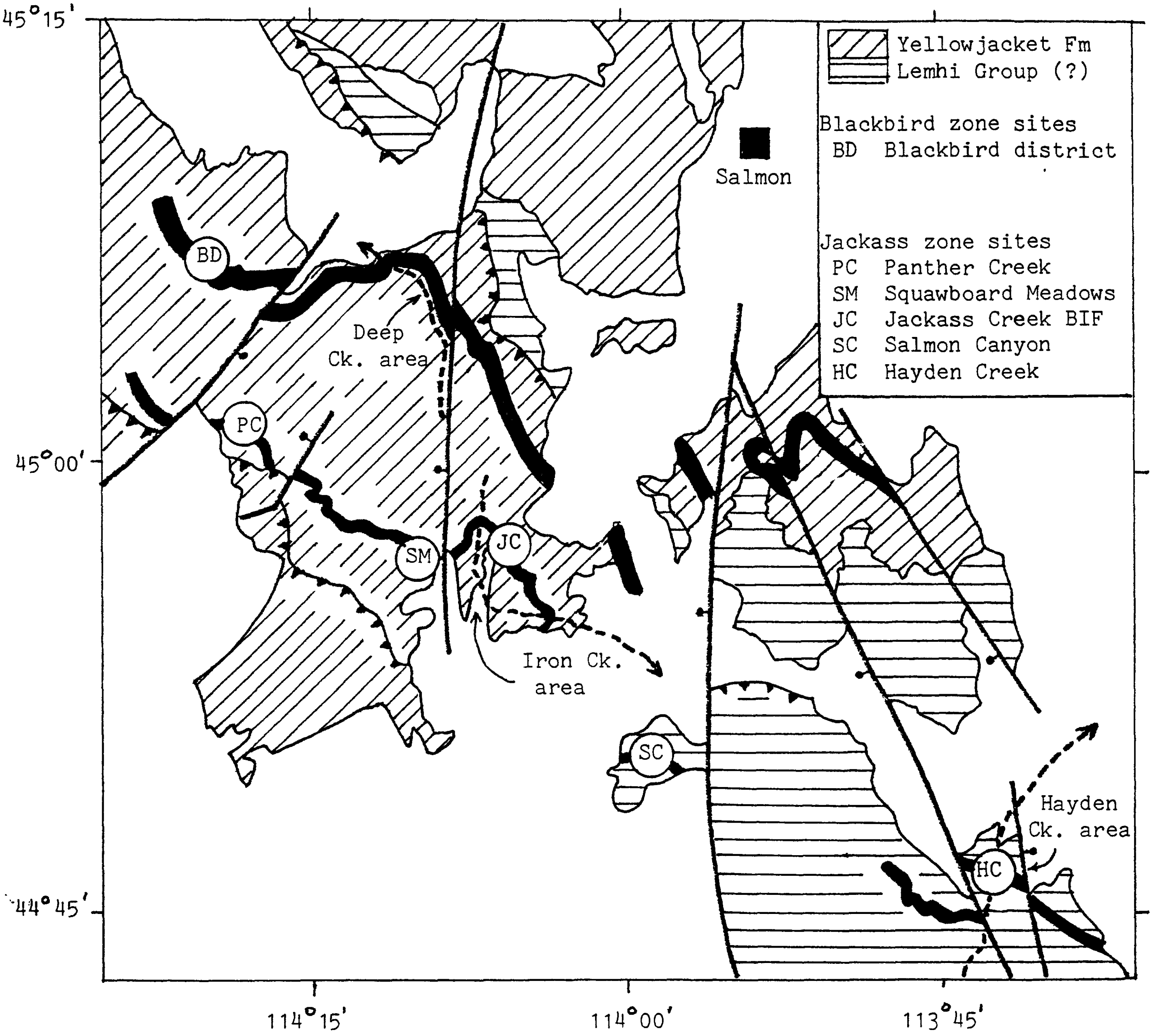

Figure 3.--Reconnaissance geologic map showing Blackbird zone (thick black line), Jackass zone (thin black line), and localities mentioned in text. Selected creeks shown as dashed lines. Geology adapted from Connor (1990), Fisher and others (1983), Staatz (1979), and Tietbohl (1986).

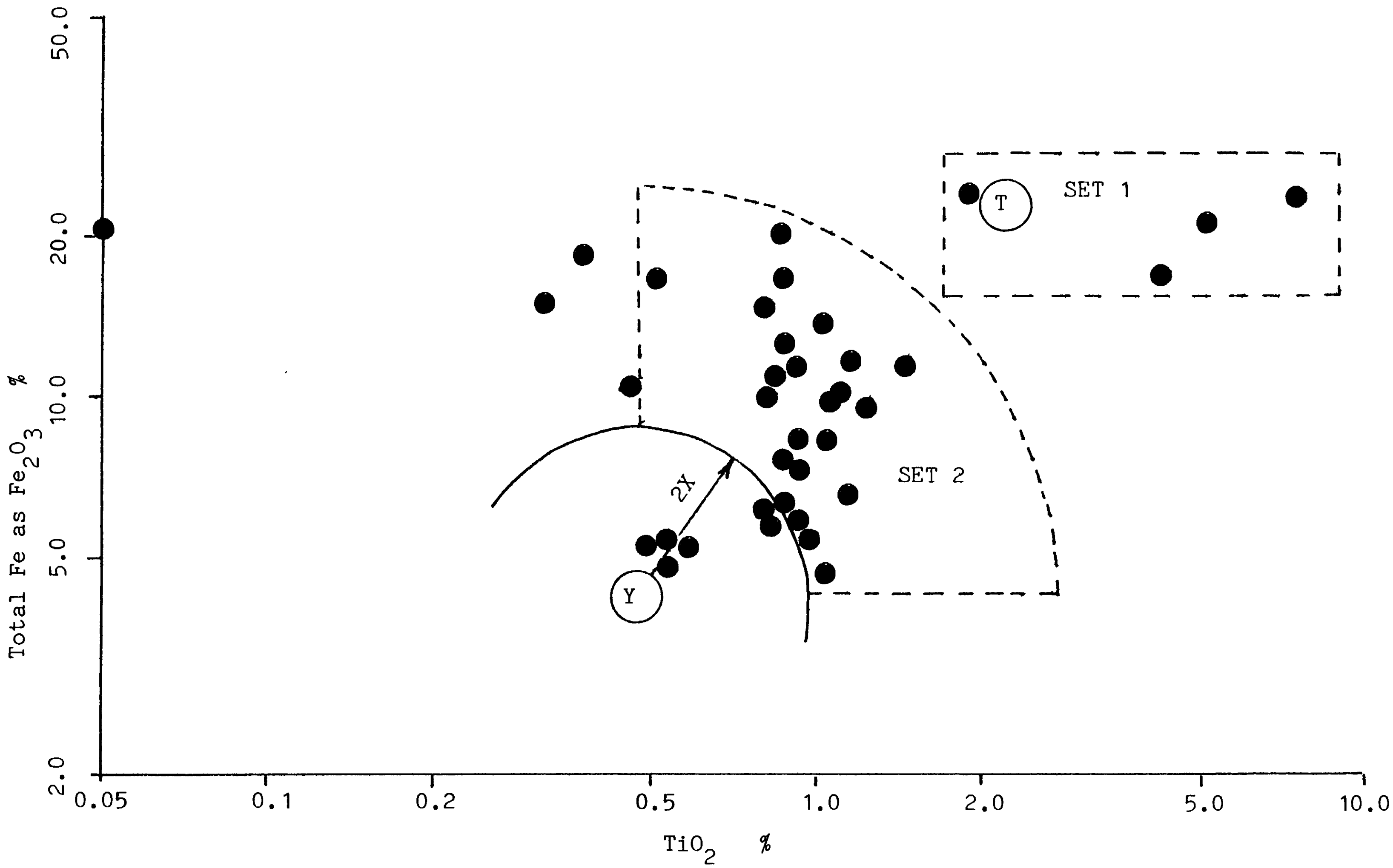

Figure 4.--Fe-Ti-oxide scatter plot of biotitite.

Y - Composition of average Yellowjacket Formation
T - Composition of average mafic tuff of Nash and Hahn (1986)

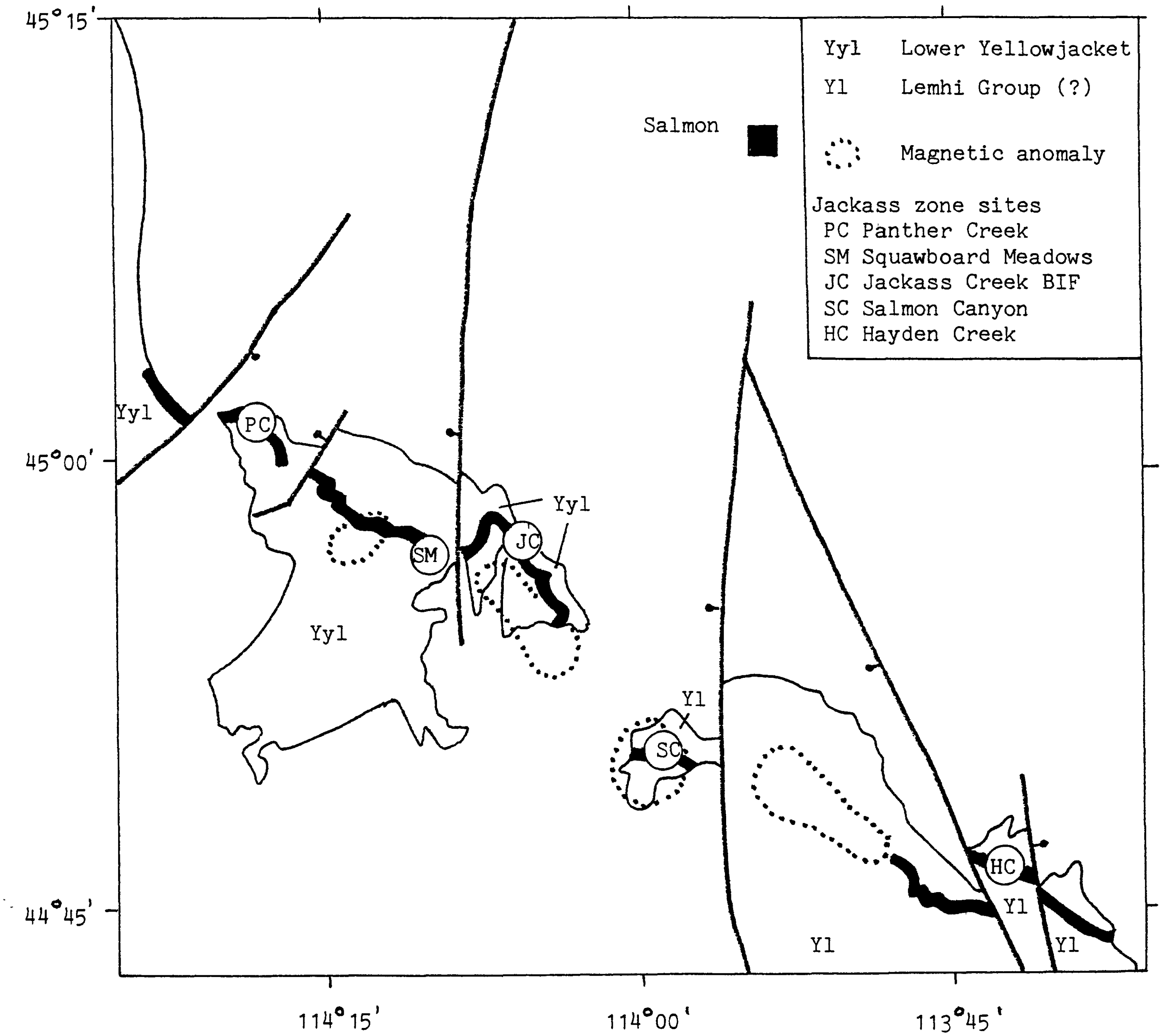

Figure 5.--The Jackass zone and aeromagnetic anomalies. Anomalies represent magnetic intensities greater than 100 gammas (from Worl and others, 1989, plate 2).

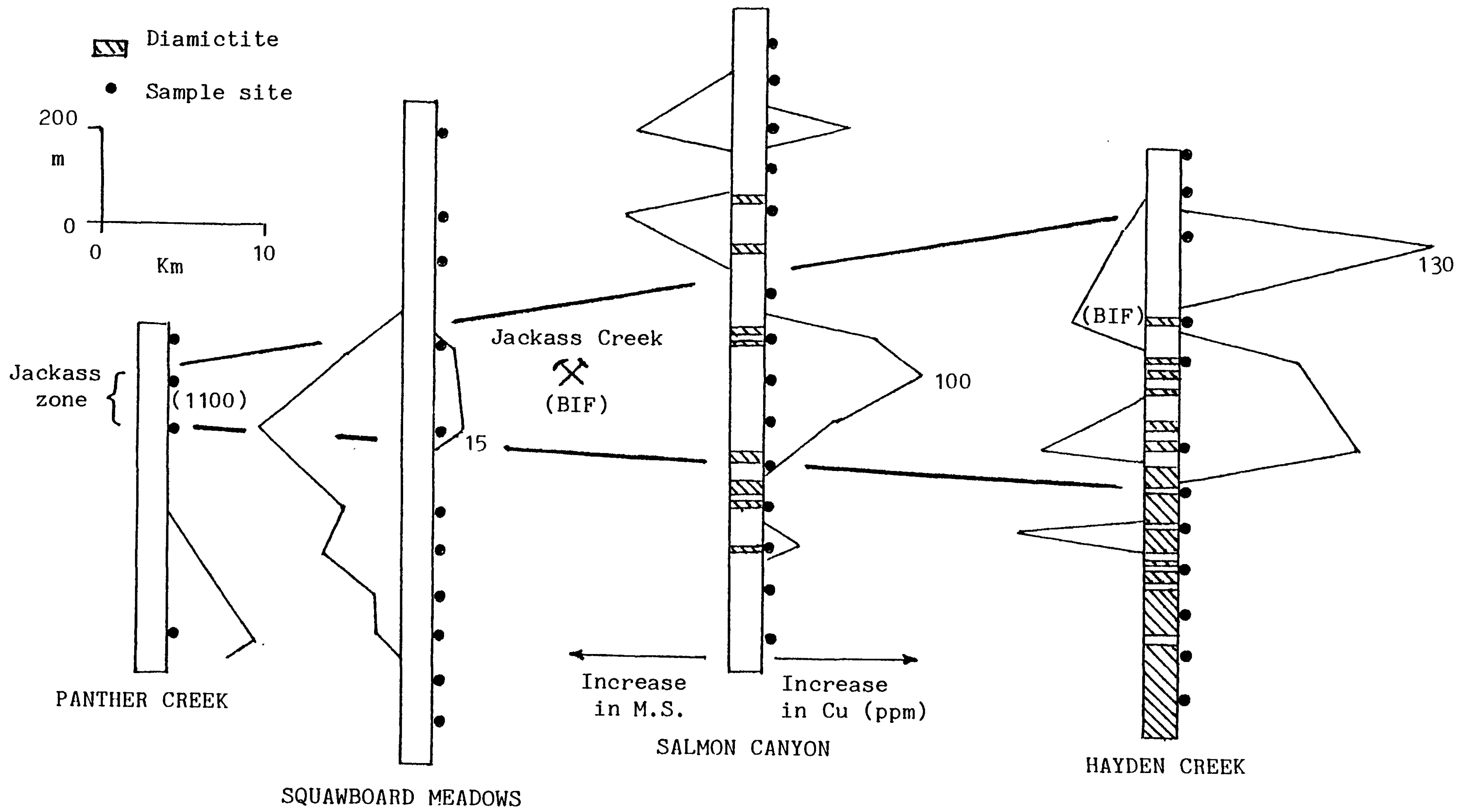

Figure 6.--The Jackass zone in cross-section. Cu variation displayed on right side of each section (maximum concentrations given); magnetic susceptibility (M.S.) displayed on left side of each section. Outcrops of banded iron-formation (BIF) identified.

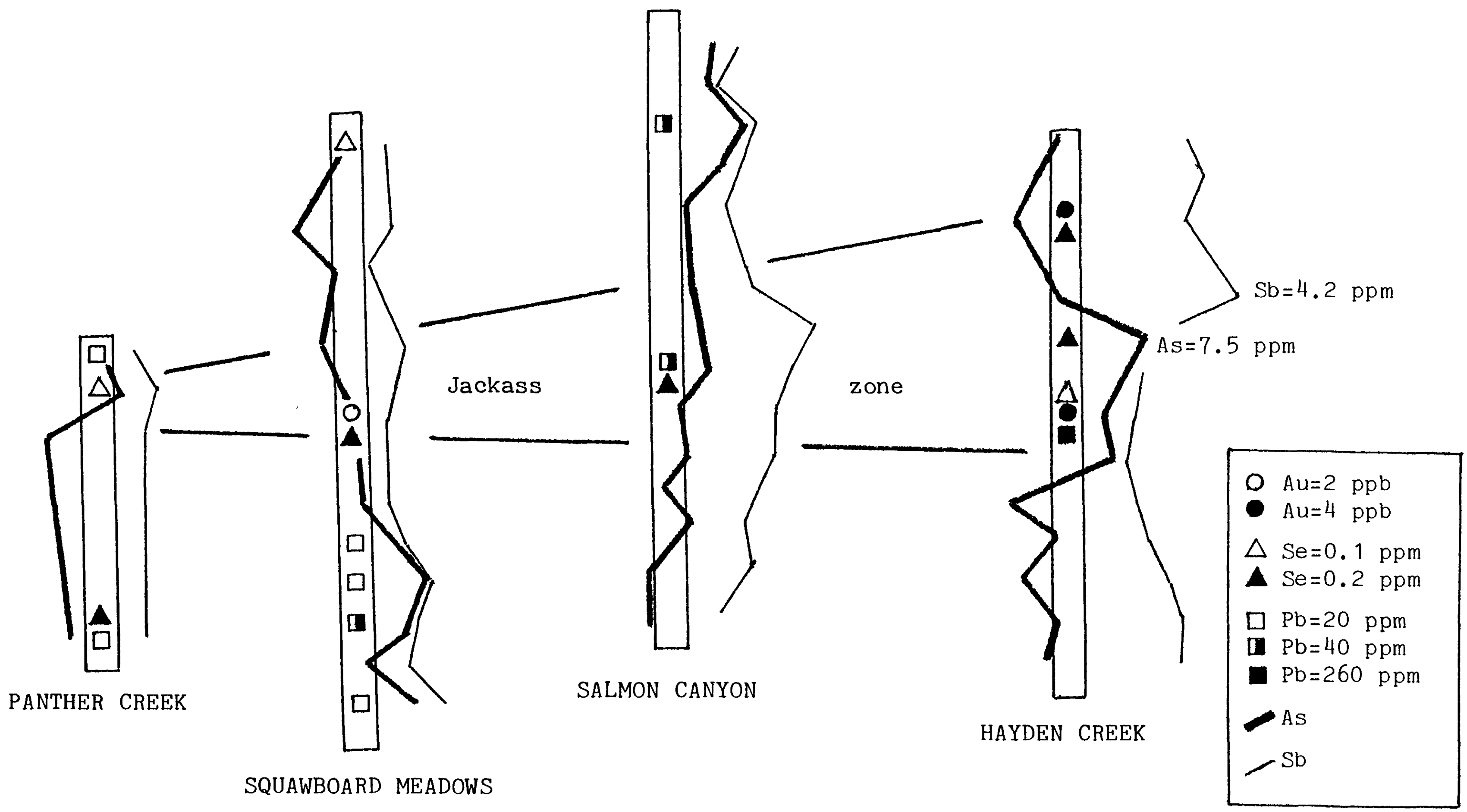

Figure 7.--Distribution of As, Au, Pb, Sb, and Se in the Jackass and adjacent rocks. Right side of each column taken as average concentration of As and Sb in the Yellowjacket (see table 4). Maximum concentration of As and Sb shown.

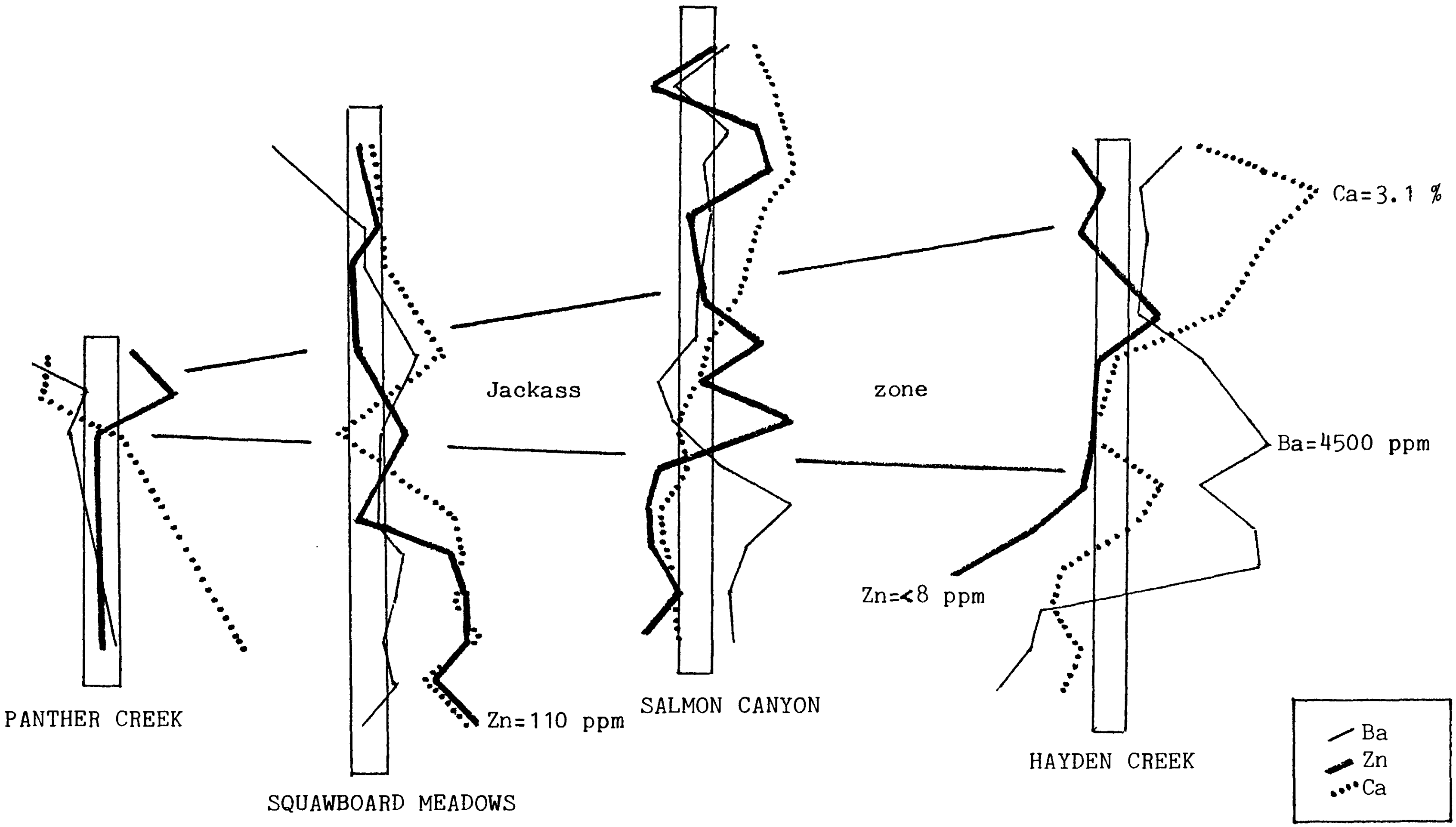

Figure 8.--Distribution of Ba, Ca and Zn in the Jackass and adjacent rocks. Right side of each column taken as average concentration of element in the Yellowjacket (see table 4). Maximum concentrations shown; minimum concentration also shown for Zn (Hayden Creek).

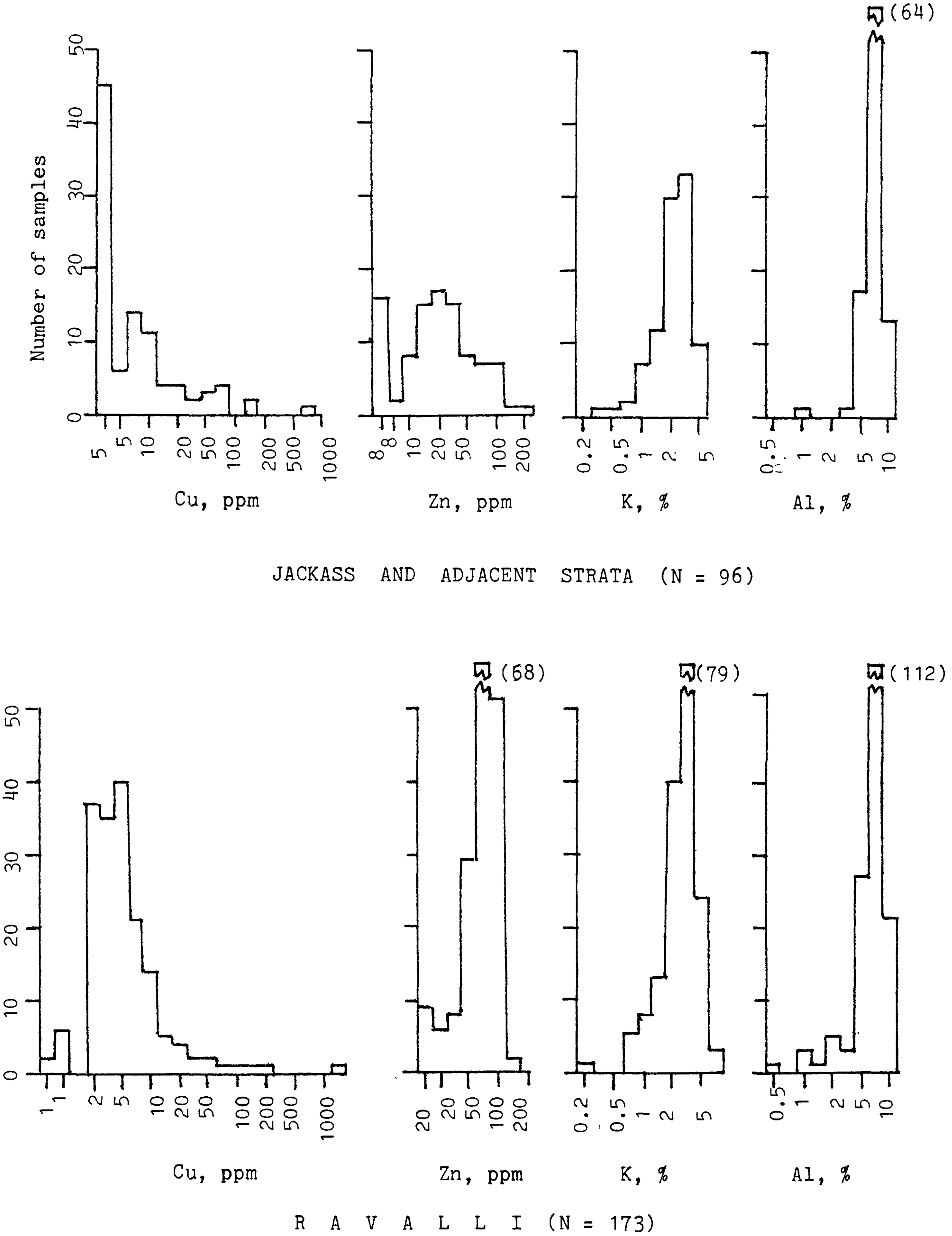

Figure 9.--Histograms of Cu, Zn, K, and Al in Jackass and Ravalli units. (Ravalli data from Connor, 1991).