VIRGINIA DIVISION OF MINERAL RESOURCES

PUBLICATION 112

GOLD MINERALIZATION, AND TIN, BASE METALS, AND THORIUM ANOMALIES AT YANKEE HORSE RIDGE, IRISH CREEK TIN AREA, ROCKBRIDGE COUNTY, VIRGINIA

Richard S. Good

COMMONWEALTH OF VIRGINIA

DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES
R. C. Milici, State Geologist

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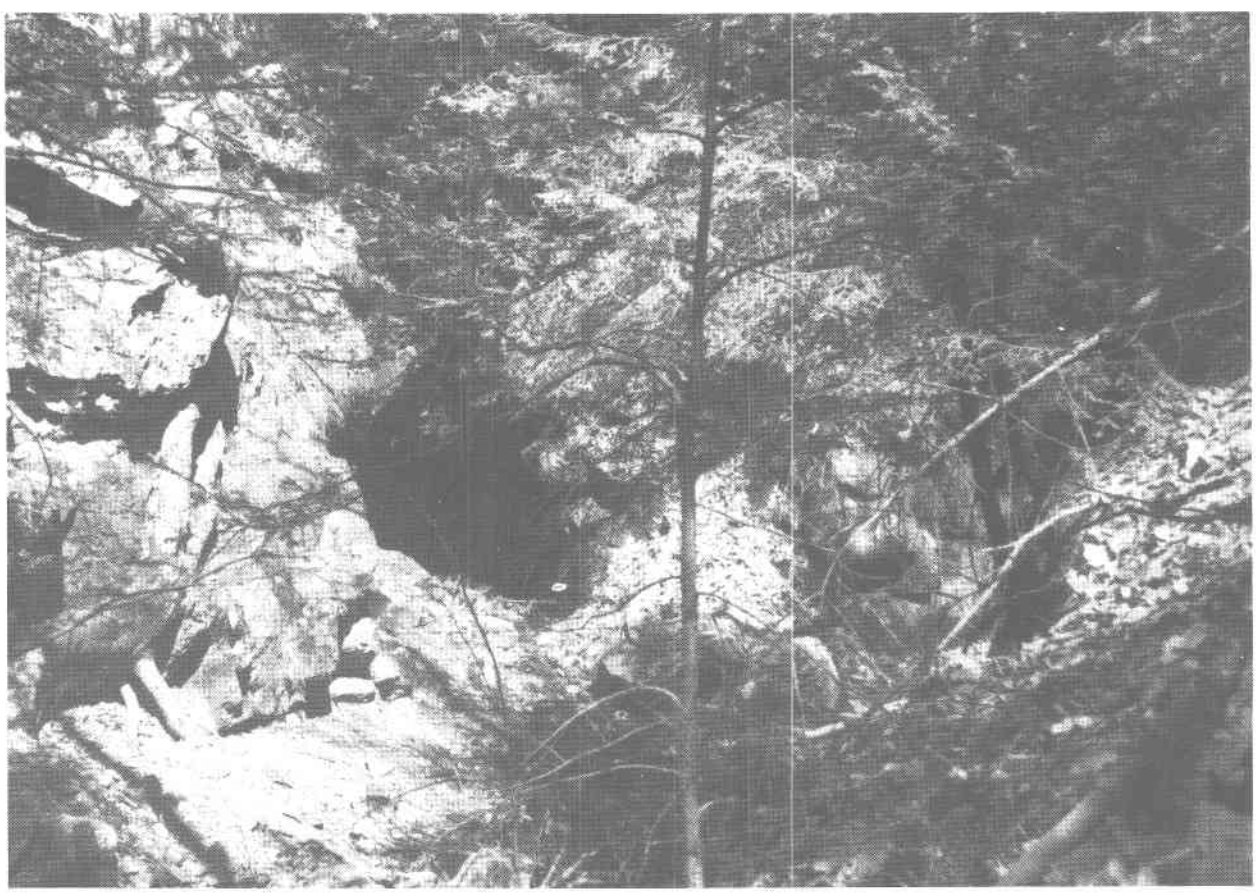

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FRONT COVER: Adit entrances of the abandoned Irish Creek tin mine, Montebello 7.5-minute quadrangle, Rockbridge County.

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DEPARTMENT OF MINES, MINERALS AND ENERGY
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ERRATA FOR PUBLICATION 112

PAGE 9, FIGURE 8: Appendix III, in Key, and Appendix I, in caption, should read Appendix IV.

PAGE 9, FIGURE 10: Abbreviations on figure:

IAG:	Island arc granitoids
OP:	Oceanic palgiogranites
POG:	Post-orogenic granitoids
CEUG:	Continental epeirogenic uplift granitoids
RRG:	Rift-related granitoids
CCG:	Continental granitoids
CAG:	Continental arc granitoids

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GOLD MINERALIZATION, AND TIN, BASE METALS, AND THORIUM ANOMALIES AT YANKEE HORSE RIDGE, IRISH CREEK TIN AREA, ROCKBRIDGE COUNTY, VIRGINIA

Richard S. Good

ABSTRACT

Gold mineralization was identified by soil geochemistry on Yankee Horse Ridge three miles southwest of the abandoned Irish Creek tin mines in the central Blue Ridge province of Virginia. The highest concentrations of gold in the soil samples ranged from 0.33 to 0.51 ppm. Anomalous tin (44 ppm), lead (521 ppm), zinc (457 ppm), copper (59 ppm), arsenic (25 ppm), rubidium (70 ppm), and thorium (45 ppm) are also present in the soil samples. Samples of mylonitic bedrock, exposed by shallow trenching, have whole-rock assays of up to 0.17 ounces/short ton (5.8 ppm) of gold. The bedrock is hydrothermally altered and sheared, gray to greenish-gray, aphanitic, felsic quartz monzonite with sparse, limonitic and hematitic vugs with sparse boxworks, and contains disseminated relict pyrite, jarosite, and beudantite(?). The slightly deformed bedrock is leucocratic quartz monzonite, which in places is felsic enough to be classed as an alaskite. Some highly sheared rock contains smoky-quartz clasts. Subvolcanic rhyodacite and basalt dikes occur at and near the anomaly. About 700 feet north-northwest of the anomaly is an occurrence of pyrrhotite, arsenopyrite, chalcopyrite, and fluorite mineralization with anomalous arsenic (600 ppm) and fluorine (5495 ppm) in the soil.

The Yankee Horse Ridge prospect is less than 800 feet from a fluorite-bearing biotite granite on Nettle Mountain (informally called the Nettle Mountain granite). This biotite granite is intruded into a Grenville-age clinopyroxene-hypersthene-hornblende granulite gneiss with a contact zone containing felsic dikes and xenoliths. The Nettle Mountain granite contains a chemical signature, including a Rb/Sr ratio of 5.05, characteristic of highly differentiated, volatile-rich intrusives similar to those associated with tin districts in England, Nigeria, Australia, and Canada. The Nettle Mountain granite has generated enrichments of up to 14.5 ppm beryllium in soil and 6 ppm in nearby stream sediments. The stream sediment values are similar to those found in sediments downstream from the Irish Creek tin mines.

The rocks enclosing the mineral deposit are part of a complex allochthonous imbricate tectonic thrust sheet, with a northeast trend and southeast low-angle dip, that lies over lower Paleozoic-age clastic sedimentary rocks. Thrust sheets in the area are characterized by anastomosing, cataclastic zones west of the Rockfish Valley fault. Gold mineralization on Yankee Horse Ridge may have been generated from paleo-hot springs associated with subvolcanic rhyolite dikes present in the Late Precambrian-age, Crossnore-related Nettle Mountain fluorite-biotite pluton. The gold mineralization could also have been controlled by metal-rich brines or possibly much younger, metal-rich solutions that were remobilized following reactivated paleo-rift faults. These faults are now mapped as low-angle mylonitic thrust zones.

INTRODUCTION

This study describes the results of a geochemical investigation for tin and precious metals in the Irish Creek area of Rockbridge County. Except for negligible placer deposits in Alaska there is no significant primary production of tin in the United States (Carlin, 1988). The only tin mine in Virginia is at Irish Creek, Rockbridge County. This small operation has been inactive for more than 70 years (Figure 1).

The recorded occurrences of gold and silver in the vicinity of the Irish Creek mines indicate that the area has the potential for precious metals as well as tin. Hotchkiss (1883) reported values of 0.1 to 7.36 ounces/short ton of gold (3.4 - 252 ppm) and 38 to 73.73 ounces/short ton (2528 ppm) of silver in the arsenopyrite in the vicinity of Irish Creek. Brown (1885) also noted auriferous arsenopyrite occurring with wolframite and cassiterite. A recent assay for gold on an arsenopyrite sample from the #2 dump at Irish Creek indicates 7.8 ounces/short ton (267 ppm) of gold and 11.1 ounces/short ton (381 ppm) of silver (Virginia Division of Mineral Resources samples, 1985).

Sulfide mineralization (pyrrhotite) occurs about 3 miles southwest of the Irish Creek tin mines along Nettle Creek, a tributary of Irish Creek (Herbert L. Grow, personal communication, 1985; Figure 2A, traverse F). Assay records at the Virginia Division of Mineral Resources indicate that pyrrhotite from this locality contains negligible gold and silver. There are stories of a small gold mine or gold prospect that was worked by Hubbard near the headwaters of Nettle Creek in the late 1800s or early 1900s (Herbert Clark, personal communication, 1985). This prospect might be the sulfide occurrence, F, on Nettle Creek. However, the Hubbard prospect(?) was never located with certainty by the writer. On the east bank of Nettle Creek at the pyrrhotite locality (Figure 2A, traverse F), the writer identified white fluorite, arsenopyrite, and chalcopyrite in a mafic granulite gneiss. There is no visible evidence of an adit or shaft in the area, but several cylindrical marks that indicate very limited drilling and blasting can be observed on a rock face along the creek. Analysis on one of three soil samples taken near the site (traverse F) indicates 600 ppm arsenic, 5495 ppm fluorine, 492 ppm copper, and 132 ppm lead (Appendix I, sample 3W-1). There is a series of very shallow, barely visible, 5 feet long, 1 to 2 feet deep exploration trenches about 800 feet up slope from the Nettle Creek sulfide-fluorite occurrence. The trenches are on a spur on the west slope of Yankee Horse Ridge (Figure 2A, traverse C-C'). The Nettle Creek sulfide-fluorite occurrence is located along the eastern contact of a small, fluorite-bearing biotite granite that is intrusive into Grenville-age granulites (Figure 2A). The granite at Nettle Mountain has been described by Hudson (1981). Fordham (1978) analyzed stream sediments from this same area and

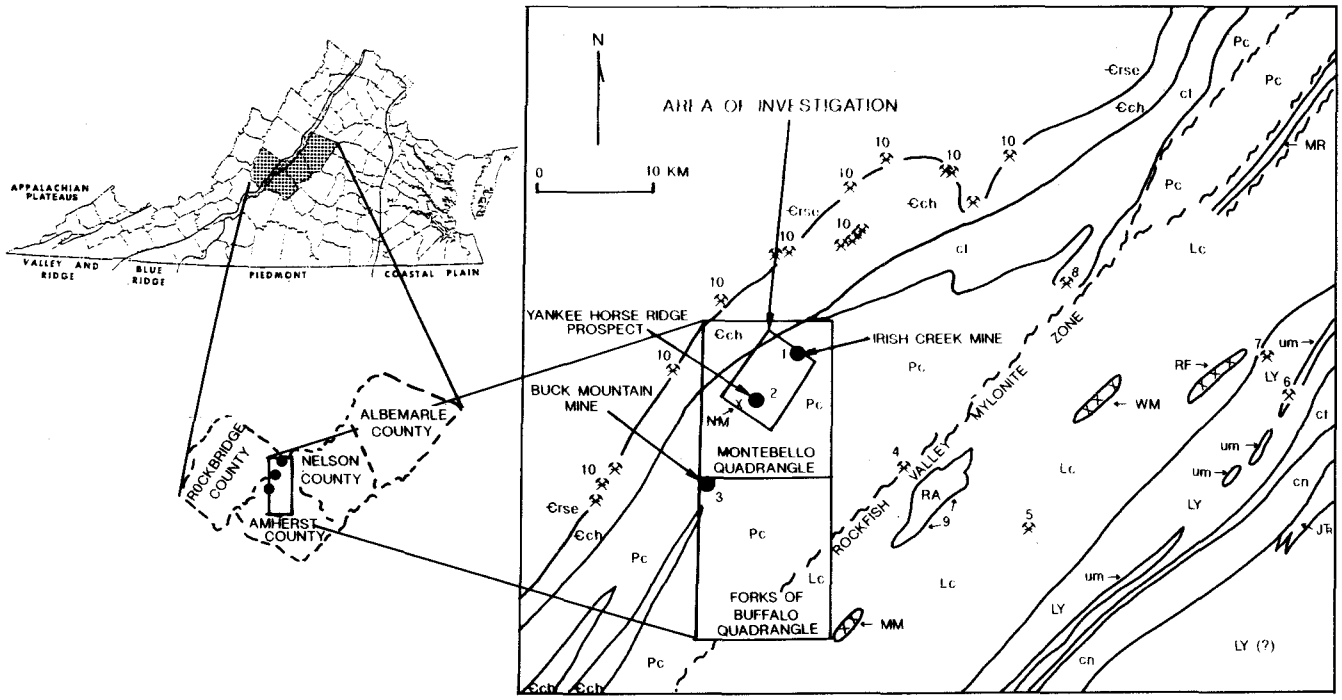


Figure 1. Regional geologic setting of the Irish Creek tin mine, Buck Mountain gold silver mine, and other nearby mines and prospects.

EXPLANATION

1 - Irish Creek mine (Sn)
2 - Yankee Horse Ridge prospect (Au)
3 - Buck Mountain mine (Ag, Au)
4 - Jack's Hill mine (Au, Ag)
5 - Colleen prospect (Au, Ag, Pt)
6 - Ivy Creek prospect (Au)
7 - Faber mine (Pb, Zn, Ag)
8 - Allen mine (Cu)
9 - Roseland anorthosite titanium deposits (Ti)
10 - Iron, manganese, and iron-manganese mines

Triassic-Jurassic JTr
siltstone, feldspathic sandstone, and conglomerate of the Scottsville rift basin

Cambrian Crse
marine limestone, dolomite, shale, and sandstone of the Valley and Ridge province; Rome, Shady, and Erwin Formations

Cambrian Cch
Chilhowee Group: arenitic shelf to shore face sedimentary rock, phyllite, metasiltstone, feldspathic sandstone, with a minor amount of basalt at the base

Late Precambrian ct
Catoctin Formation: rift-related metabasalt and minor amounts of sedimentary rock

Late Precambrian LY
Lynchburg Group (Ashe Formation, Alligator Back Formation): rift-related oceanic metasediment, generally deeper water deposits of the continental slope with some shallow water deposits; turbidite, submarine conglomerate, and includes greenstone which may represent a partial ophiolitic sequence

Late Precambrian LY(?)
deep water metasediment, dominantly schist with quartzite, marble, amphibolite, and felsic gneiss, mapped as the Evington Group, Paleozoic metasediment

Late Precambrian cn
Candler Formation: phyllite with quartzite and marble

Late Precambrian mr
Mechum River Formation: rift-related shallow water arkose with conglomerate and conglomerate with coalescing fans of conglomerate

Late Precambrian
Crossnore Suite pluton: biotite granite and granodiorite with fluorite and accessory rare earth minerals
NM-Nettle Mountain granite, 637 m.y. (?)
MM-Mobley Mountain granite, 652 m.y.
WM-Woods Mountain pluton age not determined
RF-Rockfish 573 m.y.

Precambrian Pc
Pedlar Complex: Grenville (~1100 m.y.) and Pre-Grenville (~1700 m.y.) age massive and layered charnockite, massive and layered granulite gneiss, leucocratic quartz monzonite and alaskite; dominantly pyroxene and pyroxene with hornblende-bearing granulite facies rocks characterized by anastomosing, narrow mylonite zones and bands which pervade a southeast-dipping, northeast-trending stack of thrust plates; steeply dipping to vertical northwest-trending transverse faults.

Precambrian Lc
Lovingston Complex: Grenville (~1100 m.y.) and pre-Grenville (~1700 m.y.) biotite augen gneiss, granulite gneiss, minor charnockite, granite, ferrodiorite, anorthosite and nelsonite; dominantly biotite-and hornblende-bearing rocks with minor pyroxene; separated from the Pedlar Terrane by the Rockfish Valley mylonite thrust zone
RA-Roseland anorthosite

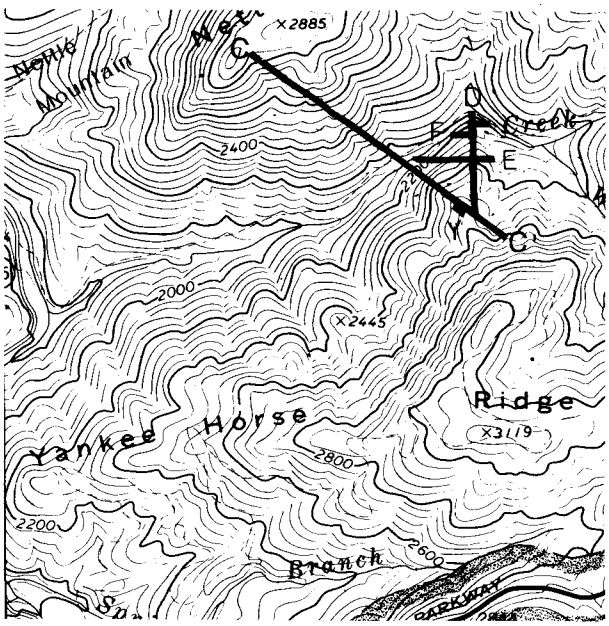


Figure 2A. Location and topography of the geochemical soil traverses across Nettle Mountain and Yankee Horse Ridge, Montebello 7.5-minute quadrange, Rockbridge County, Virginia.

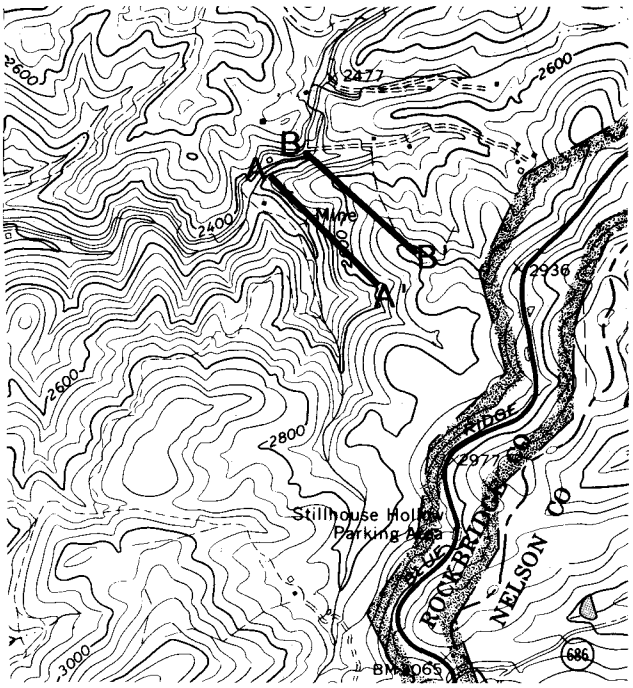


Figure 2B. Location and topography of geochemical traverses A-A and B-B across and close to Irish Creek tin mine, #1 working, Montebello 7.5-minute quadrangle, Rockbridge County, Virginia.

found an anomalously high beryllium signature similar to anomalous values downstream from the Irish Creek tin mines (Figure 3). There are also slightly elevated fluoride values (180 and 240 parts per billion) in the stream water near the Nettle Creek showings, but not as high as fluoride values downstream from the tin mines (910 parts per billion) (Figure 4). Fresh waters average 100 ppb (Rose and others, 1979).

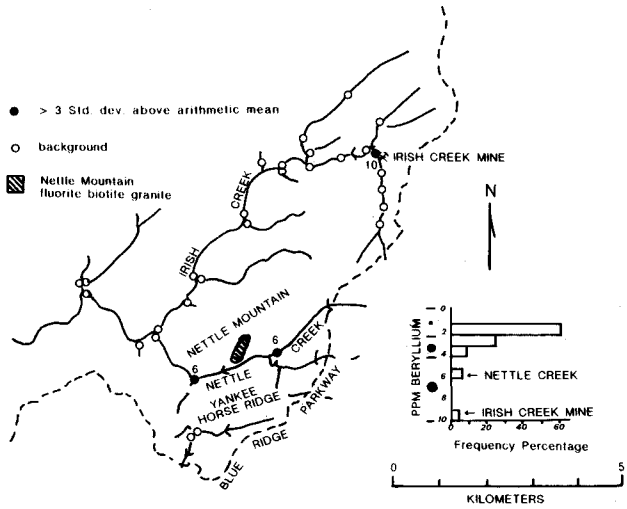


Figure 3. Parts per million beryllium in stream sediments, Irish Creek tin mine vicinity, Rockbridge County, Virginia.

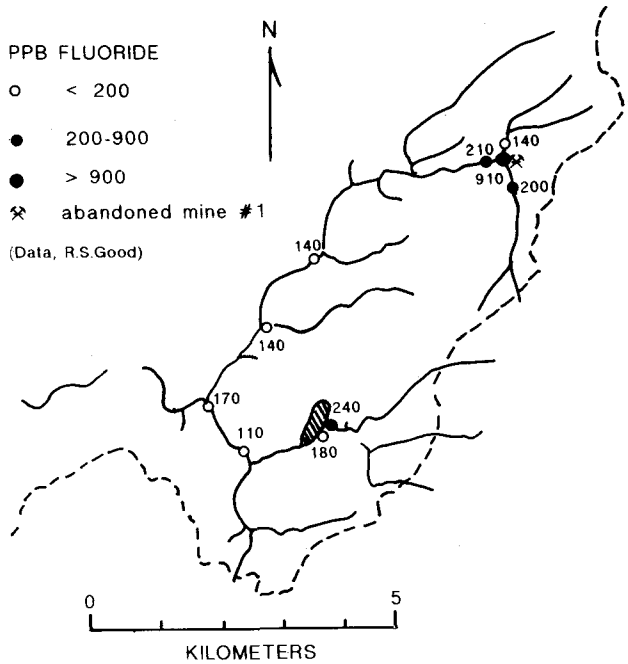


Figure 4. Parts per billion fluoride in stream water in vicinity of Irish Creek tin mine and Nettle Mountain granite.

Penick and Sweet (1984) noted a previously unrecorded gold and silver mine (now called the Buck Mountain mine) on strike with the Nettle Creek sulfide-fluorite occurrence in Amherst County. This locality is about 10 miles southwest of the Irish Creek tin mines. The Buck Mountain mine is within host rocks similar to those at Irish Creek (Figure 1). Assays on adit samples from a quartz vein in a shear zone from Buck

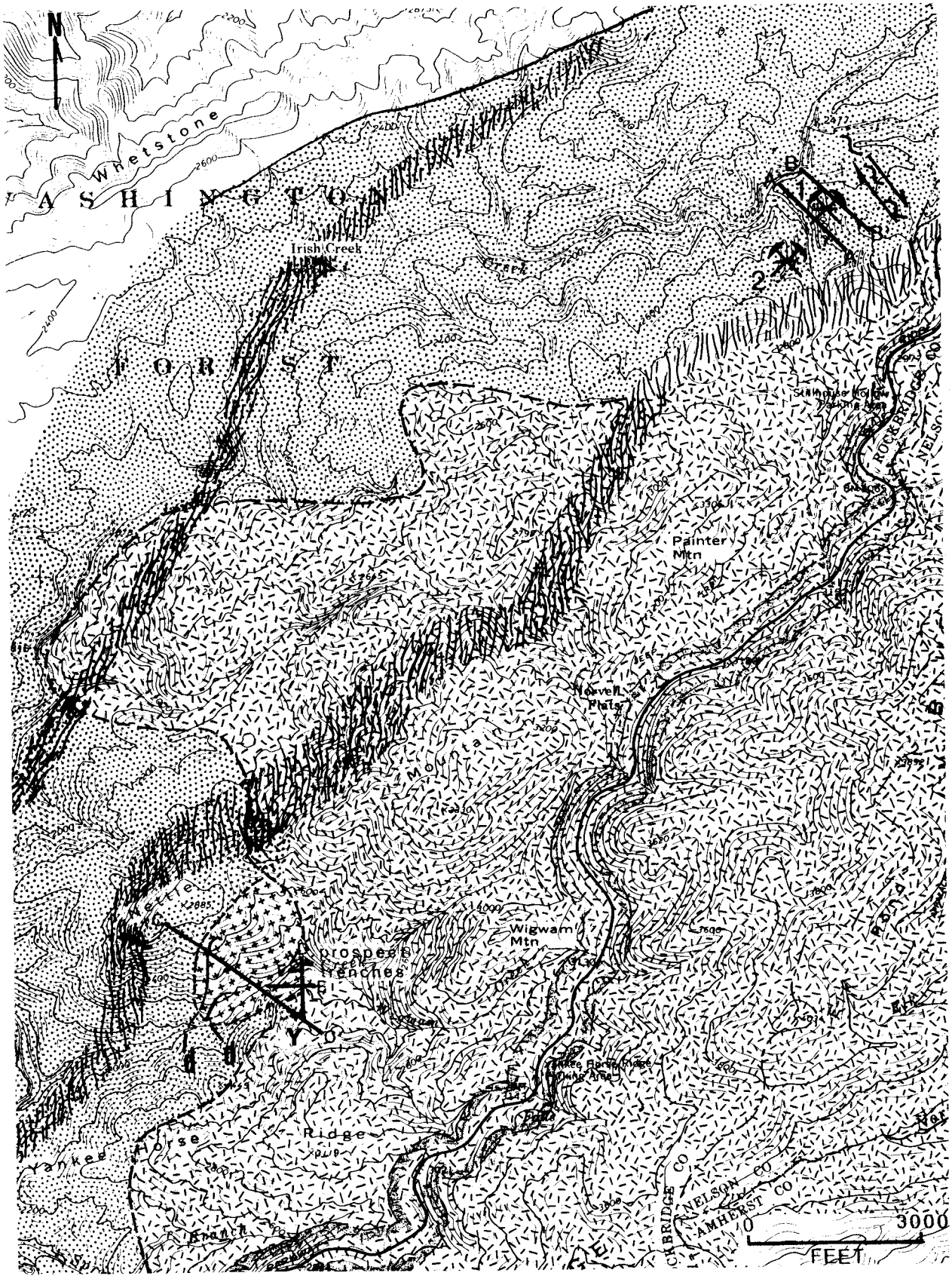


Figure 5. Geology of the portion of the Montebello Quadrangle of investigation with location of the geochemical soil traverses, designated A-A', B-B', C-C', D-D', and E-E' (Geology modified from Hudson, 1981).

EXPLANATION

Cataclastic zone.

Fault.

A—— A' Geochemical soil and spectrometer traverse.

Irish Creek mine, Panther Run #1, main workings, 2 accessible adits and trenches.

Irish Creek mine, Panther Run #2, workings inaccessible except for pits.

Chilhowee Group: metasediment sand metavalcanics; phyllite, feldspathic sandstone and meta basalt.

d Catoctin metabasalt feeder dikes.

Crossnore Group pluton: Nettle Mountain fluorite-bearing biotite granite with accessory florencite.

Porphyritic leucocratic quartz monzonite with blue quartz, locally alaskitic; with disseminated, anastomosing, thin mylonite zones separated by undeformed or slightly deformed rock.

Poikiloblastic clinopyroxene, hypersthene, hornblende granulite gneiss; layer hornblede, clinopyroxene, hypersthene granulite gneiss; quartzofeldspathic granulite gneiss; charnokite facies of Pedlar terrance characterized by local, thin, anastomosing mylonite zones, often with little or no displacement.

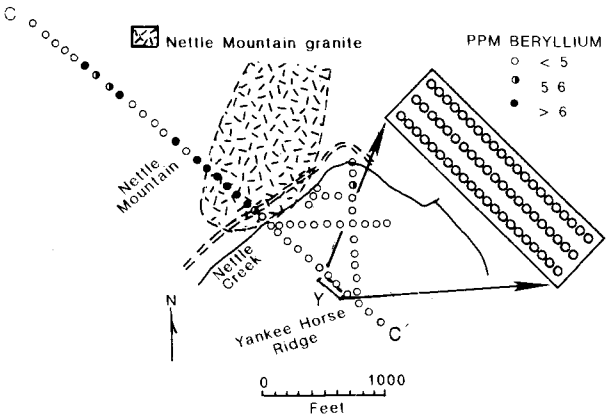


Figure 6. Parts per million beryllium in soil traverses on Nettle Mountain and Yankee Horse Ridge.

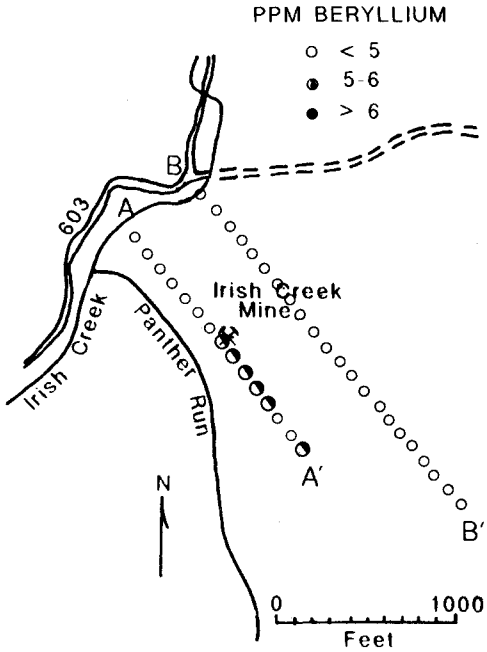


Figure 7. Parts per million beryllium in soil traverses in the vicinity of Irish Creek tin mine, #1 working.

Mountain range from 0.04 to 1.31 ounces/short ton of gold and from 1.82 to 5.4 ounces/short ton of silver (Appendix II). The mineralogy of the quartz vein is pyrite, arsenopyrite, scorodite, fluorite, and gypsum. The writer also found highly elevated tin values in the soil around the adit (20 to 416 ppm), but no cassiterite has been identified. Additional anomalously high metal values in the soil are lead (400 to 607 ppm), beryllium (6.1 ppm), arsenic (12,500 ppm), and silver (2 to 5 ppm); fluorine in the soil is 1195 ppm (Appendix III). Three other small precious metal mines or prospects (Jack's Hill, Colleen prospect, Ivy Creek, Figure 1) have been identified by Sweet and Lovett (1985), but there is no data regarding the history or grade of ore from these mines.

The Irish Creek mine sites and the Yankee Horse Ridge prospect are both within a 5500 acre tract of private land owned by Dr. Laurie Landeau of New York. The tract was formerly owned by Owens-Illinois Company, Forest Products Division, which became the Nekoosa Packaging, Inc. in the 1980s.

GEOLOGIC SETTING

IRISH CREEK TIN DEPOSITS

The Irish Creek tin mines are located in the central Virginia portion of the Blue Ridge physiographic and geologic provinces (Figure 1). The mines are located on a small tributary of Irish Creek (Panther Run on 15-minute topographic map) that is unnamed on the 1965 edition of the Montebello 7.5-minute topographic map. The sites are located on the 7.5-minute Montebello quadrangle (Figures 1 and 2B). The mines were active from 1884 to 1886, 1890 to 1892, and 1918 to 1919 (Ferguson, 1918). However, total

production has been estimated at only 3200 short tons of ore with an average grade of 1 percent. This ore produced an estimated 17 short tons of tin metal (Koschmann and others, 1942). The grade estimate was lowered to 0.49 percent based on data obtained from drilling by Bethlehem Steel (Adair, 1942; French, 1956). Several exploration companies including International Nickel and Billiton Metals did additional trenching and assaying in the 1970s and 1980s.

Tin occurs at Irish Creek in cassiterite that is formed in greisenized gray-quartz veins that intrude clinopyroxene-hypersthene-hornblende granulite gneiss. These regional host rocks were formerly all grouped within the Pedlar Formation (Bloomer and Werner, 1955) (in this study called Pedlar complex), but Hudson (1981) recognized mappable lithologic units locally that included quartz monzonite, and felsic and mafic granulites. All of these lithologies as well as Lovingston complex rocks are intruded by younger Late Precambrian-age granites (NM, WM, RF, Figure 1) and Late Precambrian- to Cambrian-age Catoctin basalt feeder dikes and flows (Figure 1). Minerals reported from Irish Creek include arsenopyrite, pyrite, hematite, pyrrhotite, galena, galenobismutite, aikinite, beryl, phenakite, scheelite, wolframite, sphalerite, siderite, apatite, scorodite, parisite, and titanomagnetite (Glass and others, 1958). Lesure and others (1963) described the beryllium mineralization associated with the deposits. Fordham (1978) notes anomalous beryllium values (above three standard deviations) in stream sediments downstream from the mines and at one other location in Nettle Creek (Figure 3). Hudson (1981) mapped a fluorite-biotite granite in the vicinity of Fordham's stream sediment anomaly and concluded that this granite was the Irish Creek "tin granite." Soil geochemistry done for this investigation indicates elevated beryllium values in the bedrock over both Hudson's fluorite-biotite granite and near the tin mines (Figures 6 and 7).

PETROLOGY AND TECTONICS

A simplified regional geologic map shows the area of investigation to be within Pedlar complex rocks (Figure 1). The term Pedlar was established by Bloomer and Werner (1955) in the mapping of an area that included the Yankee Horse Ridge-Nettle Mountain-Irish Creek areas. They combined pre-Grenville-, Grenville-, and post-Grenville-age granites, granodiorites, syenites, quartz diorites, anorthosites, and unakite of the Blue Ridge Mountain into the Pedlar Formation. Bartholomew and others (1981) and Sinha and Bartholomew (1984) retained the term Pedlar in describing a large complex tectonic block consisting of a stack of allochthonous plates west of the Rockfish Valley fault (Rockfish mylonite zone, Figure 1), as Pedlar massif. The Rockfish Valley fault was first described and defined by Gathright and others (1977) and Bartholomew (1977) in an area northeast of the area of investigation.

Northwest of the Rockfish Valley fault (Rockfish mylonite zone, Figure 1) lithologies are dominantly Grenville- (1100 m.y.) and pre-Grenville-age (1700 m.y.) massive and layered charnockites, massive and layered felsic and mafic granulite gneisses, and leucocratic, quartz monzonites partially reflecting different degrees of deformation. A Grenville age of 1075 m.y. was obtained from zircons extracted from Pedlar complex charnockite by Pettingill and others (1984). Mapping of an individual fault may be misleading. The local scale tectonic style consists of anastomosing faults which pervade a southeast-dipping, northeast-trending stack of thrust sheets which appears to form a duplex.

Southeast of the Montebello quadrangle Herz and Force (1987) used the term "Pedlar massif" as an informal term to describe rocks northwest of the Rockfish mylonite zone. Within the Montebello quadrangle, Hudson (1981) dropped the term Pedlar and mapped four granulite gneiss units: massive ilmenite-hornblende granulite gneiss, massive clinopyroxene-hypersthene hornblende granulite gneiss, poikiloblastic ilmenite-hornblende granulite gneiss, and layered granulite gneiss. Within the area of this investigation (Figure 5), Hudson (1981) mapped most of the bedrock as poikiloblastic clinopyroxene-hypersthene-hornbende granulite, layered hornblende-clinopyroxene- hypersthene granulite gneiss with small amounts of quartzofeldspathic gneiss and a large area of porphyritic, leucocratic quartz monzonite (Figure 5). The writer indicates all of these rocks as Pedlar complex (Pc) in the regional map (Figure 1).

Rocks that occur to the southeast of the Rockfish mylonite zone (Figure 1) are Grenville- (1100 m.y.) and pre-Grenville-age (1700 m.y.) biotite augen gneiss, granulite gneiss, minor charnockite, granite, ferrodiorite, anorthosite, and nelsonite (Herz and Force, 1987; Evans, 1984). These rocks are dominantly biotite and hornblende-bearing rocks with minor pyroxene. The rocks are shown informally as Lovingston complex (Figure 1). The term Lovingston originated with (Jonas, 1928), was continued by Bloomer and Werner (1955), and was retained informally by Herz and Force (1987) as "Lovingston massif."

The Rockfish mylonite zone (Figure 1) marks lithologic differences but its significance is undergoing reevaluation. The zone is about 1 to 3 miles in width and contains mylonites along with rocks less intensely deformed. It is considered by many workers to be part of a major fault system, the Hayesville-Fries-Rockfish Valley fault, extending on strike to the southwest and northeast. The fault system also extends as subparallel fractures to the northwest and southeast of the trace indicated in Figure 1.

The Rockfish mylonite zone (RMZ) has been considered one of dominantly ductile deformation and was called the ductile deformation zone (DDZ) by Bartholomew and others (1981). The assumed Ordovician-age Taconic deformation of the Rockfish mylonite zone through arc-continent collision (proto-Atlantic Ocean, Iapetus of Wilson (1966), closing) is now open to question. Evans (1984) found evidence of both ductile and brittle deformation in his detailed mapping across the RMZ. The Rockfish mylonite zone is considered the trace of a reactivated hinge zone (Wehr and Glover, 1985; Evans, 1984) marking the uplift and stretching of a continental margin which developed rift grabens on each flank in Late Precambrian time. Late Precambrian- to Early Cambrian-age rift-related faulting occurs along the entire Blue Ridge geologic province from Alabama to Pennsylvania (Costello and Hatcher, 1985). The driving force causing uplift is widely viewed as a mantle plume convection cell

(Wehr and Glover, 1985; Seyfert, 1987). Based on stratigraphic evidence Fichter and Diecchio (1986) have suggested 630 m.y. as the beginning date for rifting. Odom and Fullager (1984) believe rift-related events started earlier at 690 m.y. with felsic intrusions of the Crossnore plutonic-volcanic suite. The Crossnore group was originally defined to describe late Precambrian- to Early Cambrian-age igneous rocks including the Catoctin, Mount Rogers, and Grandfather Mountain volcanic rocks (basalts and rhyolites) plus the Crossnore, Beech, Striped Rock, Brown Mountain, and Lansing plutons of northernmost North Carolina and southwest Virginia. On stratigraphic, mineralogic, and isotopic-geochronological grounds, Rankin, 1968a, 1968b; Rankin and others, 1969; Rankin, 1975, 1976, presented evidence that these rocks constitute a single bimodal suite and an orogenic magmatic suite, the Crossnore complex. The Crossnore plutonic suite, a subdivision of the Crossnore complex, is characterized by felsic members which have mildly to distinctly peralkaline affinities. The Crossnore plutonic-volcanic suite is characterized by enrichments in niobium, yttrium, thorium, uranium, rare-earth elements, potassium, and depletions in strontium and barium (Rankin, 1975). The plutons are fluorite-bearing and biotite rich granitoid rocks. A few are truly peralkaline, that is, the sum of Na_2O and K_2O exceeds Al_2O_3 on a molecular basis (Bailey, 1989) and contain small amounts of alkali pyroxenes (aegirine) and alkali amphiboles (riebeckite) (Rankin, 1976). Felsic extrusives (rhyolite) are associated with some of the Crossnore felsic plutons.

In the Blue Ridge province of central Virginia there are four known small, fluorite-bearing, rare earth-enriched, thorium and uranium-enriched biotite granitoid plutons which intrude the Pedlar Complex and Lovingston Complex rocks. Because of their intrusive relationships, their lithology, and ages, they are called Crossnore plutons in this investigation. Granitoid Crossnore plutons indicated in Figure 1 are: Nettle Mountain granite, NM; Mobley Mountain Granite, MM; Woods Mountain pluton, WM; and Rockfish pluton, RF. Two of these plutons have been dated as Late Precambrian, the Nettle Mountain Granite indirectly at 637 m.y. (Hudson and Dallmeyer, 1982) and the Mobley Mountain Granite at 652 m.y. (Brock, 1981). The locations of the plutons and ages of intrusion are evidence for melting accompanying doming or uplift prior to, or during, earliest rifting. The other biotite fluorite-bearing granitoid plutons intrusive into Grenville-age rocks, the Rockfish (RF, Figure 1) and the Woods Mountain (WM, Figure 1) have been described briefly but not dated: Woods Mountain by Smith and others (1981); and Rockfish by Evans (1984). Three of these Crossnore plutons (MM, RF, and WM) occur southeast of the Rockfish mylonite zone and the Nettle Mountain granite (NM) occurs to the northwest (Figure 1).

Within the Montebello quadrangle, Hudson (1981) identified a small (1900 feet by 600 feet) fluorite-bearing biotite granite on the east flank of Nettle Mountain, 2.84 miles southwest of the Irish Creek tin mines (Figure 5). This granite was described but never formally named by Hudson (1981). In this study, this granite is informally referred to as the Nettle Mountain granite. Hudson and Dallmeyer (1982) obtained an age of 637 m.y. (by A^{40}/A^{39}) from muscovite taken from Irish Creek tin mine greisen samples. They concluded that the nearby (2.84 miles) Nettle Mountain granite and its associated aplites are the source of Irish Creek tin mineralization, even though no rock similar to the Nettle Mountain granite has been identified at or close to the tin mines. Compared to the "average granite" (2485 samples from Le Maitre, 1976) the Nettle Mountain granite shows a depletion in barium and enrichment of rubidium, yttrium, niobium, uranium, thorium, zirconium, and zinc (Table 1). Rankin (1975) noted enrichments in niobium, yttrium, thorium, uranium, rare earths, potassium and depletion of strontium and barium in the Crossnore plutonic suite. Additionally, the average of three Nettle Mountain granite samples tends to match the distinctive signature of the average mineralized granite of Stemprok and Skvor (1974). Their data shows a signature of a high SiO_2, low TiO_2, low MgO and CaO, high K_2O and Na_2O, and enrichment in a number of trace elements including beryllium (Table 1). Further evidence to support the Nettle Mountain granite, or a very similar pluton as the source of tin mineralization, is shown by the Rb/Sr value of 5.05 (range 3.61 to 7.48) which places the Nettle Mountain granite within the lower range of mineralized plutons of various tin districts when compared to barren granitoid rocks. All other granitoid bodies fall well below a Rb/Sr ratio of 5.0 (Figure 8).

Other evidence that supports a genetic relationship between the Nettle Mountain granite and Irish Creek mineralization is Fordham's (1978) beryllium data from stream sediments. The stream sediment values for beryllium show that the only anomalies in the area surveyed are downstream from the tin mines and from the Nettle Mountain granite (Figure 3). Elevated geochemical values in soil for beryllium (this study) over the Nettle Mountain granite strengthens Fordham's data (1978) (Figure 6).

A plot of the Nettle Mountain granite on a modified A-K-F diagram shows that it is close to the Crossnore plutonic-volcanic group, and that although none of the samples are truly peralkaline, one sample plots very close to the peralkaline divide at the base of the diagram (Figure 9). One truly peralkaline Crossnore granite from Rappahannock County, northern Virginia Blue Ridge province, is shown in Figure 9 but others are not included (Mount Rogers felsic volcanic rocks).

Alkalic and peralkaline rocks are well known in their association with tensional or rifting environments as opposed to a subduction setting. Early studies by Martin and Piwinski (1972) on relating the chemistry of rocks to tectonic setting were noted by Rankin (1975) who observed that the Crossnore volcanic and plutonic rocks matched rifted areas rather than subducted settings. Later refinements using discriminant functions with whole rock chemistry by Maniar and Piccoli (1989) clearly places the Crossnore plutonic suite within a rift-related setting (RRG in Figure 10).

As uplift continued and grabens deepened on each flank of the hinge zone (Rockfish mylonite zone, Figure 1) elongated basins were formed. On the ocean (east) side elongated basins were filled with turbidite-dominated sediments and mafic and ultramafic oceanic intrusives shown as Lynchburg Group, Ashe Formation, and Alligator Back Formation (Figure 1). Lynchburg Group rocks occur in narrow, subparallel basins both northeast, southwest, and east of, as well as within the area shown in Figure 1 (Conley, 1985, 1987). Some of the

Table 1. Whole-rock chemical signature of Nettle Mountain granite compared with average mineralized and average unmineralized granites.

	Average granite[1]	Nettle Mountain granite[2]	Average of mineralized granites[3]
SiO_2%	71.30	74.5	73.02
TiO_2%	0.31	0.08	0.21
Total Fe as Fe_2O_3%	3.03	2.48	2.27
MgO%	0.71	0.11	0.52
CaO%	1.84	0.78	1.24
K_2O%	4.07	4.92	4.57
Na_2O%	3.68	4.76	3.28
Rb/Sr	2.76	5.05	high
Rb/Ba	0.33	2.18	high
U ppm	3.9	7.7	high
Th ppm	20.0	24.1	high
Zr ppm	175.0	391.0	high
Nb ppm	20.0	157.0	high
Be ppm	3.0	(anomalous, in soil over granite, up to 14.5)	high
Li ppm	40.0	(anomalous, in soil over granite, up to 67)	high
Sn ppm	3.0	(anomalous, in soil over granite, up to 16-19)	high variable >15-20
Rare earths ppm	41.0 Y	179.0 Y, Nd, Ce	high

[1]Average granite, whole-rock analyses of major element oxides from 2485 samples (Le Maitre, 1976); trace element average from Turekian (1977), in Rose and others (1979).
[2]Average of three whole-rock analyses of fluorite-biotite granite which crops out on Nettle Mountain (Hudson, 1981) and is informally called Nettle Mountain granite in this investigation. This granite is 2.8 miles from the Irish Creek tin mine and is thought to be the "tin granite." Soil data on Be, Li, and Sn over the granite are from this study.
[3]Average for specialized granitoid host rocks in mineralized areas Stemprok and Skvor (1974) in Taylor (1979).

mafic rocks within Lynchburg Group rocks are greenstones and may represent partial ophiolite sequences (Conley, 1985, 1987). Ultramafic rocks (Figure 1) now altered to soapstone also occur within the Lynchburg Group. In places close to hot spots within the Lynchburg-Ashe basins, warm and hot metal-rich and silica-rich brines deposited the syngenetic, stratiform, massive sulfides of iron, copper, zinc, and lead of the Gossan Lead of southwest Virginia (Gair and Slack, 1984), and also the stratabound barite, manganese oxide, and banded iron formations of the western Piedmont of Virginia (Sweet and others, 1989). The Faber lead-zinc mine (number 6, Figure 1) and the Ivy Creek gold prospect (number 7, figure 1) are excellent examples of rift-related mineralization within the Lynchburg Group rocks. Saline brines are known to have an important role in the mylonitization process (Kirby and others, 1989). Saline brines generated in Late Precambrian-age Lynchburg rift basins may have augmented the faulting process. With or without brines, however, the Late Precambrian-age rift faults are believed to be favored sites for repeated faulting through Paleozoic and perhaps even Mesozoic time. Metamorphism altered but did not completely obliterate these paleofractures. Mesozoic-age rift basins of the Triassic and Jurassic (Figure 1) follow the trend of Late Precambrian-age rifts. It is not clear whether these are reactivated older faults or a combination of newer faults with older ones.

On the landward (west) side of the hinge line fluvial conglomerates and arkoses were deposited in narrow elongated rift basins coeval or partially coeval with Late Precambrian-age Lynchburg deposition as the Mechum River Formation (Figure 1). Other rift-related deposits coeval with the Mechum River, but not shown, are the Swift Run and Fauquier Formations. Some of the Mechum River deposits are subaerial conglomerates with some shallow-water clastics.

As rifting continued from Late Precambrian time into earliest Cambrian time, rift-related fractures directed basaltic flows which follow the northeast trend of the Mechum River-Lynchburg basins. Basalts (now greenstones) directly overlie the rift graben clastics (Catoctin Formation, Figure 1) and have a chemical signature of continental margin rifting, not subduction (Mose and others, 1985; Badger and Sinha, 1988). The Catoctin Formation also contains some minor sedimentary and volcaniclastic beds. Catoctin feeder dikes are shown in Figure 2.

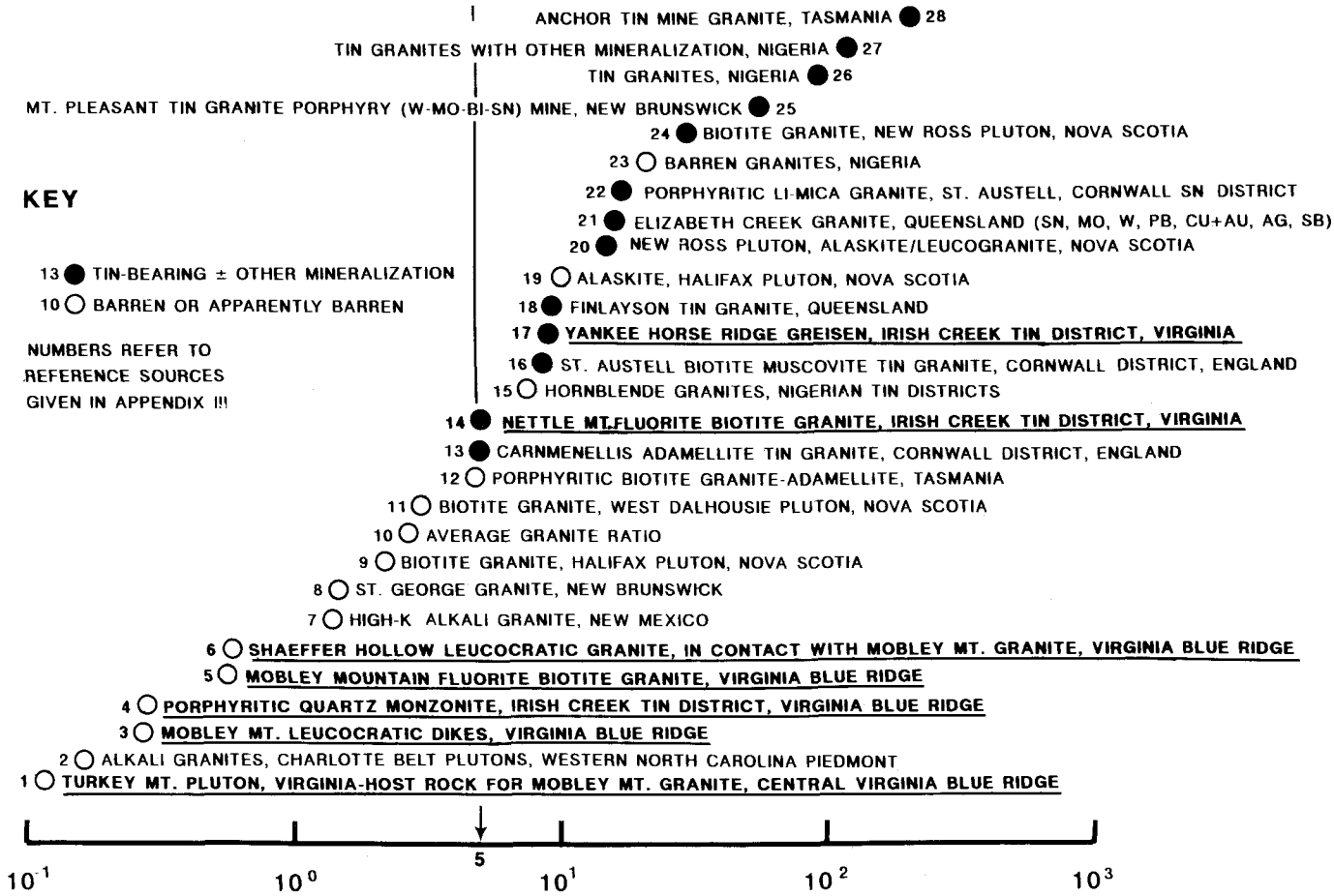


Figure 8. Whole-rock Rb/Sr ratios for Blue Ridge province granitoid plutons from Virginia compared to granitoid plutons from selected tin districts of the world. Sources listed in Appendix I.

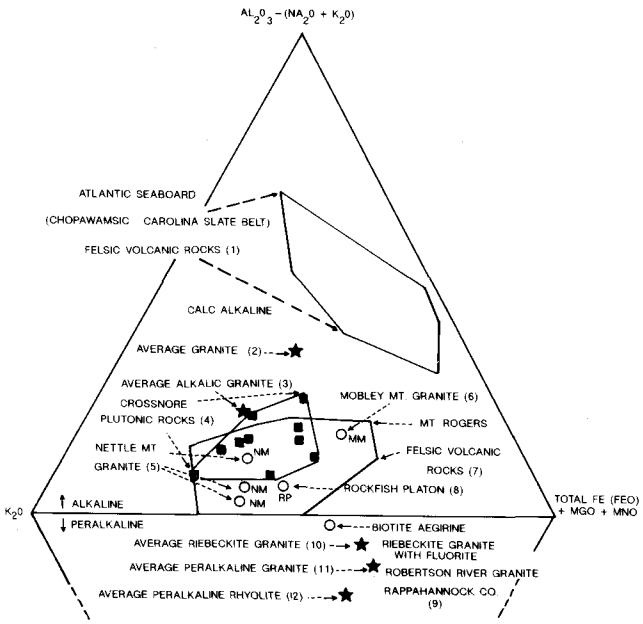


Figure 9. Modified A-K-F diagram in molecular percent for granites and felsic volcanic rocks. (Data partly adapted from Rankin, 1975).

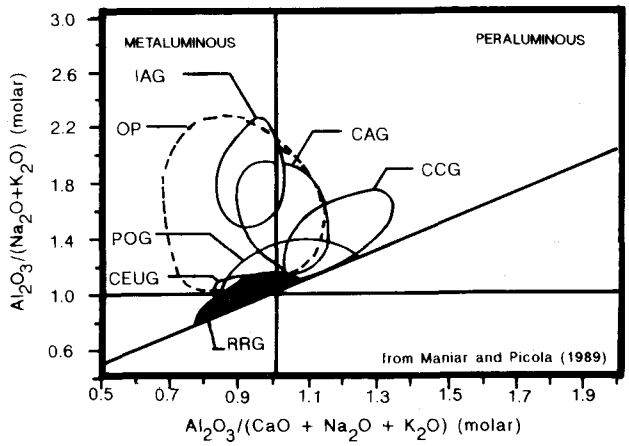


Figure 10. Shand indices of Nettle Mountain granite and other Crossnore Intrusive Suite rocks (RRG) in relation to tectonic settings as classified by Maniar and Piccoli (1989).

Further evolution of the Early Cambrian-age rift system is described by Simpson and Eriksson (1989). They examined the transition from rift to passive margin within the Unicoi and

lower Hampton Formations (shown as Chilhowee, Figure 1). Rifting is indicated by thick alluvial fan sediments, basalts, abundant lithic clasts, and the feldspathic character of the sandstones in the lower and middle Unicoi. The overlying upper Unicoi, quartzose sandstones, represents the incipient phase of passive margin sedimentation. Stratabound iron, manganese, and iron-manganese deposits were deposited within the sediments of the Chilhowee Group (Antietam, Harpers, and Weverton Formations) rocks and the overlying Cambrian carbonates and shales of the Shady and Rome Formations (Figure 1). A regional treatment of current thinking on Blue Ridge rifting and tectonics can be found in Glover (1989). Conley (1987) has suggested that a subduction/obduction event may have also occurred in Late Precambrian time in addition to rifting.

Although the evidence for Late Precambrian-age rifting is substantial, any interpretation must be tempered with the realization that the entire Blue Ridge geologic province is tectonically rootless. Seismic data indicates continuous horizontal reflectors at 3.7 to 5 mi beneath the Blue Ridge and western Piedmont province. These reflectors are interpreted as being flat-lying lower Paleozoic-age strata (Clark and others, 1978; Cook and others, 1979; Harris and others, 1982; Glover and others, 1982; Wehr and Glover, 1985). The tectonic style is now seen by many workers to be affected by right lateral movement in late Paleozoic-time.

The Nettle Mountain Granite is one of four Crossnore plutons indicated on the regional geologic map (Figure 1). Hudson (1981) considered the Nettle Mountain granite to be the Irish Creek tin granite, but no granite was identified at or near the mine, although Ferguson (1918) indicates ten other "veins" up to more than a mile away from Irish Creek #1 and #2 workings. This lack of a source granite may be because it is not prominently exposed or it may be because the Irish Creek tin mineralization and the Nettle Mountain granite lie within a very thin, southeast dipping thrust sheet. Hudson (1981) indicates an extensive cataclastic zone (Figure 2) and the writer noted parallel shearing on Yankee Horse Ridge. Evidence for the thinness of a Pedlar complex thrust sheet is the comment of Ferguson (1918) who noted "purple slates" at the #2 underground tin workings (now inaccessible). This observation would tend to support an interpretation of Pedlar complex granulite gneiss containing greisen lying over younger Catoctin or Chilhowee rocks (Figure 2). Herz and others (1981) and Brock and others (1987) postulated that the Nettle Mountain granite is a rootless roof pendant of the Mobley Mountain Granite (Brock, 1981).

The Nettle Mountain granite according to these workers is a detached cupola of the Mobley Mountain granite, a fluorite-bearing biotite granite 14.3 miles to the southeast of Nettle Mountain. The roof pendant is thought to have been transported during Paleozoic-aged (probably Taconic) thrusting to the northwest. The geologic age determined for the Mobley Mountain Granite, 652 m.y., by Brock (1981) is marginally compatible with Hudson and Dallmeyer's (1982) date for Irish Creek greisen mineralization, although the 637 m.y. age is only an inferred date for the Nettle Mountain granite. The overall mineralogic and whole-rock chemical evidence connecting the two granites is very weak and cannot entirely be explained by enrichment of volatiles. Table 2 shows that the Mobley Mountain granite does not meet any of the criteria for mineralized granites discussed earlier and shown in Table 1. Furthermore, the Mobley Mountain granite does not show a high Rb/Sr value (Figure 8). Brock (1981) and Brock and others (1987) underplay the chemical and mineralogic discrepancy by postulating upper mantle melting (possibly of a lherzolite) and fractional crystallization leading to a volatile-enriched pluton cupola. The fractional crystallization for Brock's model (1981) was derived from computer modeling (XLFRAC, mass balance simulation). It is certainly reasonable to envision dismemberment of plutons in this allochthonous thrust belt setting, but it should be noted that the data for the Rockfish pluton plots closer to the Nettle Mountain granite than the Mobley Mountain granite on a modified A-K-F diagram (Figure 9).

Table 2. Average major chemical and mineral differences between Nettle Mountain granite and Mobley Mountain granite.

	Nettle Mountain granite[1]	Mobley Mountain granite[2]
SiO_2%	74..5	67.6
TiO_2%	0.08	0.47
Total Fe as Fe_2O_3%	2.48	5.61
MgO%	0.11	0.36
CaO%	0.78	1.14
Rb ppm	437.0	97.0
Sr ppm	82.0	190.0
Y ppm	179.0	22.0
U ppm	7.7	0.57
Th ppm	24.1	7.2
Rb/Sr	5.05	0.59
Quartz (modal %)	27.5	24.8
Albite (modal %)	5.2	12.1
Epidote (modal %)	-	5.4

[1]Nettle Mountain granite data from Hudson (1981), mean of three analyses.

[2]Mobley Mountain granite data from Brock (1981), mean of 14 analyses.

THORIUM AND URANIUM

Anomalous thorium values may have a potential use in the Blue Ridge province as a rapid guide to poorly exposed or buried mineralized pegmatite or pegmatoid zones, mineralized cataclastic zones, tin-bearing greisen, and surface expressions of uranium at depth. Late Precambrian-age, Crossnore-type plutons (fluorite-bearing biotite granitoid rocks rich in thorium and rare-earth elements) have been proposed as prime exploration targets for uranium in igneous-metamorphic rock terranes (Rogers and others, 1978). Uranium mineralization is associated with tin deposits in England and Europe in geologic settings similar to Irish Creek. Mineralization is associated with granites containing

more than 5 ppm uranium (Rich and others, 1977). In the eastern United States, exploration for uranium is difficult and misleading because surface leaching, transportation, and redeposition can easily remove all direct indications of unoxidized uranium mineralization at depth, or leave only shallow concentrations of secondary uranium minerals at the surface.

Thorium, because of similar ionic radius and valence charge compared to uranium and rare-earth elements, accompanies these elements in magma evolution. Crossnore-type granitoid plutons are enriched in these elements as well as rubidium, beryllium, lithium, tungsten, tantalum, and tin, and thus might be considered rift-related because of the known association of alkalic/peralkalic felsic rocks in tensional settings. Upper mantle plume melting during uplift preceding rifting is the most probable source.

Uranium (U^{+4}) separates from thorium (Th^{+4}) as it oxidizes to U^{+6} and forms more soluble and mobile complexes during the weathering cycle in humid climates. The Th^{+4} remains unoxidized in rock and soil as a stable compound. One example in Virginia where the surface radioactivity is not superficial, or due to disseminated thorium minerals, is the Marline Uranium Corporation's Swanson ore body in Pittsylvania County. This deposit consists of an estimated 30-million pounds of U_3O_8 in coffinite-pitchblende-uraninite ore averaging 0.20 percent U_3O_8 (Chenowith, 1983). The mineralized zone is contained in a sheared late Precambrian-age augen gneiss in contact with a younger granite along a border fault of the Danville Triassic basin. This deposit might represent mineralization along a reactivated late Precambrian-age rift fault.

Deformation of accessory uranium and thorium-bearing minerals is known to markedly enhance radioactivity in mylonite zones because of redistribution of the oxidized and soluble U^{+6} cation and radon gas movement within more permeable cataclastic textures. In studying sources of radon enrichment in Virginia and Pennsylvania, Gunderson and Gates (1988) noted that uranium content could be positively correlated with shear strain as determined by the angle between C and S bands. In the Late Precambrian-age Reading Prong allochthon of Pennsylvania, uranium was found hosted in allanite, titanite, and monazite in unsheared rocks, but was redistributed in association with hematite in the foliation of mylonite at levels of 25 to 50 ppm uranium (Gunderson and Gates, 1988).

Allanite and chevkinite/perrierite are common in small amounts in the Blue Ridge province of Virginia (Mitchell, 1966a). Thorium always substitutes in varying small amounts for cerium in allanite (Ce, Ca, Y) (Al, Fe^{+3})$_3$ (SiO_4)$_3$ (OH), perrierite $(Ca,Ce,Th)_4(Mg,Fe^{+2})_2(Ti,Fe^{+3})_3Si_4O_{22}$, monoclinic perrierite (chevkinite), florencite $(Ce,Al_3)(PO_4)_2(OH)_6$, and bastnaesite (Ce,La) $(CO_3)(F,OH)$, all of which are known to occur in the Crossnore plutons and the Robertson River plutons and pegmatites (Hudson, 1981; Brock, 1981; Lukert and Halladay, 1980). Complications in interpretation could occur because allanite is also found in association with pegmatoid intrusion zones near older charnockites. Allanite and chevkinite may be related to late Precambrian-age Crossnore pegmatoids. Hudson (1981) notes a radioactivity anomaly associated with dark-gray quartz veins containing iron oxides (200 ppm thorium, 7 ppm uranium) about 0.6 mile from the fluorite-biotite granite along Nettle Mountain. Whole- rock analyses by Hudson on the Nettle Mountain granite showed a range of 13.5 ppm to 17.9 ppm for thorium and an average of 7 ppm for uranium. His mapping indicates aplites and greisen in the peripheral zone of the fluorite-biotite granite, one of which outcrops on the west slope of Yankee Horse Ridge. Hudson noted thorium enrichment along a cataclastic zone on Grapevine Ridge in the southwest corner of the Montebello quadrangle (Figure 1) and reported thorium values of 194 ppm and only 3.4 ppm uranium. A southern projection of Hudson's mapping of a radioactive cataclastic zone was checked by the writer. Gamma-ray spectrometry indicated thorium and uranium values similar to Hudson's data (Figure 11).

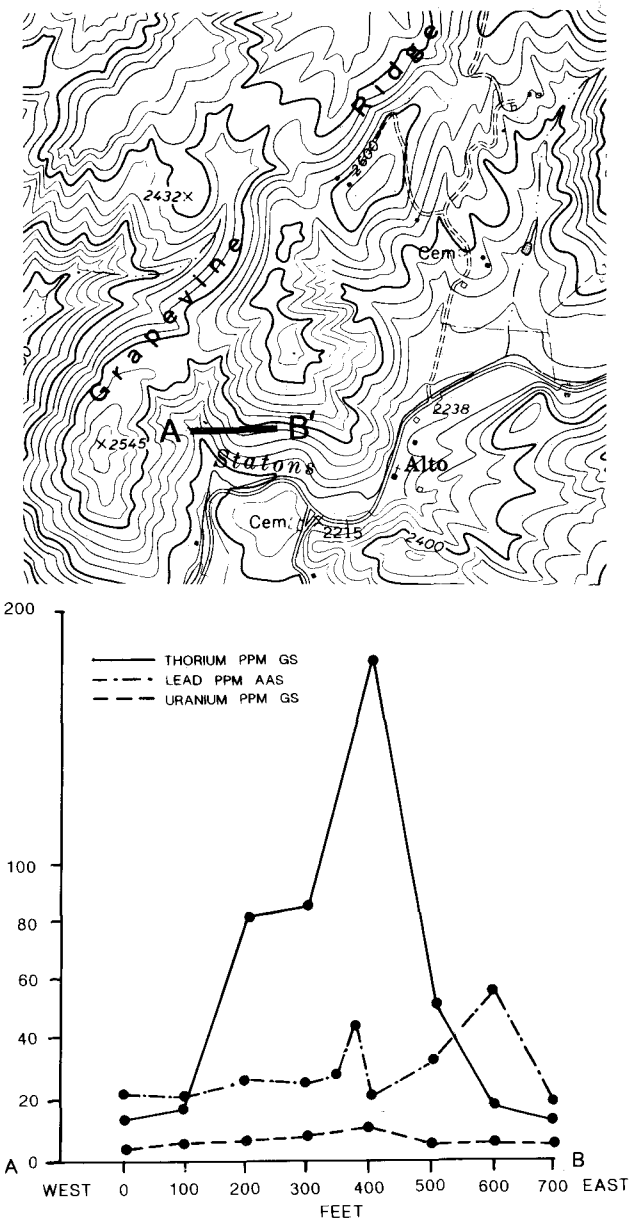


Figure 11. Gamma-ray spectrometer and geochemical traverse across a projection of the cataclastic zone mapped by Hudson (1981) on Grapevine Ridge, Montebello 7.5-minute quadrangle, Rockbridge County, Virginia.

Ames (1981) noted thorium enrichments of 275 ppm and 15.3 ppm uranium in the felsic mylonites of the Rockfish mylonite zone southeast of the Irish Creek mines (Figure 1). This area is northeast of the Montebello quadrangle. Values of 50,000 ppm thorium and 4800 ppm uranium were reported in saprolites of shear zones with enrichments of tin, tungsten, lanthanum, scandium, titanium, vanadium, zinc, and yttrium in the Lovingston Formation southwest of Charlottesville (Baillieul and Daddazio, 1982). The radioactivity in this cataclastic zone is generated primarily from monazite, uranothorite, and thorogummite. A strong north-northeast trending thorium and uranium anomaly is indicated by stream sediments in the National Uranium Resources Evaluation (NURE) survey (Herz, 1982). This anomaly is south of the Montebello quadrangle in the adjacent Forks of Buffalo quadrangle. A low-level thorium enrichment is noted (Th/U greater than 4.0, 13.4 ppm thorium, 3.3 ppm uranium: Appendix VI) at Irish Creek tin mine (Figure 12) and in an area peripheral to the Nettle Mountain granite (61 ppm thorium, 7.5 ppm uranium: Appendix IX; 44.7 ppm thorium, 7 ppm uranium: Appendix X; Figure 13).

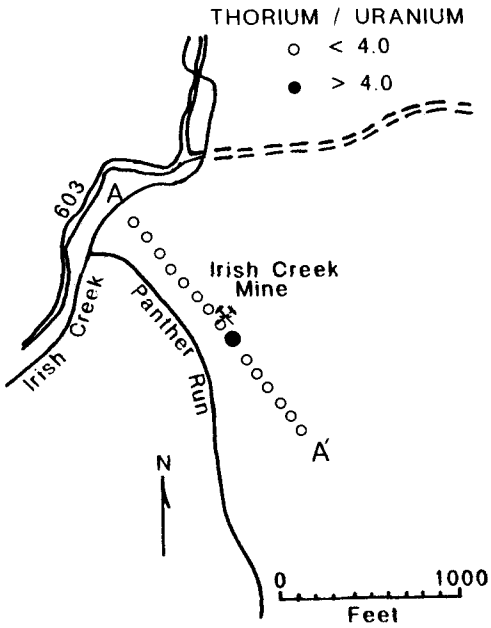


Figure 12. Soil Th/U ratios for the gamma spectrometer traverse across Irish Creek tin mine, #1 working, Montebello 7.5-minute quadrangle, Rockbridge County.

RESULTS OF INVESTIGATION

GEOCHEMICAL SOIL TRAVERSES

A geochemical soil traverse with 100-foot intervals was designed to cross the fluorite-biotite granite on Nettle Mountain (described by Hudson, 1981) and intersect a small greisen and aplite area on Yankee Horse Ridge. The initial reconnaissance soil traverse clearly indicates a tin, lead, and zinc anomaly (Figures 14, 16, 18, and 20). Reference soil traverses were made over mineralized and contaminated soil

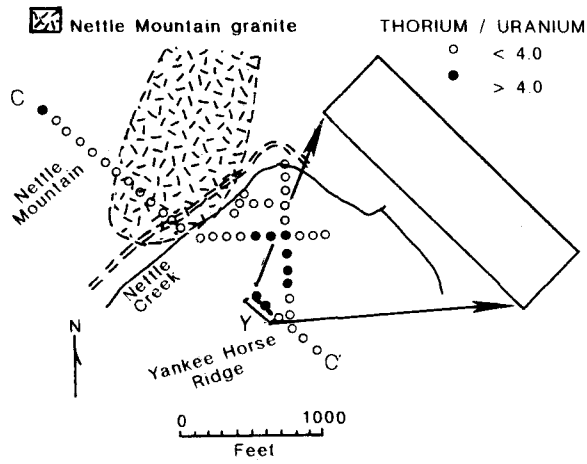


Figure 13. Soil Th/U ratios for the gamma spectrometer traverse across Nettle Mountain and Yankee Horse Ridge, Montebello 7.5-minute quadrangle, Rockbridge County.

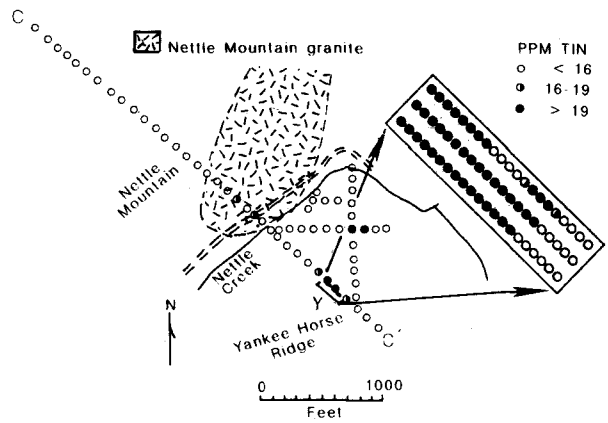


Figure 14. Parts per million tin in soil traverses on Nettle Mountain and Yankee Horse Ridge.

at Irish Creek mine (traverse A-A' in Figures 15, 17, and 19) and apparently uncontaminated and unmineralized soil (traverse B-B', figures 14, 16, and 18). Traverse B-B' is 250 feet northeast of the mine and parallel to the traverse across the mine adits. The values are listed in Appendices VI, VII, VIII, and IX. Background values were computed from geochemical soil values from traverse B. Additional geochemical soil data from the literature helpful for establishing or evaluating anomalies for tin, lead, and zinc as well as for other metals analyzed in this investigation are given in Appendix V.

A topographic-geochemical profile of the southeast portion of reconnaissance traverse C-C' across Nettle Mountain (Figure 20) shows elevated tin, lead, and zinc values. In the other traverses (Figures 14, 16, and 18) detailed sampling at 10-foot intervals along three, 200-foot sample traverses is indicated within in the large rectangle representing an enlarged view of anomaly Y on Yankee Horse Ridge. Additional short north-south and east-west traverses with 100-foot intervals, D, E, and F have metal values listed in Appendices X, XI, and XII.

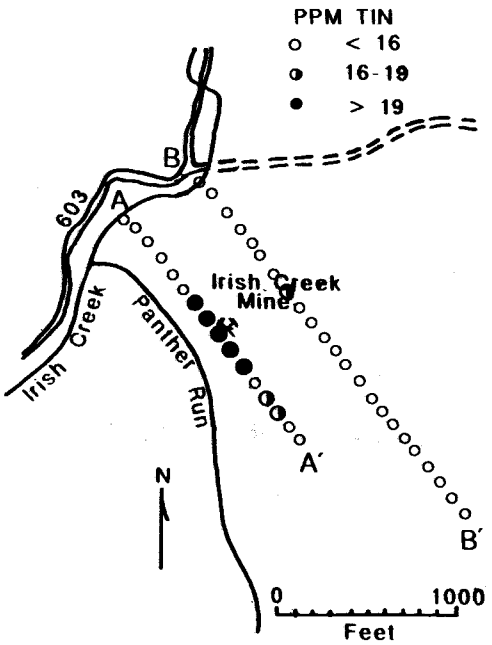


Figure 15. Parts per million tin in soil traverses at and near Irish Creek tin mine, #1 working.

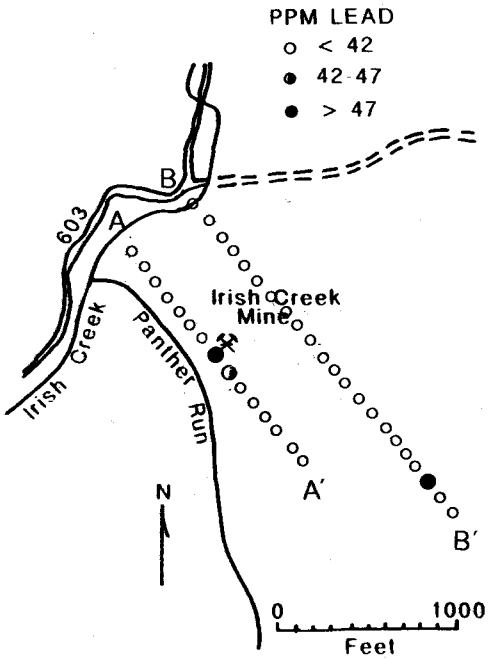


Figure 17. Parts per million lead in soil in the vicinity of the Irish Creek tin mine, #1 working.

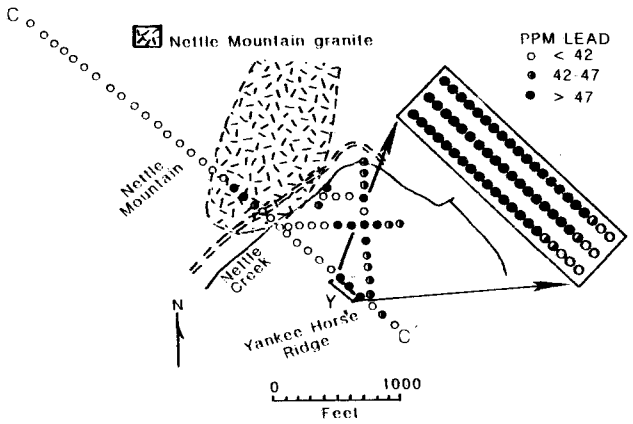


Figure 16. Parts per million lead in soil traverses on Nettle Mountain and Yankee Horse Ridge.

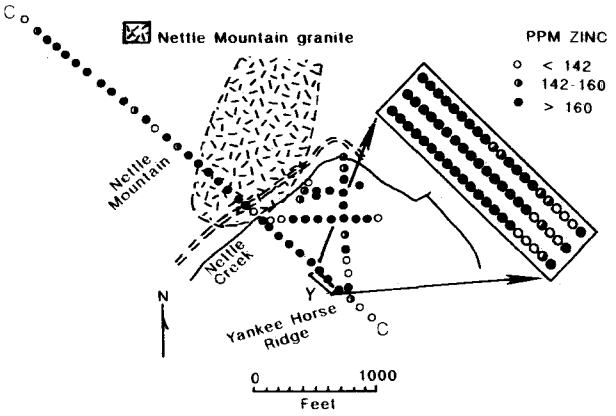


Figure 18. Parts per million zinc in soil traverses on Nettle Mountain and Yankee Horse Ridge.

The Yankee Horse Ridge anomaly shows elevated values of rubidium (Figure 21), arsenic (Figure 23), gold (Figure 25), and silver. A small thorium anomaly with a maximum value of 61 ppm thorium (Figure 13) is also present. Metal values from samples along the traverses are shown in Appendices VIII, IX, X, XI, and XII.

Comparison of the geochemical soil anomalies at Yankee Horse Ridge with the reference traverse A at Irish Creek tin mine show that there are elevated values of tin, lead, beryllium, lithium, zinc, copper, fluorine (Figure 27), rubidium (Figure 22), and silver very close to the mine adits (but not on mine dump soil). No soil samples were taken for gold analysis along the Irish Creek mine traverse. Soil values with elevated beryllium, tin, lead, lithium, zinc, and arsenic were found over the Nettle Mountain granite in traverse C. Some tungsten values (apparently anomalous) are also present (Figures 7, 15, 17, 29, 19, and 24). Traverses showing fluorine, lithium, and copper are shown in Figures 26, 28, and 30 with reference traverses in Figures 26, 28, and 31. In the detailed traverse (10 foot intervals) on Yankee Horse Ridge anomalous iron, manganese, nickel, and cobalt values are also noted associated with a Catoctin greenstone feeder dike.

Both gold and silver are identified in anomalous amounts in the soil at levels indicating the presence of gold mineralization in the bedrock. This non-visible mineralization is confirmed by assays of the bedrock. The initial precious metal anomaly was suggested from the routine use of atomic absorption for silver alone. Silver has been used as a "crude" pathfinder element for precious metals as well as base-metal mineralization. Silver has been demonstrated to be a useful, rapid, and inexpensive discriminator element even when used with routine geochemical analyses with hydrochloric

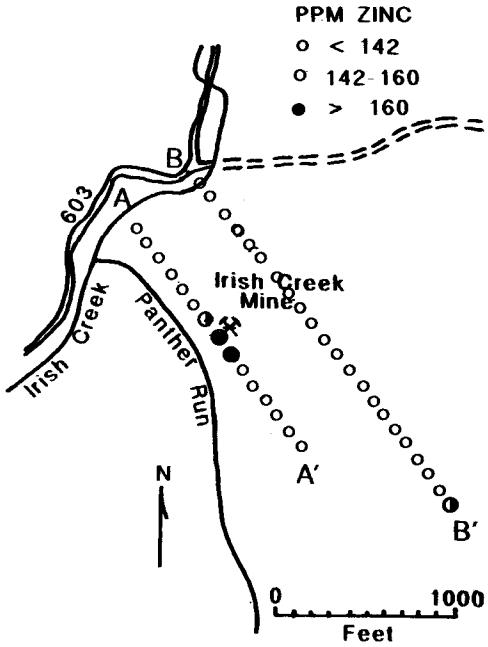


Figure 19. Parts per million zinc in soil in the vicinity of Irish Creek tin mine, #1 working.

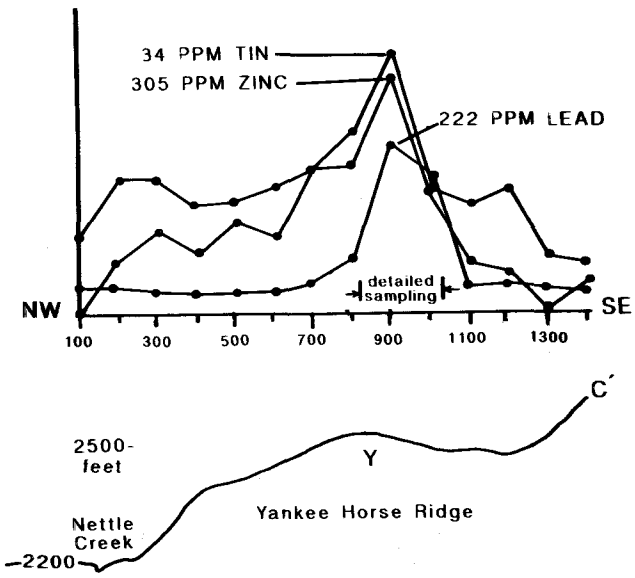


Figure 20. Geochemical soil profile for tin, lead, and zinc southeastern portion of C, location Y (Figure 2A), Yankee Horse Ridge.

acid sample digestion. Enough silver remains in solution even though silver in large amounts is precipitated by chloride, to provide low level silver anomalies with a detection limit of 1 ppm silver.

At Yankee Horse Ridge and Nettle Mountain only two soil samples on traverses C, D, E, and F (Figures 2A, 5) show detectable (more than detection 1 ppm limit) silver. Sample 3-W-1 (traverse F, Appendix I) contains 5 ppm silver. One other sample contains detectable silver (1 ppm) (BL on traverse YC, detailed sampling, Appendix XII). All other

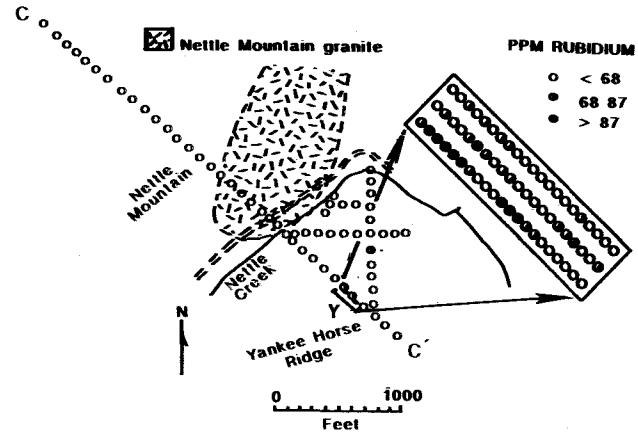


Figure 21. Parts per million rubidium in soil traverses on Nettle Mountain and Yankee Horse Ridge.

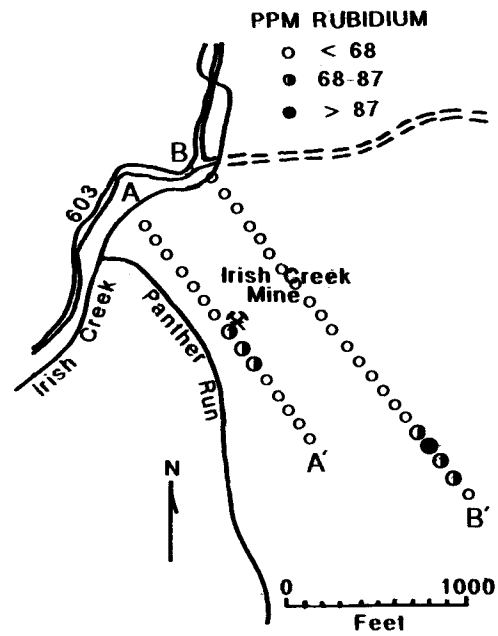


Figure 22. Parts per million rubidium in soil traverses in the vicinity of Irish Creek tin mine, #1 working.

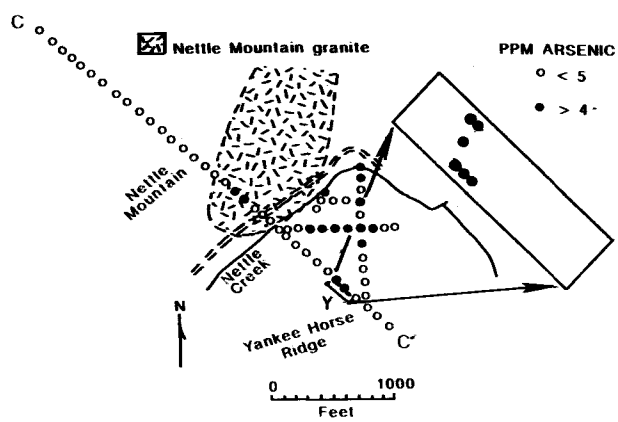


Figure 23. Parts per million arsenic in soil traverses on Nettle Mountain and Yankee Horse Ridge.

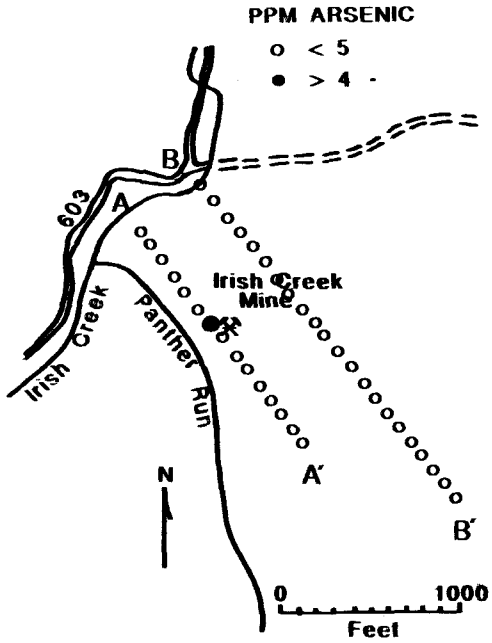


Figure 24. Parts per million arsenic in soil traverses in the vicinity of Irish Creek tin mine, #1 working.

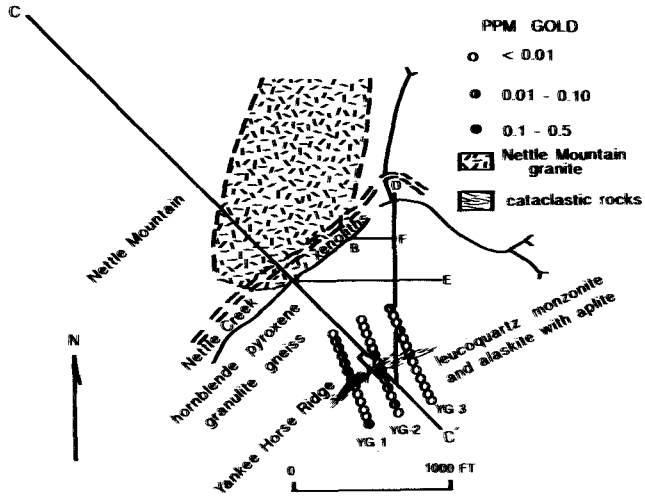


Figure 25. Parts per million gold in soil at tin-lead-zinc geochemical anomaly Y (Figure 2a), location Y (Figure 5), Yankee Horse Ridge.

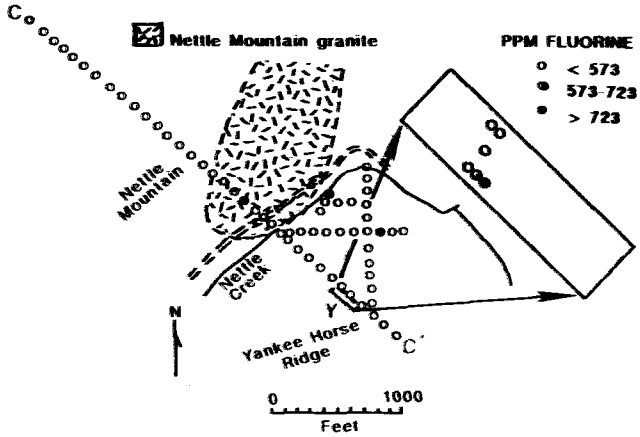


Figure 26. Parts per million fluoride in soil traverses on Nettle Mountain and Yankee Horse Ridge.

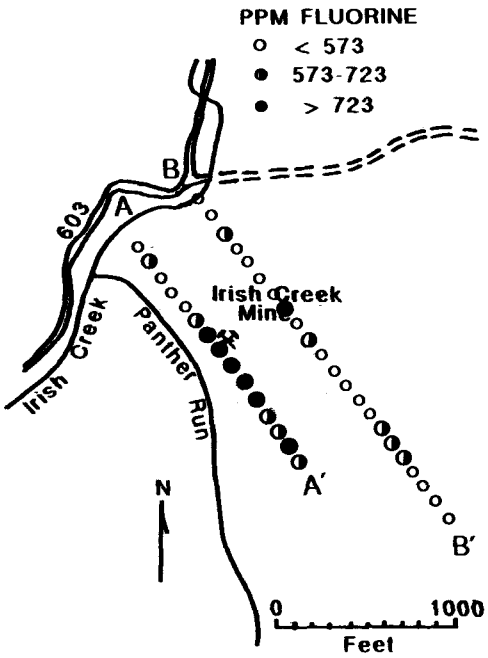


Figure 27. Parts per million fluoride in soil traverses in the vicinity of Irish Creek tin mine, #1 working.

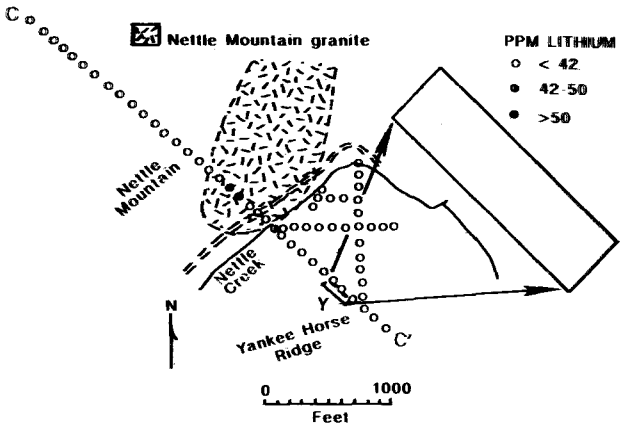


Figure 28. Parts per million lithium in soil traverses in the vicinity of Irish Creek tin mine, #1 working.

routine soil samples contain no detectable silver except two samples on the reference traverse across Irish Creek (traverse A, Appendix VI). These values are 13 and 1 ppm silver at the Irish Creek adit and 100 feet southeast of the adit. It is of interest to note that four soil samples from the Buck Mountain mine (Figure 1), ten miles southwest of the Irish Creek mine, contain from 2 to 5 ppm silver (Appendix III). According to Smith and Carson (1977) the range of silver in unmineralized soils is 0.03 to 0.09 ppm. Even in mineralized soils, silver seldom exceeds 1 ppm, although the humic layers in mineralized areas may in exceptional cases reach levels of 2 to 5 ppm (Shacklette and Boerngen, 1984).

Because of the clearly anomalous silver values in the soil, additional soil samples were taken on a separate grid. These samples were analyzed for gold and silver by fire assay (Figure 25). Three soil samples contained 0.326 ppm, 0.470

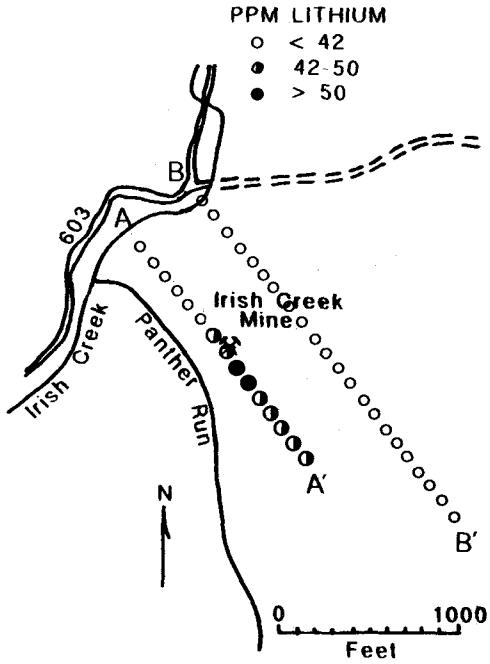


Figure 29. Parts per million lithium in soil traverses on Nettle Mountain and Yankee Horse Ridge.

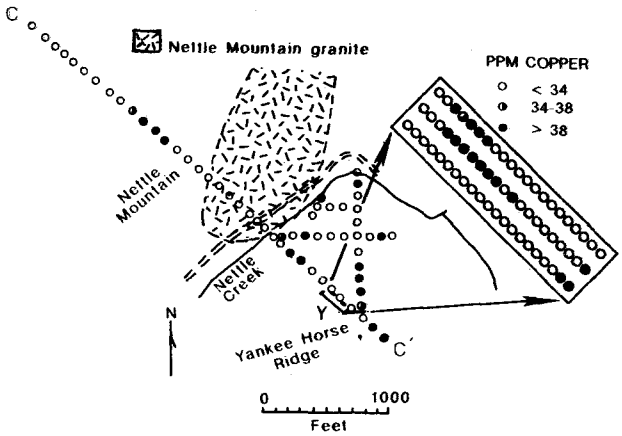


Figure 30. Parts per million copper in soil traverses on Nettle Mountain and Yankee Horse Ridge.

ppm, and 0.512 ppm gold. All of these values unambiguously indicate gold mineralization in underlying or nearby bedrock. Anomalous gold is indicated in 14 out of 39 soil samples using 0.01 ppm as the threshold (Appendix XIII). The results indicate typical patchy anomalous values consistent with gold mineralization elsewhere. In soils over one of the largest gold mines in Virginia's gold/pyrite belt, the Tellurium mine, anomalous soil values range from 0.02 to 0.42 ppm gold with all background samples below 0.02 ppm (Good and others, 1977). In abandoned South Carolina gold mines, Kinkel and LeSure (1968) found soil values to range from 0.02 to 0.52 ppm gold. Rose and others (1979) list 0.002 ppm gold as background for soils and Kabata-Pendias and Pendias (1984) give 0.001 to 0.002 ppm gold as a background range for all unmineralized soils regardless of climate. Lakin and others (1974) studied gold distribution in soil profiles. They show that depending on the origin of the soil and its weathering

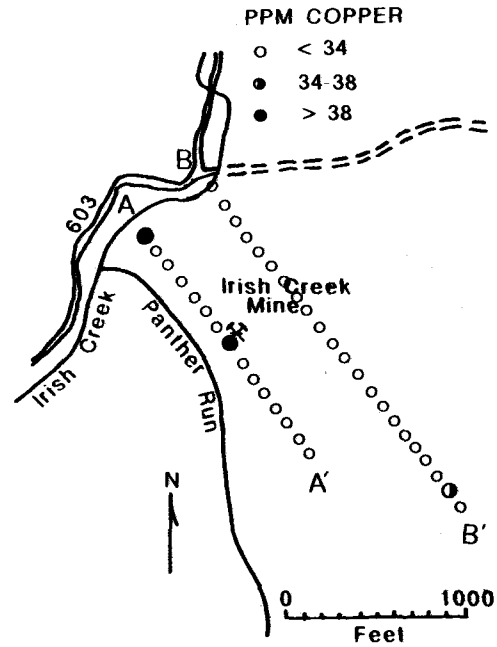


Figure 31. Parts per million copper in soil traverses in the vicinity of Irish Creek tin mine, #1 working.

stage, gold can be present in soil particulates or in cobbles and pebbles. Gold is most often enriched in the humus layers because it can act as a reductant and precipitation medium for mobile forms of gold. In mineralized areas Lakin and others (1974) found forest mull (a special form of humus) to contain 0.05 to 5 ppm gold.

TRENCHING AND DRILLING ON THE YANKEE HORSE RIDGE ANOMALY

The soil anomaly on Yankee Horse Ridge was exposed by trenching. The rocks and soil in the trench revealed massive, sheared, and mylonitized and hydrothermally altered leucocratic, quartz monzonite and alaskite bedrock beneath a shallow soil cover (Figures 5, 20, 29, 32, and 33). In unsheared quartz monzonite the quartz is bluish gray and thin sections indicate that perthitic K-feldspar is abundant. The mylonite is a light gray to greenish gray, schistose, aphanitic rock with 1 to 3 millimeters elongated smoky gray, quartz porphyroclasts. Much of the uncrushed rock shows anastomosing, paper-thin, limonite or hematite-filled fractures in thin section. Mylonitic material contains quartz with mortar texture and Boehm lamellae, as well as sericite and chlorite leaves between the quartz clasts. Unweathered mylonitic bedrock is shown in Figure 32.

A few samples contained visible hematitic vugs with disseminated pyrite. Other rock fragments contained isolated limonitic and hematitic boxworks from 2 to 4 centimeters in diameter. Boxwork casts suggest both tetrahedra and cubes. Several fragments show traces of powdery yellow and yellow-green films. X-ray diffraction indicates jarosite and possibly beudantite, a lead arsenate mineral.

No definite greisen zone could be observed in the excavations. The exposed area indicated sparse, scattered miner-

Figure 32. Freshly bulldozed bedrock at geochemical soil anomaly Y (Figure 2a), location Y (Figure 5), Yankee Horse Ridge, showing sparsely mineralized, sheared leucoquartzmonzonite. Selected loose grab samples showed gold assays up to 0.17 ounces of gold/per short ton.

Figure 33. Freshly bulldozed bedrock at geochemical soil anomaly Y in Figure 2a, location Y (Figure 5), Yankee Horse Ridge, showing sparsely mineralized leucoquartzmonzonite. Selected grab samples showed gold assays up to 0.17 ounces of gold/per short ton but samples were not in place.

alization, not an obvious vein or dike. White aplite with paper-thin, hematite-filled fractures occurs in the vicinity of the geochemical anomaly, away from the area of trenching and about 500 feet down slope to the north of the trenched area.

Three mineralized grab samples were assayed from the trenched geochemical soil anomaly (Figures 20 and 32). The assays show marginal to ore grade values of 0.03, 0.05, and 0.17 ounces/long ton gold (assays 1, 2, and 10; Appendix XIV) and up to 8.72 ounces/long ton silver (assay 1, Appendix XIV). A fourth mineralized bedrock sample from anomaly Y showed 0.002 ounces/long ton gold (assay 12, Appendix XIV).

ORIGIN OF MINERALIZATION AND EXPLORATION TARGETS

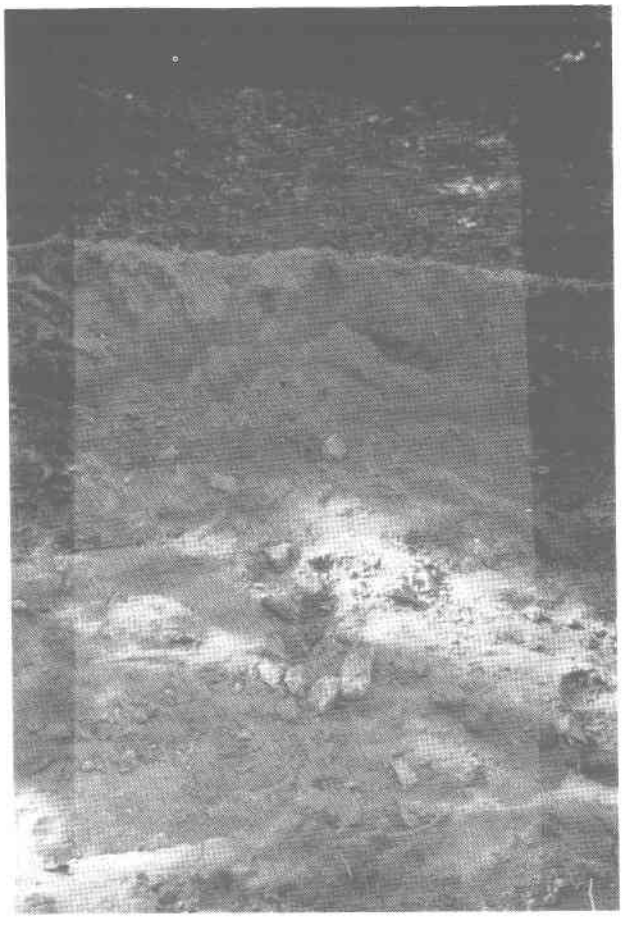
TIN

Current geologic evidence supports the association of tin mineralization with Late Precambrian- to Early Cambrian-age continental margin rifting as discussed earlier. The identification of rift-generated felsic plutons as a potential source for tin and tungsten should focus on any granitoid rock with a specialized chemical signature, especially fluorite-bearing granites with biotite more abundant than muscovite.

Lithochemical or whole-rock chemical signatures of potential mineral-rich granitoid source rocks should show low TiO_2, low total Fe as Fe_2O_3, low MgO, low CaO, high K_2O, and enrichments in rubidium, fluorine, lithium, tin, beryllium, tungsten, and molybdenum with or without elevated values of niobium, tantalum, caesium, uranium the, rare earths, and boron. Specific element values based on a wide variety of mineralized areas of the world are summarized in Column 2 of Table 1. Additionally, element pairs can be used. A specialized signature would show low ratios for K/Rb, Mg/Li, and Ba/Rb.

Hudson (1981) and Rankin (1975, 1976) did not include chemical data for tin, beryllium, or lithium, thus an evaluation of whole rock signature for the Irish Creek area is limited. If possible, chemical analyses in a tin exploration program should include tin, lithium, strontium, barium, selected rare earths, thorium, and uranium. Because of the limitations on chemical data for the Irish Creek area, a Rb/Sr value of greater than 5.0 is tentatively suggested as a simple criterion for identifying a potentially mineralized pluton. The basis for this value is summarized in Figure 8. Where complete chemical data is available, several chemical elements can be combined in a discriminant formula. Govett (1983) found one of the most useful to be: Rb^2 x Li/K x Mg x Sr with resultant discriminant numbers above 500 indicating a pluton with favorable mineralization. This figure was based on computation from known mineralized and apparently barren rocks.

The evaluation of areas containing plutons with a special chemical signature and exploration in areas without chemical analyses for granites, can be focused on areas surrounding stream sediment sample stations with values of more than 6 ppm beryllium. Tin may or may not be anomalous in the sediment depending on the drainage. Values of tin in soil above 20 ppm should be considered an indication of miner-



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GOLD

The origin of the gold in the Blue Ridge province is less clear than for tin. At the Irish Creek mines, gold occurs with arsenopyrite in the tin greisens and quartz veins that are close to a cataclastic zone. The extent of the gold mineralization is unknown. Ten miles southwest of Irish Creek, in rocks similar to those at Irish Creek, gold and silver occur in amounts large enough to have been mined in a small operation at Buck Mountain. The precious metals occur in quartz veins in association with arsenic minerals that are confined to a narrow shear zone. In between these two occurrences, gold was identified at Yankee Horse Ridge in sheared bedrock in a splay from a mylonite zone that is close (800 feet) to the probable tin granite at Nettle Mountain. The Rockfish mylonite zone shown in Figure 1 is believed to be continuous to the southwest and joins with the Fries fault zone. At Brush Creek, Montgomery County, Virginia, gold occurs within mylonitized metavolcanic rocks and metasediments (Pilot gneiss and Little River gneiss) of the Fries fault (Driscoll, 1989). Detailed laboratory examination of Brush Creek samples from within the Fries mylonite zone showed that the gold is epithermal and occurs in irregular and discontinuous quartz veins. The epithermal quartz vein has a distinctly different inclusion signature from, and truncates, mylonitic quartz. Driscoll concluded that the Brush Creek gold deposits were controlled by brittle fracture tectonics and were therefore probably related to a tectonic event sometime after late Mississippian time (latest mylonitization associated with the Fries fault).

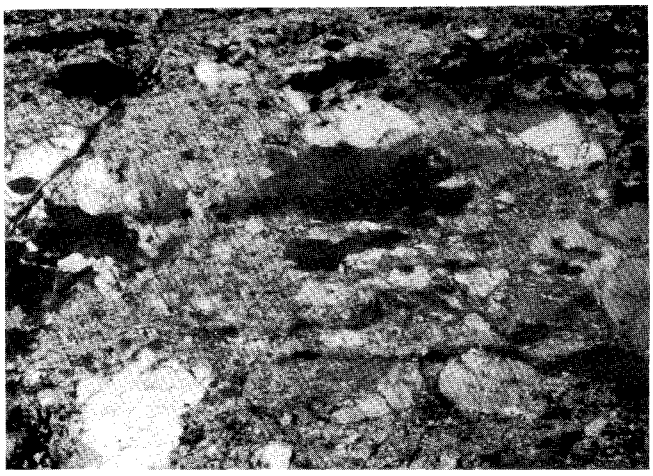

Figure 34. Microphotograph of a sample of cataclastic leucoquartzmonzonite under cross-polarized light at 20x showing hematite-filled fractures with traces of pyrite. From bedrock at anomaly Y (Figure 2A), location G (Figure 5), Yankee Horse Ridge.

At Yankee Horse Ridge the precious metal anomalies are associated with very sparse mineralization within cataclastized, felsic, quartz monzonite (alaskite). Geochemical anomalies are also spatially associated with nearby rhyodacite dikes (Figure 35). The dikes are the aplites of Hudson (1981) who considered them to be peripherally associated with the Nettle Mountain granite which intrudes mafic granulite, not quartz monzonite. The emplacement of Late Precambrian-age felsic plutons like the Nettle Mountain granite is considered to be rift-related and therefore close to subparallel, high-angle rift faults. These rift faults would later be reactivated and become low-angle mylonite zones in Paleozoic time. Any felsic pluton of Crossnore affinity (mantle plume driven) and its associated dike swarms and paleo-hot springs would necessarily be contained in or close to cataclastic zones. It is also possible, but less likely, that metal-rich brines and hot springs were active along the rift fractures themselves without coming from a near surface felsic pluton. The metal-rich brines would later be remobilized during Paleozoic-age cataclastic events. Gold is now known to be much more mobile than previously thought so that caution must be shown in genetic interpretations.

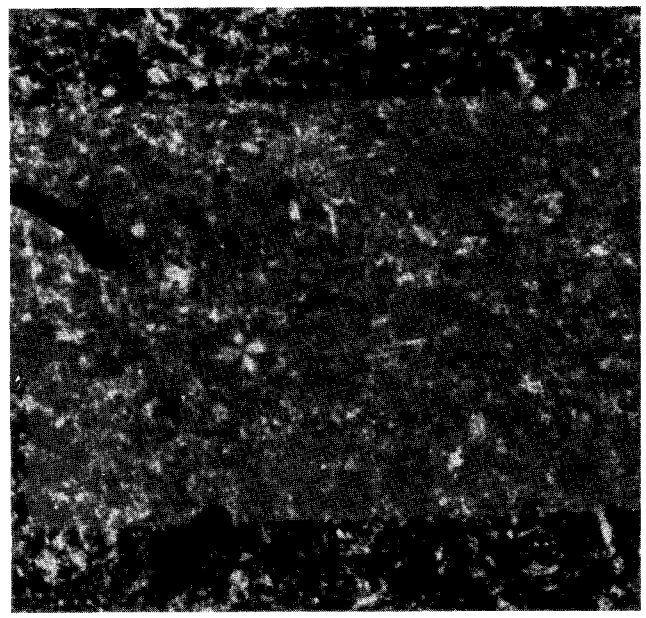

Figure 35. Microphotograph of a sample from the rhyodacite dike under cross-polarized light at 20x showing radiate structure which may be a devitrification spherulite. From felsite outcrop 150 feet from anomaly Y (Figure 2A).

Hudson and Dallmeyer (1982) might be incorrect in their assumption that the date of 634 to 637 m.y. for the mica from Irish Creek greisen is coeval with the Nettle Mountain granite because the Nettle Mountain material was never dated directly and does not occur, or at least has not been observed, at the Irish Creek mines. There may be multiple intrusions of different ages at the Yankee Horse Ridge-Nettle Mountain locality.

During this investigation, the writer noted exposures of a hornblende granite in the stream bed of Nettle Creek between the area mapped as biotite granite and the greisen aplite on Yankee Horse Ridge. The hornblende granite in the Nettle Creek stream bed contains xenoliths, up to three feet in

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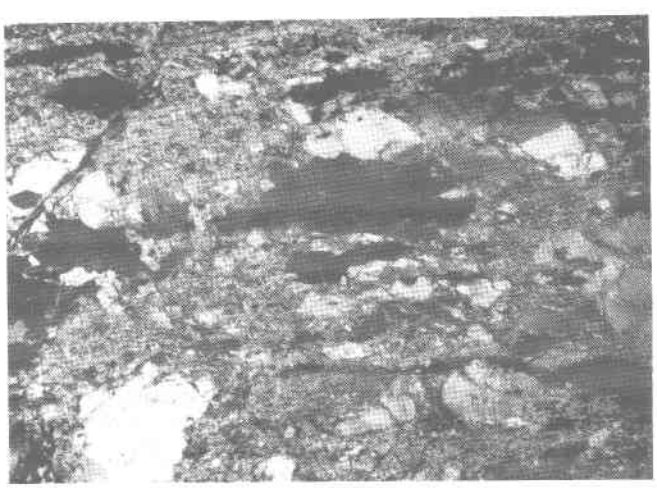

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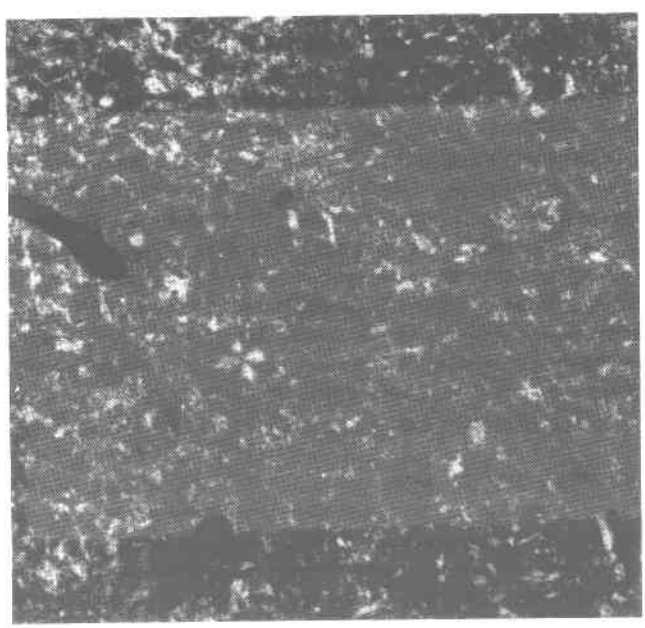

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During this investigation, the writer noted exposures of a hornblende granite in the stream bed of Nettle Creek between the area mapped as biotite granite and the greisen aplite on Yankee Horse Ridge. The hornblende granite in the Nettle Creek stream bed contains xenoliths, up to three feet in

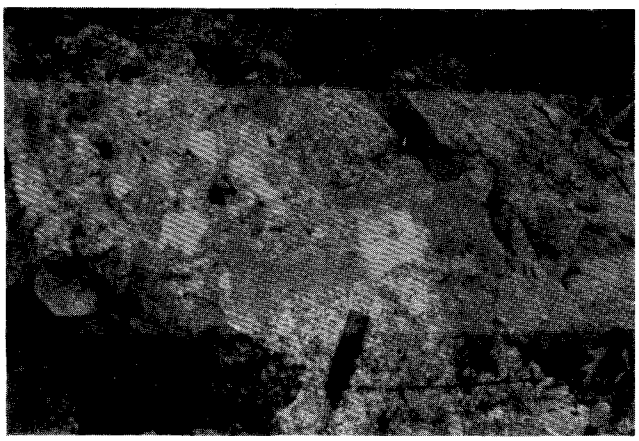

Figure 36. Bedrock in Nettle Creek showing rhyodacite and Catoctin(?) metabasalt xenoliths in hornblende granite, location F, Figure 2A.

Figure 37. Bedrock in Nettle Creek showing Catoctin(?) metabasalt xenoliths in hornblende granite, location F, Fiugre 2A.

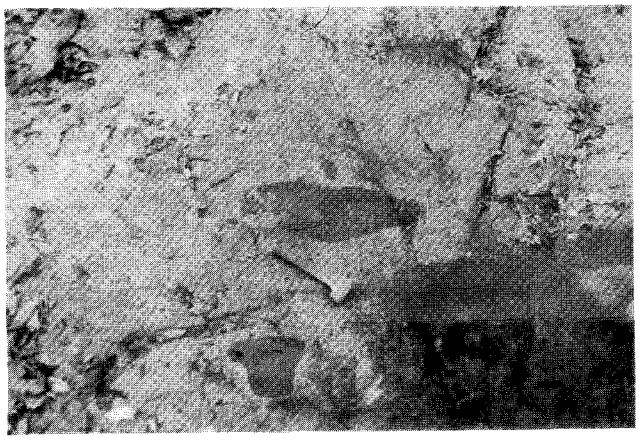

Figure 38. Bedrock in Nettle Creek showing Catoctin(?) metabasalt xenoliths in hornblende granite, location F, Figure 2A.

Figure 39. Bedrock in Nettle Creek showing Catoctin(?) metabasalt xenoliths in hornblende granite.

length, of Catoctin-like greenstone, felsic dike rock, and feldspathic quartzite containing visible, rounded, clasts (Figures 36, 37, 38, and 39). The occurrence of the xenoliths in the hornblende granite at the periphery of the Nettle Mountain granite supports the supposition of multiple intrusions as noted in association with fluorite-biotite granites in Rappahannock County by Lukert and Halladay (1980) and Tollo and Arav (1987). It is possible that the xenolithic granite in Nettle Creek could be Paleozoic in age and not Late Precambrian. It is also possible that the granite is not a xenolithic border facies of different composition than the Nettle Mountain biotite granite. There is also no date on the rhyodacite dikes at Yankee Horse Ridge. The assumption is that the dikes are associated with the Nettle Mountain granite and are Late Precambrian age, but the Nettle Mountain granite has never been directly dated. Similar felsic dikes are known to cut Lynchburg Group rocks.

It is possible that gold might also be associated with Middle Cambrian-, Devonian-, Mississippian-, or even as yet, unrecognized Mesozoic- or Eocene-age hydrothermal events. Without more data, the writer prefers a Late Precambrian-age gold-tin event with reactivation.

At the Yankee Horse Ridge gold occurrence, no visible gold has been observed. It is a reasonable assumption that gold probably occurs in association with hematite-filled fractures cutting across mylonitic textures (Figure 34). It is known from other Yankee Horse Ridge samples that pyrite is occasionally preserved as unoxidized cores with limonite or hematite husks as well as in rare boxworks (in a few places). Additionally, typical oxidation minerals from pyrite, like jarosite, have been identified in fresh bedrock at Yankee Horse Ridge. The general association of gold with and in pyrite or arsenopyrite is well known. The time of mineralization however, remains uncertain until gold has been located and identified by microscopic and microprobe examination and additional rock age dating is done.

Blue Ridge province gold is associated with cataclastic zones. Elevated thorium, uranium, and potassium values are also associated with limited sections of a few cataclastic zones. High radioactivity might also be associated with tin and gold mineralization as well as pegmatoid zones. Further

Figure 36. Bedrock in Nettle Creek showing rhyodacite and Catoctin(?) metabasalt xenoliths in hornblende granite, location F, Figure 2A.

Figure 37. Bedrock in Nettle Creek showing Catoctin(?) metabasalt xenoliths in hornblende granite, location F, Fiugre 2A.

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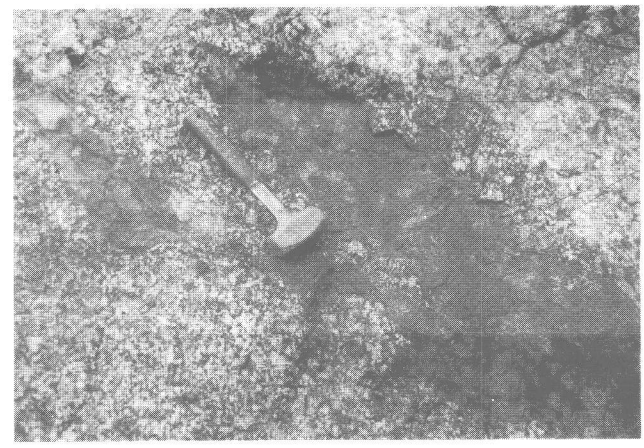

Figure 39. Bedrock in Nettle Creek showing Catoctin(?) metabasalt xenoliths in hornblende granite.

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Blue Ridge province gold is associated with cataclastic zones. Elevated thorium, uranium, and potassium values are also associated with limited sections of a few cataclastic zones. High radioactivity might also be associated with tin and gold mineralization as well as pegmatoid zones. Further

work is needed to establish anomalously high radioactivity as a reliable prospecting technique for other elements besides uranium.

Discrimination of potentially mineralized cataclastic zones can be made by selective geochemical soil traverses across ductile and brittle deformation zones using analyses for gold (0.01 ppm or greater), silver (1 ppm or greater) and arsenic (5 ppm or greater) as guides. Tin values (greater than 20 ppm) in soil may indicate either tin, base metal, or gold mineralization. The base-metal anomalies found in this investigation may indicate a previously unrecognized type of mineralization in Virginia.

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APPENDIX I

Results of the geochemical analysis of soil samples from traverse F, Yankee Horse Ridge
Stations are in hundreds of feet west of a north-south baseline 273 feet on Yankee Horse Ridge south of Nettle Creek (Figure 2a).

STATION	ELEMENTS																				
	Sn	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Th/U**	**K_2O(%)**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
1W	10	3.0	4	55	<1	53	26	210	21	45	172	21	11.2	4.9	2.3	2.7	2.7	156	11	12	10
2W	13	3.2	3	100	<1	69	41	210	17	42	194	19	13.0	4.0	3.2	3.9	2.4	156	9	11	10
3W-1	<4	2.3	600	5495	5	51	19	160	110	132	148	492	10.8	4.8	2.2	4.2	11.8	606	16	31	7
3W-2	8	4.0	4	115	<1	38	12	830	109	47	151	27	38.6	11.3	3.4	4.7	1.4	2837	11	9	10
3W-3	4	2.5	4	60	<1	22	15	240	34	48	108	13	10.0	3.1	3.2	3.9	1.9	1100	9	9	10

Samples 3W-1, 3W-2, and 3W-3 are near site B, on the east bank of Nettle Creek, near a boulder of pyrrhotite and fluorite and a cliff face with a slight show of chalcopyrite, pyrite, and arsenopyrite mineralization.

3W-1: soil beneath rock rubble by pyrrhotite boulder

3W-2: organic material at base of tree, 15 feet downstream from pyrrhotite boulder

3W-3: sandy bank soil 25 feet downstream from pyrrhotite boulder and 5-10 feet above creek level at low-water level

APPENDIX II

Gold and silver assays of vein material from the Buck Mountain gold mine, Amherst County.

	Au		Ag	
	oz/short ton	Parts per million	oz/short ton	Parts per million
1.	0.070	2.40	5.4	185.14
2.	0.006	0.21	1.82	62.40
3.	1.31	44.91	3.88	133.03
4.	0.04	1.37	5.20	178.28

Assays 1, 2, and 3 done for the Virginia Division of Mineral Resources by Barringer Resources Laboratory, Sparks, Nevada and by Iron King Assay, Inc., Humboldt, Arizona; assay 4 done by North American Exploration, Charlottesville, Virginia by Blue Ridge Analytical Laboratory, Charlottesville.

APPENDIX III

Results of the geochemical analysis of soil samples from the Buck Mountain gold mine Amherst County, data by R.S. Good

	BM-1	BM-2	BM-3	BM-4
ppm Ag	2	1	4	5
ppm Sn	58	20	149	416
ppm F	495	310	495	1,195
ppm As	2000	700	1500	12,500
ppm Be	3.4	2.9	4.7	6.1
ppm Pb	72	118	400	607
ppm Zn	119	189	161	161
ppm Cu	37	26	108	109
ppm Ba	130	160	230	160
ppm Rb	40	31	23	38
ppm Li	43	30	18	32
% Fe	4.35	3.32	3.74	4.85
ppm Mn	277	475	553	562
ppm Ni	12	12	6	7
ppm Co	11	11	15	16
ppm Cr	15	14	7	9

BM-1: residual soil above entrance to adit
BM-2: soil near entrance to adit
BM-3: soil on leveled area in front of adit
BM-4: soil 20 feet downslope from adit

Gamma spectrometer stations:

BMR-1: 100 feet northwest of Buck Mountain mine adit
BMR-2: 25 feet northwest of adit
BMR-3: entrance to adit
BMR-4: 30 feet inside adit at rock face
BMR-5: 100 feet southeast of adit entrance
BMR-6: 100 feet southeast of adit

	BMR-1	BMR-2	BMR-3	BMR-4	BMR-5	BMR-6
ppm Th	10.6	7.8	7.4	4.7	7.6	13.9
ppm U	2.8	8.9	4.9	3.8	5.0	3.2
Th/U	3.8	0.9	1.5	1.2	1.5	4.3

APPENDIX IV

Whole-rock Rb/Sr values in granitoid plutons and dikes
The reference number is the point plotted on the graph in Figure 8.

1. Rb/Sr = 0.12 Turkey Mountain pluton, central Blue Ridge province of Virginia; massive charnockite and quartz mangerite and host rock for Mobley Mountain fluorite-biotite granite; age uncertain, probably Grenville; apparently barren; two analyses (Brock, 1981; Brock and others, 1987).

2. Rb/Sr = 0.17 Alkali granites, five plutons from Charlotte belt of western North Carolina piedmont; coarse grained, discordant, minor biotite; age about 300 m.y.; barren (Sando, 1979; Rogers and Greenberg, 1981)

3. Rb/Sr = 0.38 Mobley Mountain leucocratic dikes, central Blue Ridge province of Virginia; average of 5 analyses; barren (Brock, 1981; Brock and others, 1987).

4. Rb/Sr = 0.39 Porphyritic quartz monzonite (adamellite), Irish Creek tin area; proximal to Nettle Mountain "tin granite," age uncertain, may be Grenville; barren; average of 3 analyses (Hudson, 1981).

5. Rb/Sr = 0.59 Mobley Mountain fluorite-biotite granite, 14.3 miles southeast of Nettle Mountain granite (Irish Creek tin granite ?), central Blue Ridge province of Virginia; arithmetic mean of 14 analyses (Brock, 1981; Brock and others, 1987).

6. Rb/Sr = 0.60 Shaeffer Hollow leucocratic granite in contact with Mobley Mountain granite, central Blue Ridge Mountains or province of Virginia; barren; (Brock, 1981; Brock and others, 1987).

7. Rb/Sr = 1.44 High potassium alkali granite, New Mexico; barren; age approximately 1400 m.y.; average of 15 analyses (Condie, 1978; Condie and Buddington, 1979; Rogers and Greenberg, 1981, p. 62).

8. Rb/Sr = 1.5 Saint George granite, New Brunswick, Canada; vicinity of tin bearing plutons; barren of all mineralization (Dagger, 1972; Govett, 1983).

9. Rb/Sr = 2.24 Biotite granite, Halifax pluton Nova Scotia; barren (reference in Govett, 1983).

10. Rb/Sr = 2.76 Average from abundance data for granites of all kinds (Turekian, 1977); earlier publication (Turekian and Wedepohl, 1961) indicates Rb/Sr is 0.25 in high-calcium granitic rocks and 1.70 in low-calcium granitic rocks.

11. Rb/Sr = 3.09 Biotite granite, West Dalhousie pluton, Nova Scotia, Canada; barren (Govett, 1983).

12. Rb/Sr = 4.9 Porphyritic biotite granite-adamellite, Anchor mine, Tasmania, Australia; average of 6 analyses; barren country-rock pluton (Groves, 1972).

13. Rb/Sr = 5.0 Carnmenellis-adamellite tin granite, Cornwall tin district, SW England; 1 sample (Butler, 1953; Govett, 1983).

14. Rb/Sr = 5.05 Nettle Mountain fluorite-biotite granite, 3 miles from Irish Creek tin mine, central Blue Ridge Mountains or province of Virginia; average of 3 analyses ranging from 3.61 to 7.48 (Hudson, 1981).

15. Rb/Sr = 7.45 Barren hornblende granite; Nigerian tin district (Olade, 1980).

16. Rb/Sr = 8.6 St. Austell biotite-muscovite tin granite, Cornwall district, SW England; 1 analysis (Exley, 1958; Govett, 1983).

17. Rb/Sr = 8.74 Yankee Horse Ridge greisen, central Blue Ridge Mountains or province of Virginia; 1 sample (Hudson, 1981).

18. Rb/Sr = 9.1 Finlayson tin granite, Queensland, Australia; economic mineralization; average of 6 analyses (Sheraton and Black, 1973 *in* Govett, 1983).

19. Rb/Sr = 10.0 Alaskite, Halifax pluton, Nova Scotia, Canada; barren (Smith and Turek, 1976; Govett, 1983).

20. Rb/Sr = 14.9 New Ross pluton, alaskite and leucogranite, Nova Scotia, Canada (Smith and Turek, 1976; Govett, 1983).

21. Rb/Sr = 16.0 Elizabeth Creek granite, Queensland, Australia; Sn, Mo, W, Pb, Cu, and minor Au, Bi, Ag, and Sb mineralization (Sheraton and Black, 1973 in Govett, 1983).

22. Rb/Sr = 16.9 Porphyritic lithium-mica granite, St. Austell, Cornwall tin district, SW England; mineralized (Exley, 1958; Govett, 1983).

23. Rb/Sr = 21.5 Barren granite from Jurassic ring complex, Nigerian tin district; average of 73 samples (Olade, 1980).

24. Rb/Sr = 29.9 Biotite granite, New Ross pluton, Nova Scotia, Canada; mineralized (Smith and Turek, 1976; Govett, 1983).

25. Rb/Sr = 57.1 Mt. Pleasant mine, granite porphyry, New Brunswick, Canada; W, Mo, Bi, and Sn mineralization (Dagger, 1972; Govett, 1983).

26. Rb/Sr = 93 Mineralized tin granite, Jurassic ring complex, Nigeria; average of 73 samples (Olade, 1980).

27. Rb/Sr = 140 Granite with other mineralization, Nigeria (Olade, 1980).

28. Rb/Sr = 207 Biotite-muscovite granite, Anchor mine, Tasmania, Australia (Groves, 1972).

APPENDIX V

Background and anomaly statistics for soil geochemistry

Background statistics are based on 22 soil samples taken along traverse B 250 feet NE of, and parallel to, the NW-SE trending traverse A across Irish Creek mine adit #1 on Panther Creek.

Tin	ppm
Background soil value, this study, arithmetic mean	6.2
Background standard deviation, this study	4.1
Mean plus one standard deviation	10.3
Mean plus two standard deviations	14.4
Mean plus two-and-one-half standard deviations	16.4
Mean plus three standard deviations	18.6
Background values from literature	
Soil, average (Rose and others, 1979)	10.0
Soil over granite and gneiss, mean (Shacklette and Boerngen, 1984)	1.2
Standard soil, England, mean (Ure and Bacon, 1978)	4.5
Unmineralized soil, Bathurst tin district, Canada range (Presant, 1971)	1.1-4.6
Unmineralized soil, range (Chapman, 1972)	1-11
Threshold soil value, in this study	16
Anomalous soil value, in this study	20

Tungsten	ppm
Background soil value, this study, arithmetic mean	2.36
Background standard deviation, this study	2.87
Mean plus one standard deviation	5.23
Mean plus two standard deviations	8.1
Mean plus three standard deviations	10.97
Background value from literature	
Soil, average (Brooks, 1972)	1
Two soils from the United States, mean (Furr and others, 1980)	1.2, 2.5

Beryllium	ppm
Background soil value, this study, arithmetic mean	2.8
Background standard deviation, this study	1.1
Mean plus one standard deviation	3.9
Mean plus two standard deviations	5.0
Mean plus two-and-one-half standard deviations	5.5
Mean plus three standard deviations	6.1
Background values from literature	
Soil over granite and gneiss, range (Shacklette and Boerngen, 1984)	1-2
Soil over granite and gneiss, mean (Shacklette and Boerngen, 1984)	1.6
Unmineralized soil near beryl pegmatite in Rhodesia and Uganda, range (Debnam and Webb, 1960)	0.5-4
Threshold soil value, this study	4
Anomalous soil value, this study	5

Arsenic	ppm
Background soil value, this study, arithmetic mean	<1
Background standard deviation, this study	<1
Mean plus one standard deviation	-
Mean plus two standard deviations	-
Mean plus three standard deviations	-
Background values from literature	
Surface soil over granite and gneiss in the United States, mean (Shacklette and Boerngen, 1984)	3.6
Surface soil over granite and gneiss in the United States, range (Shacklette and Boerngen, 1984)	0.7-15
Surface soil, uncultivated, median (Connor and Shacklette, 1975)	7.5
Normal (unmineralized) soil, worldwide, 327 localities, range (Boyle and Jonasson, 1973)	0.1-55
Soil and till near an arseniferous deposit, 193 samples, worldwide, range (Boyle and Jonasson, 1973)	2-8000
Arsenic content of granite and aplite, 116 samples, worldwide, range (Boyle and Jonasson, 1973)	0.18-15
Threshold soil value, this study	4
Anomalous soil value, this study	5

Fluorine	ppm
Background soil value, this study, arithmetic mean	422
Background standard deviation, this study	150
Mean plus one standard deviation	573
Mean plus two standard deviations	724
Mean plus two-and-one-half standard deviations	800
Mean plus three standard deviations	875
Background values from literature	
Soil, median value (Connor and Shacklette,1975)	300
Soil over granite and gneiss, range (Shacklette and Boerngen, 1984)	20-540
Threshold soil value, this study	724

Rubidium	ppm
Background soil value, this study, arithmetic mean	49.7
Background standard deviation, this study	18.6
Mean plus one standard deviation	68.3
Mean plus two standard deviations	86.9
Mean plus two-and-one-half standard deviations	96.2
Mean plus three standard deviations	105.5
Background values from literature	

Soil, uncultivated, median (Connor and Shacklette, 1975)	35
Soil over granite and gneiss, range (Shacklette and Boerngen, 1984)	<20-210
Threshold soil value, this study	68
Anomalous soil value, this study	87

Lithium	ppm
Background soil value, this study, arithmetic mean	27.1
Background standard deviation, this study	7.5
Mean plus one standard deviation	34.6
Mean plus two standard deviations	42.1
Mean plus two-and-one-half standard deviations	45.9
Mean plus three standard deviations	49.6
Background values from literature	
Uncultivated soil, median (Connor and Shacklette, 1975)	22
Soil over granite and gneiss in the United States, mean (Shacklette and Boerngen, 1984)	23.5
Range in soil over granite and gneiss Shacklette and Boerngen, 1984	10-45
Threshold soil value, this study	42
Anomalous soil value, this study	50

Lead	ppm
Background soil value, this study, arithmetic mean	31.6
Background standard deviation, this study	5.1
Mean plus one standard deviation	36.7
Mean plus two standard deviations	41.7
Mean plus two-and-one-half standard deviations	44.3
Mean plus three standard deviations	46.8
Background values from literature	
Uncultivated soil, median (Connor and Shacklette, 1975)	17
Surface soil over granite and gneiss in the United States, mean (Shacklette and Boerngen, 1984)	21
Surface soil over granite and gneiss, range Shacklette and Boerngen, 1984	10-50
Threshold soil value, this study	42
Anomalous soil value, this study	47

Zinc	ppm
Background soil value, this study, arithmetic mean	104.9
Background standard deviation, this study	18.5
Mean plus one standard deviation	123.4
Mean plus two standard deviations	141.9
Mean plus two-and-one-half standard deviations	151.2
Mean plus three standard deviations	160.4
Background values from literature	
Uncultivated soil, median (Connor and Shacklette, 1975)	36
Surface soil over granite and gneiss in the United States, mean (Shacklette and Boerngen, 1984)	73.5
Surface soil over granite and gneiss, range (Shacklette and Boerngen, 1984)	30-125
Threshold soil value, this study	142
Anomalous soil value, this study	160

Copper	ppm
Background soil value, this study, arithmetic mean	14.8
Background standard deviation, this study	7.6
Mean plus one standard deviation	22.4
Mean plus two standard deviations	30.0
Mean plus two-and-one-half standard deviations	33.8
Mean plus three standard deviations	37.6

Background soil values from literature	
Uncultivated soil, median (Connor and Shacklette, 1975)	15
Surface soil over granite and gneiss, mean (Shacklette and Boerngen, 1984)	24
Surface soil over granite and gneiss, range (Shacklette and Boerngen, 1984)	7-70
Threshold soil value, this study	34
Anomalous soil value, this study	38

APPENDIX VI

Results of the geochemical analysis of soil samples from the Irish Creek tin mine, reference traverse A
All values are in parts per million except Fe
Stations are in hundreds of feet from adit

STATION	ELEMENTS																				
	Sn	**W**	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Th/U**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
NW 6.9	<4	<1	2.3	2	340	<1	19	31	110	30	20	102	44	8.1	6.8	1.2	4.6	447	56	23	101
NW 6	8	<1	3.3	2	580	<1	22	27	110	88	30	126	14	7.4	3.3	2.2	4.4	123	16	14	23
NW 5	5	<1	3.8	1	500	<1	34	28	250	118	27	141	15	8.9	3.5	2.5	4.5	155	17	17	18
NW 4	4	<1	3.5	2	440	<1	38	31	240	71	26	107	17	8.8	4.1	2.1	4.8	142	24	25	30
NW 3	8	1	3.3	1	640	<1	40	30	190	87	23	103	19	9.5	4.8	2.0	4.1	139	23	20	32
NW 2	20	2	3.7	1	620	<1	41	31	250	84	28	102	10	10.1	4.2	2.4	4.1	126	14	15	16
NW 1	25	3	4.1	5	740	<1	66	43	410	109	33	143	20	7.2	3.3	2.2	4.0	148	12	16	17
ADIT 0	371	760	5.8	1	2080	13	71	48	380	95	339	869	55	6.5	4.1	1.6	4.9	2354	15	28	16
SE 1	24	6	5.0	2	840	1	75	57	180	58	44	194	20	13.4	3.3	4.1	4.0	162	18	15	19
SE 2	21	3	5.1	2	780	<1	73	51	290	91	26	140	18	9.0	4.6	2.0	4.9	175	17	19	21
SE 3	14	5	5.1	3	740	<1	60	47	170	51	25	111	16	8.8	4.2	2.1	4.3	140	17	20	19
SE 4	13	5	5.3	2	720	<1	67	48	180	66	30	116	14	7.3	4.1	1.8	4.3	160	18	21	17
SE 5	16	6	4.5	2	680	<1	65	49	200	55	27	114	14	10.2	3.5	2.9	4.7	128	22	27	23
SE 6	17	6	4.3	<1	740	<1	60	48	230	69	30	121	19	8.4	6.0	1.4	4.7	148	19	20	23
SE 7	8	5	5.2	<1	640	<1	56	48	290	68	31	115	19	8.2	7.0	1.7	4.7	143	30	19	34

APPENDIX VII

Results of the geochemical analysis of soil samples from the Irish Creek tin mine, reference traverse B
250 feet NE and parallel to traverse A
All values are in parts per million except Fe
Stations are in hundreds of feet southeast of Irish Creek

STATION	ELEMENT																			
	Sn	**W**	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
SE 0	6	2	3.0	1	340	<1	28	27	190	50	28	81	10	-	-	3.4	127	10	10	13
SE 1	9	<1	3.7	<1	460	<1	34	31	190	48	26	97	15	-	-	3.3	385	17	15	20
SE 2	11	2	3.1	<1	580	<1	47	35	210	42	32	108	22	-	-	3.5	327	22	15	32
SE 3	6	2	4.2	<1	360	<1	44	24	370	56	27	118	14	-	-	3.3	857	17	14	17
SE 4	4	<1	3.4	<1	420	<1	32	24	280	44	29	111	14	-	-	4.0	520	19	19	30
SE 5	<4	<1	3.7	<1	440	<1	27	22	230	51	31	112	13	-	-	3.5	383	16	15	18
SE 6	11	2	3.2	<1	360	<1	36	32	370	70	28	112	26	-	-	3.7	201	12	16	11
SE 7	17	6	3.2	<1	740	<1	54	35	330	48	31	110	22	-	-	4.0	270	25	22	23
SE 8	8	2	3.9	<1	420	<1	44	26	270	44	33	124	13	-	-	3.5	677	19	27	18
SE 9	13	3	4.5	<1	640	<1	52	34	370	62	25	121	14	-	-	3.9	846	11	23	13
SE 10	8	3	3.3	<1	400	<1	49	32	250	35	26	115	14	-	-	3.5	1502	18	20	15
SE 11	5	<1	3.2	<1	460	<1	45	33	260	42	31	126	13	-	-	3.5	744	14	16	15
SE 12	5	2	2.6	<1	420	<1	34	37	270	54	31	129	11	-	-	3.4	712	16	15	16
SE 13	<4	2	2.4	<1	460	<1	39	28	280	64	31	110	10	-	-	3.6	387	12	15	14
SE 14	6	5	2.5	<1	420	<1	33	26	230	55	33	93	13	-	-	3.5	349	11	15	16
SE 15	6	8	2.7	<1	620	<1	42	29	330	97	37	131	14	-	-	3.7	614	13	22	14
SE 16	8	11	3.5	<1	560	<1	60	37	320	84	36	121	23	-	-	4.3	931	22	20	27
SE 17	<4	2	2.3	<1	580	<1	85	25	290	28	36	107	18	-	-	3.3	555	20	16	21
SE 18	<4	<1	1.0	<1	260	1	88	19	162	7	33	73	5	-	-	1.8	345	11	6	11
SE 19	<4	<1	1.0	<1	260	<1	80	14	150	6	49	101	4	-	-	2.2	257	8	5	5
SE 20	<4	<1	0.5	1	260	<1	77	12	110	4	31	66	36	-	-	1.7	148	20	5	6
SE 21	<4	<1	1.0	<1	320	<1	64	13	80	3	31	73	2	-	-	1.6	118	5	5	5

APPENDIX VIII

Results of the geochemical analysis of soil samples from reconnaissance traverse C, Nettle Mountain section
Stations are in hundreds of feet NW from logging road
at the base of Nettle Mountain (Figure 2a)
All values are parts per million except Fe.

STATIONS	ELEMENTS																				
	Sn	**W**	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Th/U**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
NW 0	19	2	5.7	4	360	<1	33	30	130	21	40	189	19	17.9	8.3	2.2	2.1	797	9	11	7
NW 1	11	3	6.5	3	380	<1	35	34	90	20	43	212	25	15.6	8.0	2.0	3.1	354	12	12	10
NW 2	16	5	14.5	16	580	<1	43	61	160	42	85	250	13	13.5	8.0	1.7	2.3	283	8	6	10
NW 3	6	2	10.4	8	340	<1	34	67	300	66	48	306	25	7.4	3.5	2.1	3.0	1387	12	13	12
NW 4	5	2	14.5	2	280	<1	54	34	370	50	32	228	21	10.8	3.4	3.2	2.9	1964	14	21	10
NW 5	4	2	10.9	2	280	<1	42	27	390	48	31	172	28	9.2	3.6	2.6	2.7	3007	13	20	10
NW 6	4	3	8.3	<1	340	<1	38	25	200	20	30	167	18	9.6	7.8	1.2	2.5	1350	11	17	10
NW 7	5	4	3.8	<1	560	<1	35	28	160	36	29	150	22	7.5	8.6	0.9	2.5	597	10	14	9
NW 8	<4	4	6.4	1	380	<1	42	32	240	45	27	198	33	10.3	4.6	2.2	3.2	953	15	24	12
NW 9	4	3	3.0	<1	420	<1	40	32	130	38	19	137	61	10.4	3.7	2.8	4.1	413	15	20	12
NW 10	4	3	4.4	<1	340	<1	24	28	220	37	19	160	66	8.6	5.0	1.7	3.9	1107	18	26	9
NW 11	7	4	3.2	<1	280	<1	22	26	150	31	17	146	98	10.7	2.5	4.3	4.6	500	20	24	13
NW 12	8	9	4.0	<1	380	<1	52	31	140	39	21	161	36	-	-	-	3.0	181	8	10	7
NW 13	10	2	10.6	<1	280	<1	46	20	270	46	27	209	14	-	-	-	2.4	1010	10	17	8
NW 14	6	2	5.3	1	300	<1	53	31	310	107	28	222	34	-	-	-	4.7	306	13	17	16
NW 15	8	3	5.8	2	300	<1	61	32	390	82	34	223	32	-	-	-	4.3	415	10	15	9
NW 16	8	3	7.2	1	220	<1	70	35	540	79	37	179	21	-	-	-	3.6	1525	12	21	11
NW 17	10	3	4.7	1	280	<1	56	29	330	52	39	168	20	-	-	-	3.8	647	11	16	10
NW 18	9	2	3.8	<1	240	<1	52	30	330	61	30	183	23	-	-	-	3.9	592	12	17	11
NW 19	8	2	3.2	3	280	<1	50	35	290	75	35	169	28	-	-	-	4.0	524	13	15	12
NW 20	8	2	2.9	3	200	<1	52	35	290	78	32	157	26	-	-	-	3.8	1251	14	15	13
NW 21	12	6	2.3	2	220	<1	34	27	480	84	28	108	21	-	-	-	4.1	557	9	12	11

APPENDIX IX

Results of the geochemical analysis of soil samples from reconnaissance traverse C, Yankee Horse Ridge section (Figure 2a)
Stations are in hundreds of feet SE of logging road at the base of Nettle Mountain
All values are parts per million except Fe and K_2O

STATION	ELEMENTS																					
	Sn	**W**	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Th/U**	**K_2O(%)**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
SE 1	<4	-	2.1	3	65	<1	35	27	130	34	31	139	8	-	-	-	-	2.7	372	9	7	13
SE 2	7	-	3.8	4	130	<1	41	43	170	44	32	205	35	-	-	-	-	3.5	288	11	14	18
SE 3	11	-	1.9	4	85	<1	41	40	110	28	33	209	51	-	-	-	-	3.6	284	16	12	19
SE 4	8	-	2.3	4	55	<1	41	35	120	20	28	165	39	-	-	-	-	3.3	154	15	12	19
SE 5	12	-	2.6	3	20	<1	59	32	100	21	31	161	15	-	-	-	-	3.0	170	12	12	16
SE 6	10	-	2.6	5	3	<1	56	36	160	38	25	180	11	12.8	4.7	2.7	3.28	2.5	174	12	11	14
SE 7	19	-	3.0	3	115	<1	49	32	160	34	36	228	16	16.4	4.9	3.3	3.10	3.3	306	11	14	10
SE 7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	61.0	7.5	8.1	-	-	-	-	-	-
SE 8	24	-	3.1	4	65	<1	71	35	210	64	72	207	20	32.1	7.0	4.6	2.88	3.1	172	8	12	8
SE 9	34	-	2.4	6	90	<1	79	31	240	37	223	357	31	9.1	4.0	2.3	1.72	2.2	192	6	9	5
SE 10	16	-	1.3	8	65	<1	42	15	90	4	178	186	21	13.8	5.2	2.7	1.90	1.8	113	7	6	6
SE 11	6	-	1.4	4	15	<1	54	20	190	45	31	159	46	15.4	6.1	2.5	3.40	4.2	1435	45	38	39
SE 12	10	-	1.6	5	50	<1	37	19	120	17	46	91	40	15.1	4.9	3.1	4.67	4.0	745	17	23	16
SE 13	<4	-	1.6	2	60	<1	64	21	210	27	27	78	11	13.8	3.8	3.6	4.03	2.2	414	9	11	7
SE 14	4	-	1.9	4	50	<1	68	20	230	16	26	88	18	-	-	-	-	1.8	731	9	10	8

APPENDIX X

Results of the geochemical analysis of soil samples from traverse D, north-south baseline, Yankee Horse Ridge
Stations are in hundreds of feet south of Nettle Creek (Figure 2a, 5).
All values are parts per million except Fe and K_2O

STATION	ELEMENTS																					
	Sn	**W**	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Th/U**	**K_2O(%)**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
OS	14	-	2.8	13	60	<1	36	23	210	40	57	148	18	13.2	3.9	3.4	4.5	2.8	556	9	12	9
1S	12	-	1.5	5	80	<1	35	25	140	17	45	155	57	16.9	5.3	3.2	2.6	2.6	162	10	10	13
2S	4	-	4.3	3	60	<1	42	29	280	34	70	189	33	8.7	3.1	2.8	3.8	2.8	556	15	15	11
3S	16	-	5.0	5	170	<1	44	31	290	69	110	327	34	8.6	3.7	2.3	2.7	4.2	226	10	9	9
4S	15	-	3.1	4	110	<1	63	30	260	28	72	200	20	14.7	5.9	2.5	2.5	2.7	384	13	13	17
5S	23	-	2.2	10	290	<1	53	22	160	8	104	153	19	32.8	6.0	5.5	3.2	1.6	166	5	5	7
6S	7	-	1.0	7	150	<1	21	9	60	7	139	77	19	18.6	3.0	6.0	3.5	1.7	82	3	5	6
7S	12	-	1.3	3	65	<1	71	18	130	12	67	124	12	44.7	7.4	6.0	3.0	1.8	164	6	5	4
8S	18	-	1.9	3	125	<1	62	23	130	22	92	220	42	17.4	4.0	4.3	2.4	3.6	269	12	12	9
9S	5	-	2.1	3	60	<1	-	16	170	23	62	143	41	-	-	-	-	-	-	17	24	14
10S	8	-	2.3	4	70	<1	54	14	350	43	42	127	38	-	-	-	-	-	-	36	41	29
11S	32	-	1.4	3	35	<1	48	12	140	8	55	179	27	-	-	-	-	-	-	15	23	11

APPENDIX XI

Results of the geochemical analysis of soil samples from traverse E, east-west baseline, Yankee Horse Ridge
Stations are in hundreds of feet east or west of a north-south baseline from
a station 500 feet south of Nettle Creek (Figures 2a, 5).
All values are parts per million except Fe.

STATIONS	ELEMENTS																				
	Sn	**W**	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Th**	**U**	**Th/U**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
6W	7	-	2.6	4	90	<1	46	39	140	30	35	133	59	-	-	-	3.6	177	16	16	17
5W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4W	9	-	4.1	5	75	<1	49	31	210	31	40	258	45	-	-	-	2.7	680	11	14	10
3W	10	-	3.2	6	65	<1	50	32	260	26	29	192	22	-	-	-	2.9	308	15	13	16
2W	12	-	3.4	5	75	<1	59	25	440	30	115	240	21	27.7	5.7	4.9	2.1	3110	12	13	8
1W	14	-	1.7	8	50	<1	55	25	240	29	110	182	20	30.9	6.6	4.7	1.9	405	11	11	11
1E	23	-	2.4	10	545	<1	56	20	220	14	127	130	22	-	-	-	1.9	585	7	8	9
2E	6	-	1.8	5	50	<1	35	11	140	10	42	148	45	-	-	-	5.0	970	15	29	17
3E	12	-	1.6	3	75	<1	38	12	160	10	49	124	27	-	-	-	2.9	598	11	11	8

APPENDIX XII

Results of the geochemical analysis of soil samples for the detailed grid at anomaly Y, Yankee Horse Ridge

All values are in parts per million except Fe.

Detailed geochemical soil traverses with 10-foot sampling intervals for lines 100 feet NW and 100 feet SE of site G (Figures 7 and 8). Site Y is station 900 SE on the Yankee Horse Ridge 100-foot interval reconnaissance traverse. The detailed traverses are: YA, along the original NW-SE traverse, YB, 20 feet SW and parallel to the original line, and YC, 40 feet SW and parallel to the original line. Station spacing is in tens of feet (Figures 2a, 5).

STATION	ELEMENTS																
	Sn	**Be**	**As**	**F**	**Ag**	**Rb**	**Li**	**Ba**	**Sr**	**Pb**	**Zn**	**Cu**	**Fe(%)**	**Mn**	**Ni**	**Co**	**Cr**
YA																	
10NW	31	2.7	-	-	-	60	22	170	15	213	269	21	1.9	175	5	6	5
9NW	30	2.4	-	-	-	63	24	170	18	254	308	28	1.9	171	6	7	4
8NW	25	2.6	-	-	-	80	28	180	31	242	376	43	2.4	205	6	8	5
7NW	30	2.8	-	-	-	64	26	230	28	298	373	38	2.0	285	6	7	6
6NW	44	2.6	15	280	<1	77	28	170	15	434	424	56	1.9	224	5	6	5
5NW	44	1.8	20	495	<1	64	20	190	8	457	339	48	1.1	202	3	5	4
4NW	57	2.0	-	-	-	87	25	160	5	409	314	43	1.2	311	2	6	4
3NW	20	1.6	-	-	-	84	25	160	10	188	265	33	1.3	188	6	5	4
2NW	11	1.6	-	-	-	66	20	140	8	124	250	18	1.6	196	6	5	4
1NW	9	1.3	-	-	-	47	17	120	9	124	154	14	1.6	137	6	5	5
BL	15	1.1	-	-	-	36	16	110	5	187	158	13	1.5	196	6	7	5
1SE	15	1.4	-	-	-	54	20	100	7	155	176	19	1.7	132	7	7	6
2SE	18	1.4	-	-	-	58	25	100	10	169	176	15	2.1	147	7	7	11
3SE	36	1.9	-	-	-	62	28	140	9	169	207	18	1.8	193	9	10	10
4SE	28	1.6	-	-	-	57	22	120	8	169	169	22	1.5	100	9	10	7
5SE	28	1.4	-	-	-	48	19	110	6	174	145	25	1.4	200	9	8	6
6SE	18	1.8	-	-	-	70	19	160	10	87	155	16	1.4	150	11	9	6
7SE	8	2.0	-	-	-	64	17	180	11	60	134	10	1.4	286	11	10	7
8SE	<4	1.4	-	-	-	60	16	150	14	48	88	14	2.0	272	14	11	11
9SE	4	0.9	-	-	-	55	19	100	25	35	107	24	3.0	313	17	16	19
10SE	4	3.0	-	-	-	64	22	300	60	42	195	32	3.7	2292	40	40	40
YB																	
10NW	32	2.4	-	-	-	61	24	120	17	250	346	34	1.7	139	4	6	4
9NW	31	2.7	-	-	-	70	24	160	22	262	330	25	1.6	204	5	7	4
8NW	27	2.5	-	-	-	87	25	190	29	223	343	31	1.7	333	7	8	5

	Sn	Be	As	F	Ag	Rb	Li	Ba	Sr	Pb	Zn	Cu	Fe(%)	Mn	Ni	Co	Cr
7NW	25	2.8	-	-	-	86	28	160	35	275	423	50	2.2	212	6	8	5
6NW	23	2.3	-	-	-	73	27	120	17	274	404	75	2.2	218	7	6	6
5NW	41	2.3	8	545	<1	103	31	120	14	315	402	64	1.5	380	3	6	5
4NW	34	2.3	-	-	-	75	27	140	11	275	380	51	1.6	334	7	6	5
3NW	25	2.1	-	-	-	63	27	90	11	306	342	85	1.9	169	4	6	5
2NW	31	0.8	-	-	-	85	31	100	7	297	367	64	1.7	153	7	5	5
1NW	25	1.3	-	-	-	85	29	90	7	286	293	40	1.8	164	6	7	4
BL	23	1.1	-	-	-	48	23	70	5	277	200	32	1.7	129	4	6	5
1SE	20	1.7	-	-	-	60	26	80	8	167	221	24	2.1	143	6	8	9
2SE	30	1.4	-	-	-	56	23	110	10	145	183	18	2.1	124	6	8	13
3SE	34	1.4	-	-	-	43	20	100	7	196	130	21	1.5	131	6	8	8
4SE	28	1.2	-	-	-	67	20	100	7	153	140	25	1.5	108	8	8	6
5SE	25	1.6	-	-	-	73	20	130	9	149	190	20	1.6	174	12	10	7
6SE	15	1.4	-	-	-	70	17	110	8	65	133	14	1.4	131	11	9	6
7SE	6	2.4	-	-	-	78	19	220	30	63	181	12	1.7	543	18	18	9
8SE	ND	2.0	-	-	-	67	18	150	36	44	141	14	2.2	365	22	16	19
9SE	5	1.5	-	-	-	64	21	130	45	36	145	27	3.5	404	33	20	32
10SE	6	2.3	-	-	-	71	28	220	114	29	174	46	5.0	641	62	35	65
YC																	
10NW	34	2.4	-	-	-	80	27	120	21	311	342	29	1.8	192	8	7	7
9NW	35	2.6	-	-	-	99	29	120	23	246	391	40	1.9	199	6	8	6
8NW	32	2.6	-	-	-	93	28	110	16	251	370	42	1.8	198	5	8	5
7NW	32	2.7	-	-	-	97	29	110	13	280	418	55	1.8	182	6	8	6
6NW	31	1.9	-	-	-	89	27	100	9	301	389	58	1.6	219	7	7	4
5NW	35	2.4	-	-	-	96	30	90	9	354	442	75	1.6	246	7	6	5
4NW	36	2.5	18	545	<1	71	27	90	7	463	432	89	1.6	163	6	6	5
3NW	44	2.4	25	595	<1	67	31	110	9	521	410	116	1.7	259	6	8	6
2NW	39	2.2	15	795	<1	65	32	90	11	441	457	124	1.9	160	7	8	5
1NW	28	1.7	-	-	-	62	25	110	8	244	263	51	1.5	269	5	8	6
BL	19	1.7	-	-	1	99	33	100	15	165	280	44	2.1	253	8	8	10
1SE	24	1.6	-	-	-	94	33	110	24	158	283	30	2.7	215	10	10	15
2SE	27	2.1	-	-	-	91	36	140	27	149	283	23	3.2	210	14	12	19
3SE	43	2.0	-	-	-	76	33	120	16	162	293	25	2.6	115	10	9	13
4SE	34	2.0	-	-	-	70	25	120	10	248	207	30	1.8	170	14	15	10
5SE	14	0.8	-	-	-	58	17	70	10	59	213	27	1.8	98	9	8	11
6SE	9	1.8	-	-	-	61	15	100	18	46	134	13	1.8	196	16	14	12
7SE	4	1.9	-	-	-	53	14	110	21	44	148	11	1,9	212	19	16	15
8SE	7	2.2	-	-	-	53	16	140	29	33	144	16	2.5	236	27	24	27
9SE	6	1.8	-	-	-	57	24	130	52	30	166	42	3.9	320	52	26	67
10SE	9	2.2	-	-	-	49	23	130	68	10	161	43	4.2	258	53	29	52

APPENDIX XIII

Results of the geochemical analysis of soil samples for gold, Yankee Horse Ridge

Geochemical soil traverses across Yankee Horse Ridge anomaly. Traverses trend NNW normal to the ENE mylonite trend. Traverses are 600 feet in length. Traverse YG-2 crosses area Y (with detailed soil geochemistry for other metals). Traverse YG-1 is 200 feet WSW of YG-2 and parallel to it and traverse YG-3 is 200 feet ENE and parallel to YG-2 (Figure 29). Assays, in ppm, were performed by Northeast Geochemical and Assay Company, Yarmouth, Maine.

YG-1

300NW	250NW	200NW	150NW	100NW	50NW	0	50SE	100SE	150SE	200SE	250SE	300SE
0.0.16	0.006	0.006	0.016	0.005	0.005	0.004	0.004	0.003	0.004	0.002	0.002	0.002

YG-2

300NW	250NW	200NW	150NW	100NW	75NW	50NW	0NW	25SE	50SE	75SE	100SE	150SE
0.005	0.002	0.003	0.005	0.002	0.003	0.470	0.007	0.025	0.013	0.019	0.025	0.025

200SE	250SE
0.004	0.003

YG-3

300NW	250NW	200NW	150NW	100NW	50NW	ONW	50SE	100SE	150SE	200SE
0.003	0.042	0.025	0.015	0.036	0.512	0.003	0.002	<0.002	0.002	<0.002

250SE	300SE
0.002	0.326

APPENDIX XIV

Whole-rock analyses for gold and silver, Yankee Horse Ridge
Assays of samples 1 through 13 by Northeast Geochemical and Assay Company, Yarmouth, Maine.
Values are in parts per million and Troy ounces per short ton.

	ppm Au	oz/short ton Au	ppm Ag	oz/short ton Ag
1. Yankee Horse Ridge geochemical anomaly Y: mylonitic bedrock, disturbed by bulldozer, goethite pod with relict pyrite.	1.03	0.03	299	8.72
2. Yankee Horse Ridge geochemical anomaly Y: sheared felsic bedrock, disturbed by bulldozer, traces of yellow-green mineral (beudantite?).	n.d.	nil	15	0.44
3. Yankee Horse Ridge geochemical anomaly Y: mylonitic alaskite, no obvious mineralization, bedrock disturbed by bulldozer.	n.d.	nil	19.7	0.57
4. Yankee Horse Ridge geochemical anomaly Y: sheared alaskite, bedrock disturbed by bulldozer, yellow jarositic boxworks.	1.7	0.05	10.2	0.30
5. Yankee Horse Ridge geochemical anomaly Y: diamond drill hole #1, vertical, ground core from 0-11 feet, core recovery very poor, <5%.	0.01	nil	0.80	0.023

6. Yankee Horse Ridge geochemical anomaly Y: diamond drill hole #1, ground core from 11-15 feet, core recovery very poor, <5%.	0.005	nil	0.4	0.012
7. Yankee Horse Ridge geochemical anomaly Y: diamond drill hole #1, ground core from 17 feet, felsic mylonitic rock, core recovery very poor, <5%.	0.005	nil	0.3	0.009
8. Yankee Horse Ridge geochemical anomaly Y: diamond drill hole #1, bottom of hole at 21 feet, felsic mylonite bedrock	0.004	nil	0.5	0.015
9. Yankee Horse Ridge geochemical anomaly Y: panned concentrate from drill cuttings from hole #1.	0.286	0.008	31	0.904
10. Yankee Horse Ridge: bedrock beside hole #1, iron-stained, vuggy mylonite with limonitic and hematitic boxworks.	5.85	0.171	7.3	0.213
11. Yankee Horse Ridge: grab sample, bedrock disturbed by bulldozer, 10 feet south of hole #1.	0.10	0.003	5	0.146
12. Yankee Horse Ridge geochemical anomaly Y: 125 feet ENE of hole #1, in mylonite zone, sheared sericitic, felsic mylonite.	0.057	0.002	56	1.63
13. Irish Creek tin mine, Panther Creek #2 workings: arsenopyrite with scorodite.	267.3	7.796	382.6	11.16
14. Irish Creek tin mine, Panther Creek # 2 workings, arsenopyrite, assay from Hotchkiss (1883) listed in Glass and others (1958).	252.3	7.36	2513	73.3

APPENDIX XV

Procedures

Soil samples were collected by shovel, trowel, or soil augur from beneath the humic layer of forest litter, then oven-dried and sieved to -100 mesh with nylon screened sieves. One-half gram soil samples were digested with hot 1:1 HCl in Teflon beakers, filtered, and then analyzed by atomic absorption spectroscopy. Analyses for lead, zinc, copper, iron, manganese, cobalt, chromium, lithium, strontium, barium, and rubidium were done at the Virginia Division of Mineral Resources laboratory with a Techtron AAS unit. Prior to analysis solutions for rubidium, strontium, barium, and lithium were spiked with potassium chloride. Tin values in soil were determined by X-ray emission using pressed pellets prepared by mixing one gram of soil and one gram of cellulose in a SPEX mixing unit. Measurements were made on a Diana X-ray emission unit which has a limit of detection for tin of 4 parts per million.

Gold concentration in whole-rock samples was determined by the fire assay technique by Iron King, Inc., Laboratory, Humboldt, Arizona and by Northeast Geochemical Laboratory, Yarmouth, Maine. Gold and silver concentrations in soil samples were determined by fire assay followed by atomic absorption by Northeast Geochemical Laboratory.

Fluorine, arsenic, and tungsten values in soil were determined by Western Analytical, Inc., Salt Lake City and by Blue Ridge Analytical Laboratory, Charlottesville, Virginia. Some tungsten data are included in appendices V, VI, and VII. Fluoride concentration in soils was determined by NaOH fusion and specific ion electrode; arsenic concentration was obtained by pyrosulfate fusion followed by HCl leach, dithiol extraction, and then determined colorimetrically.

Water samples from streams were filtered in the field using a Schleicher and Schuell Antlia pneumatic hand pump with a 0.45 micron millipore filter. Water samples for fluorine and sulfate were not acidified prior to ion chromatography determination at the University of Virginia Environmental Science laboratory. Stream water samples for analysis of lithium, iron, and other metals were acidified and refrigerated prior to atomic absorption analysis at the Virginia Division of Mineral Resources laboratory.

Radioactivity measurements for potassium, uranium, and thorium were made in the field with a portable Geometric GR-310 gamma spectrometer with a 2 inch x 2 inch (104 cm^3) thallium-doped sodium iodide detector and an internal Ba^{133} reference isotope. All measurements were made at ground level using the average of three 100-second count periods. Reduction of count

averages to estimates of element concentration in whole-rock was made using empirical constants based on measurements of rock analyzed by chemical techniques plus Compton stripping constants. Average counts per second (cps) were used in the element concentration estimates as:

$$\%K_2O=(1.20)(0.96)(K\ cps - 1.32U\ cps - 0.1Th\ cps)$$
$$ppm\ U=(13)(U\ cps - 0.83Th\ cps)$$
$$ppm\ Th=(28)(Th\ cps - 0.089U\ cps)$$

VIRGINIA DIVISION OF MINERAL RESOURCES – PUBLICATION 112 – GOLD MINERALIZATION, AND TIN, BASE METALS, AND THORIUM ANOMALIES AT YANKEE HORSE RIDGE, IRISH CREEK TIN AREA, ROCKBRIDGE COUNTY, VIRGINIA