

ABSTRACT

Christopher L. Corbitt. PETROGRAPHY AND GEOCHEMISTRY OF THE METASEDIMENTARY/METAVOLCANIC HOST ROCKS AND ASSOCIATED GOLD DEPOSITS AT THE PORTIS GOLD MINE, FRANKLIN COUNTY, NORTH CAROLINA. (Under the direction of Richard K. Spruill) Department of Geology, March, 1987.

The Portis mine is a low grade gold deposit located in Franklin County, North Carolina. The mine area is underlain by a thick sequence of turbidite-deposited volcanoclastic sediments interlayered with felsic to mafic submarine pyroclastic units of the Spring Hope Formation. The entire sequence is believed to have been deposited on the flanks of a subduction-related volcanic arc terrane during the late Precambrian to early Cambrian.

Epidote-amphibolite facies metamorphism has produced pervasive recrystallization and neomineralization of the Portis mine rocks. Late-stage hydrothermal activity has produced a localized zeolite facies overprint. Deformation is evident as a penetrative foliation parallel to the original bedding and as a less prominent crenulation cleavage inclined 30° to the bedding.

A biotite mineral separate yielded a K-Ar age of 269 ± 6 my. This age coincides with cooling at the end of the Alleghanian thermal event (325-275 ma) in the eastern Piedmont.

Gold is associated with quartz veins located in the ore zone and adjacent rocks. The ore zone rocks are geochemically similar to Na-

metasomatized vitric tuffs found in the Carolina Slate belt. Gold and silica precipitated within fractures in the ore zone that developed during compaction and metamorphic dewatering.

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ASSOCIATED GOLD DEPOSITS AT THE PORTIS GOLD MINE,
FRANKLIN COUNTY, NORTH CAROLINA

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Presented to
the Faculty of the Department of Geology
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In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Geology

by
Christopher Lee Corbitt

March, 1987

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INTRODUCTION

The Eastern Carolina Volcanic Slate belt (E.C.V.S.B.) is host to a small number of low grade gold deposits. Most productive of these deposits was the Portis mine (Bryson, 1936) located adjacent to Highway 561 approximately one mile east of the town of Wood, Franklin County, North Carolina (Fig. 1). The mine area is underlain by a thick sequence of volcanoclastic and epiclastic mudstones and siltstones interlayered with subordinate felsic to mafic volcanic units of the late Precambrian-Cambrian Spring Hope Formation (Farrar, 1985a; 1985b). These rocks are similar to Carolina Slate belt lithologies described elsewhere (Conley, 1962; Stromquist and Sundelius, 1969; Sundelius, 1970; Seiders and Wright, 1977; Seiders, 1978; and Harris and Glover, 1985). The Portis mine lies within the axial portion of the northeast-trending Spring Hope synform, a major deformational feature of the E.C.V.S.B. Strata at the mine dip 15° to the west, toward the center of the synformal structure.

Mining and Exploration History

Gold was first discovered on the property in 1835 (Bryson, 1936). An estimated total of one million dollars in gold was recovered during three major periods of mining (Pardee and Park, 1948). Earliest mining operations extracted placer gold from weathered surface material (saprolite). The most recent underground mining activity occurred in 1935 when Norlina Mining Company acquired the property (Bryson, 1936).

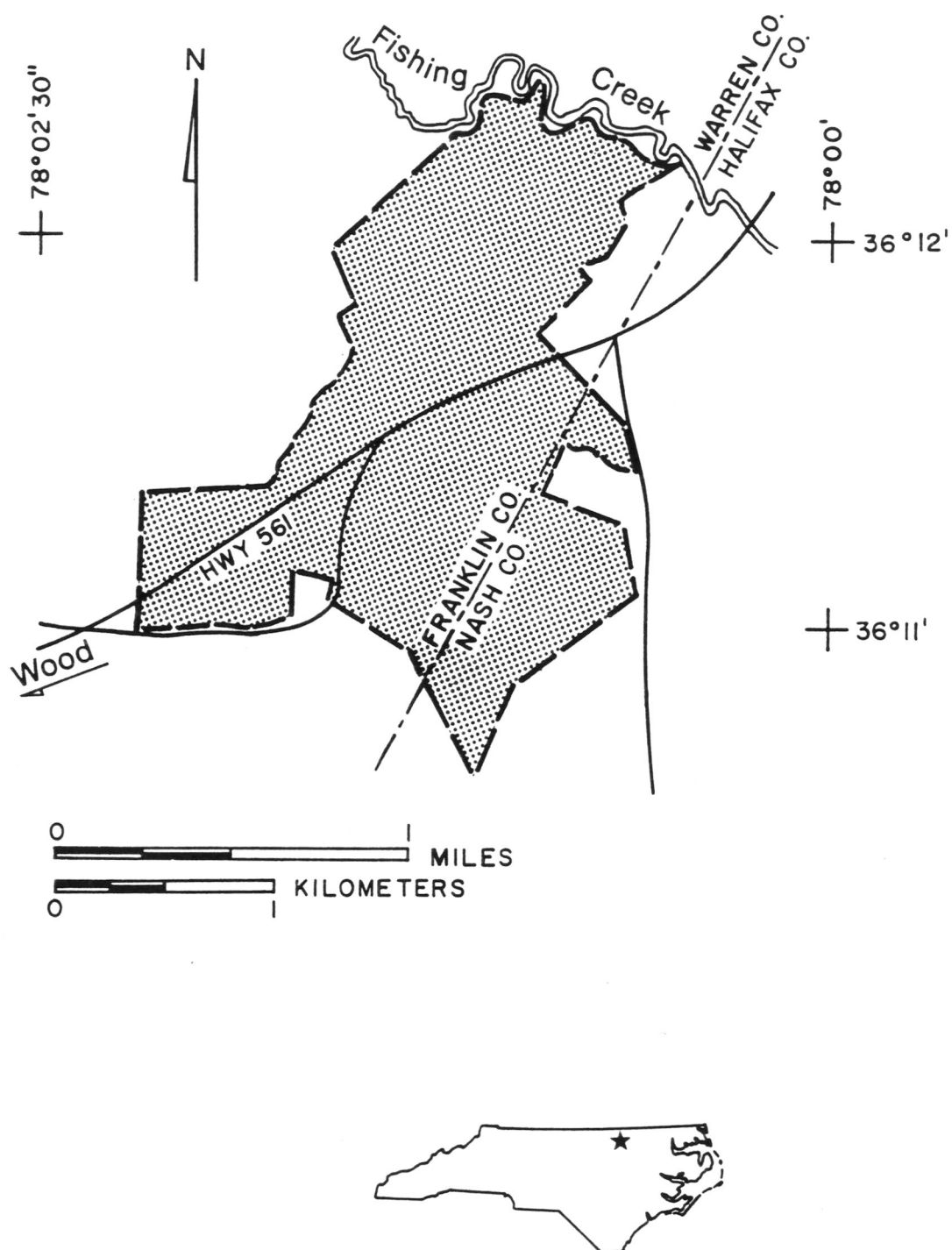


Figure 1. Location Map of the Portis Gold Mine Property, Franklin County, North Carolina.

In 1975, exploration of the Portis property was initiated by Newmont Exploration Ltd. in response to rapidly escalating gold prices in the mid-1970's. Petromet International Inc. leased the property in 1982 and drilled approximately thirty holes to facilitate study of the ore zone and host rocks at depth. A network of trenches (Plate 1) was used to examine the ore zone and host rocks where they are exposed at the surface. A combination of low gold market prices and not enough gold apparently forced Petromet to give up its lease of the Portis property in 1986.

Stratigraphy

From the 30 cores available for study, core PM-27 (325 feet, 99.1 m) was selected as the primary focus of this investigation because it contained representative lithologies, an ore zone intersection, and the greatest stratigraphic interval available, although a deeper hole has since been completed. A generalized stratigraphic column of PM-27 is illustrated in Figure 2. Core PM-27 is an apparently conformable sequence of interbedded metagraywackes, amphibolites, quartz-rich amphibolites, biotite phyllites, and the ore zone. The upper two-thirds of core PM-27 is dominated by felsic metagraywackes. The lower third consists of three massive quartz-rich amphibolite layers of intermediate chemical composition. Mafic amphibolite layers are restricted to the upper portion of PM-27 and they increase in abundance upward in the section. Biotite phyllites are the least abundant rock type but pervasive.

Visual inspection of a deeper core (PM-37) demonstrated that



Plate 1. Air photograph of surface trench network on the Portis Mine property. The paved road is Highway 561.

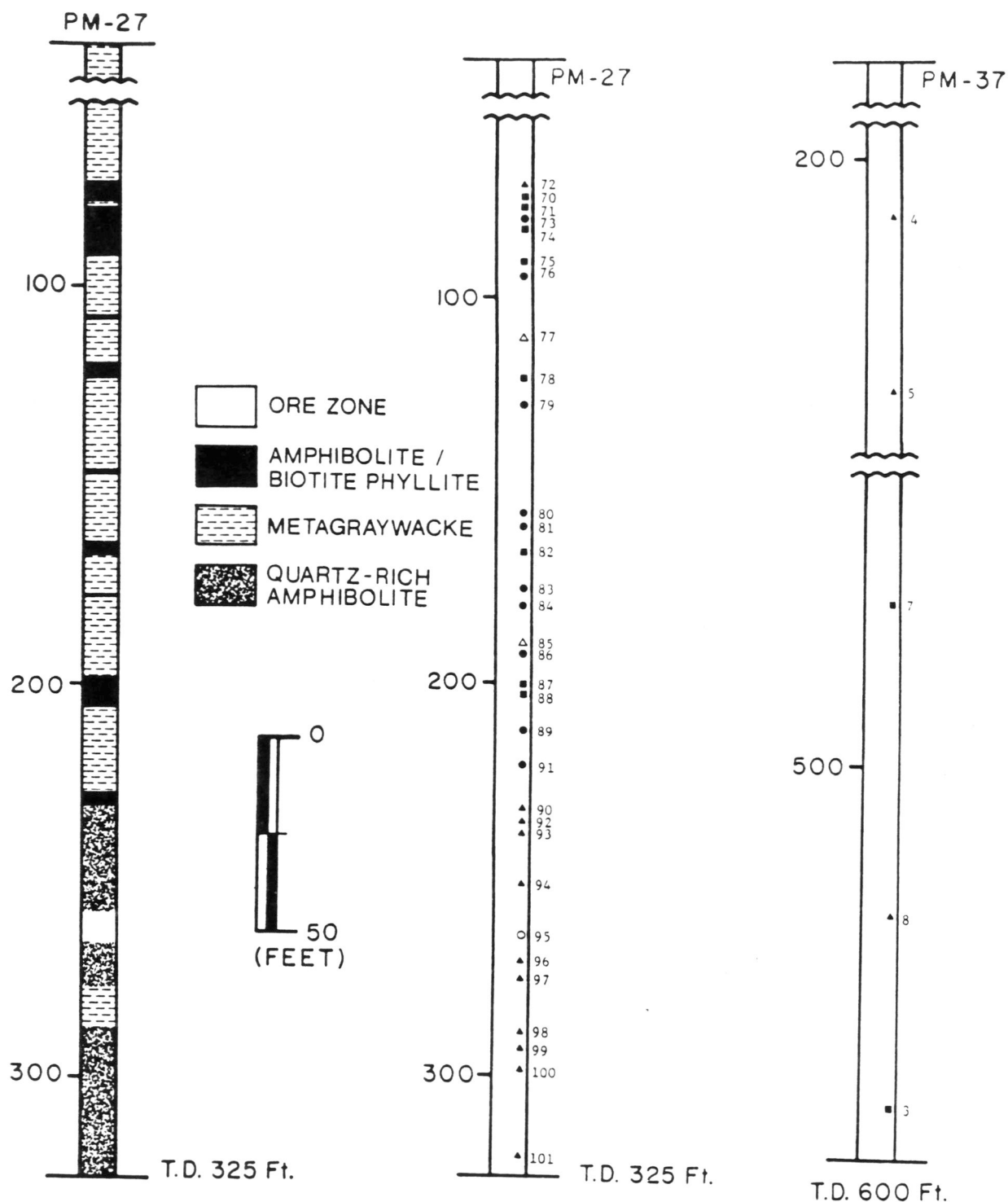


Figure 2. Generalized Stratigraphic Column of PM-27 and Geochemical Sample Locations in Cores PM-27 and PM-37. Symbols correspond to rock types; (●) metagraywackes, (■) mafic rocks, (▲) quartz-rich amphibolites, (○) ore zone rocks, and two (△) anomalous samples.

another sequence dominated by metagraywackes with interbedded amphibolites, biotite phyllites, and quartz-rich amphibolites lies beneath the massive quartz-rich amphibolites. Two samples (37-3, -7) of amphibolite and one sample (37-8) of quartz-rich amphibolite were collected from the lower third of core PM-37 and included as geochemical samples (Fig. 2).

PREVIOUS WORKS

Previous investigations and reports of gold deposits in the Eastern Piedmont of North Carolina (Nitze and Hanna, 1896; Nitze and Wilkens, 1897; Bryson, 1936; LeBaron, 1937; and Pardee and Park, 1948) describe the host rocks at the Portis as sericite schists and phyllites intruded by diorite. These authors also suggest that gold mineralization is associated with granoblastic quartz veins within the diorite. According to Pardee and Park (1948), the quartz veins formed as silica-rich solutions filled tension cracks that developed during cooling of the diorite intrusive. They proposed that the fractures served as conduits for solutions emanating from depth. The dominant weathering product of the diorite is a white clay, termed the "White Belt" where it outcrops in the Portis area (Bryson, 1936). LeBaron (1937) suggested that the sericite schist host rocks were intruded by a "Basic Rock" which was subsequently hydrothermally altered to quartz diorite. He considered the "White Belt" to be derived from a granitic source, possibly the same magma source which produced the late Paleozoic Rolesville batholith.

An alternative model for the origin of gold at the Portis mine was proposed by Tremblay (1982) in an unpublished Petromet exploration report. He postulated that the gold was associated with a subaqueous exhalative unit interbedded with intermediate to felsic tuffaceous volcanic rocks. Typically, fossil geothermal systems that produced

submarine exhalative deposits are recognized by zones of intense hydrothermal alteration (Feiss, 1985). Several gold deposits in the Carolina Slate belt are associated with intensely altered rocks and are considered to be submarine exhalative deposits (Worthington and Kiff, 1980; Spence and others, 1980; Worthington and others, 1980; Butler, 1981; and Mangan and others, 1983).

Waltman (1985) suggested a magmatic hydrothermal origin for the gold based on his identification of quartz diorite and quartz keratophyre subvolcanic intrusives. He suggested that the gold and associated sulfides were deposited by hydrothermal fluids generated during emplacement of these hypabyssal intrusives. This interpretation is similar to those of most of the earliest investigations of the Portis gold mine.

OBJECTIVES

The objectives of the following study were: 1) to petrographically describe the various lithologies observed at the Portis gold mine; 2) to describe the geochemical relationships of the host rocks and the ore zone rocks based on major and trace element analyses; 3) to describe the formation of the host rocks and the ore zone rocks and how gold deposition was related to their depositional and metamorphic histories; and 4) to determine a K-Ar age for the epidote-amphibolite facies metamorphic event.

REGIONAL GEOLOGY

The Portis gold mine is located in the eastern Piedmont of North Carolina (Fig. 3). The eastern Piedmont is a complex terrane consisting of two parallel, NNE-trending litho-tectonic provinces, the Raleigh belt and the Eastern Carolina Volcanic Slate belt (E.C.V.S.B.). Farrar (1985a) redefined these belts in terms of tectonic blocks. The Raleigh block consists of the Raleigh belt and the E.C.V.S.B. west of the Hollister shear zone. All E.C.V.S.B. lithologies east of the shear zone comprise the Roanoke Rapids block. Belt boundaries are generally regarded as faults or shear zones (Casadevall, 1977; Hatcher and others, 1977), but a metamorphic gradient has also been recognized between the E.C.V.S.B. and the Raleigh belt (Parker, 1978). At the fall line, these lithologies are overlain by Cretaceous to Recent Coastal Plain sediments.

Raleigh Belt

The Raleigh belt is a medium- to high-grade (amphibolite facies) metamorphic terrane composed of gneisses, amphibolites, quartzites, altered mafic and ultramafic complexes and pelitic schists (Parker, 1968; Stoddard and others, 1982; and Farrar, 1985a). Sillimanite, almandine, and staurolite have been identified at various locations throughout the Raleigh belt (Stoddard and McDaniel, 1979; Farrar, 1985b). A Grenville age has been suggested for the older highly

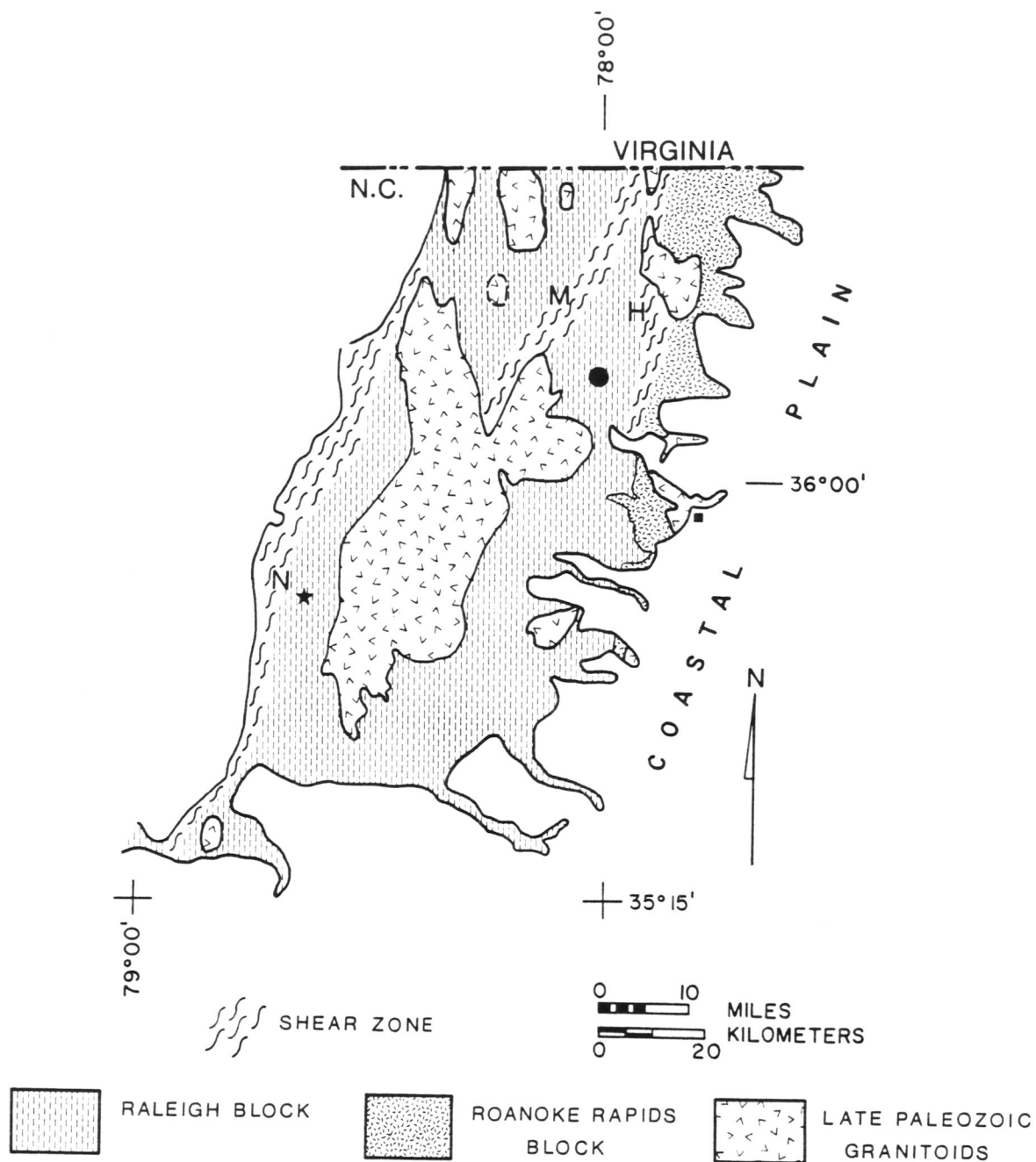


Figure 3. Regional Geologic Map of the Eastern Piedmont Terrane of North Carolina, after Farrar, 1985.
 (★) Raleigh, NC, (■) Rocky Mount, (●) Portis gold mine,
 (N) Nutbush Creek shear zone, (M) Macon shear zone,
 (H) Hollister shear zone.

deformed metasediments and metavolcanics in this area (Glover and others, 1978). The south plunging Wake-Warren anticlinorium is the major structural feature of the Raleigh belt. The entire sequence has been intruded by several late Paleozoic granitoid bodies, the largest of which is the Rolesville batholith (Parker, 1968).

Eastern Carolina Volcanic Slate Belt

The E.C.V.S.B. consists of a thick sequence of volcanoclastic and epiclastic sediments interlayered with felsic to mafic volcanic units (Parker, 1968; Farrar, 1985b). Sedimentary lithologies are considered to be submarine deposits characterized by well-laminated and graded beds. Although Ediacarian fauna (Gibson and others, 1984) and a trilobite (genus Paridoxides) (St. Jean, 1973) support a subaqueous depositional environment for the Carolina Slate belt, no fossils have been found in the E.C.V.S.B. Volcanic rocks are typically bimodal with felsic units dominant over mafics (Seiders, 1978; Feiss, 1982). The prominent volcanogenic assemblage of the E.C.V.S.B. probably originated in a subduction-related volcanic island arc terrane during the late Precambrian to early Cambrian (Feiss, 1982). In addition to the older volcanogenic rocks, there are several post-metamorphic, Alleghanian (?) granitoid intrusives. Kite and Stoddard (1984) have recognized an older meta-ophiolite sequence approximately 15 km east of the Portis gold mine which they call the Halifax Mafic complex.

Eastern Piedmont Metamorphism

A pervasive greenschist facies metamorphic event (M_1) is recognized

in the E.C.V.S.B. K-Ar muscovite ages of approximately 485 ma have been reported from argillites in the Carolina Slate belt by Kish and others (1979). These ages most likely represent the peak of greenschist facies metamorphism (M_1) in the Carolina Slate belt. Farrar (1985a) suggests a similar age for greenschist facies metamorphism in the E.C.V.S.B. An upper greenschist-amphibolite facies metamorphic event (M_2) has been recognized in the Raleigh belt and within portions of the E.C.V.S.B. (Parker, 1968; Farrar, 1985a). This M_2 event appears to coincide with the emplacement of late Paleozoic granitoid bodies during the Alleghanian (?) orogeny (325-275 ma) (Fullagar and Butler, 1979; Farrar, 1985a; and Russell and others, 1985). The E.C.V.S.B. has undergone two or possibly three deformational episodes which created regional-scale folds, penetrative foliations, and rock cleavages. Major structures include the Smithfield and Spring Hope synclinoria and the Thelma anticlinorium (Parker, 1968).

Tectonic Evolution of Eastern Piedmont

Geological interpretation of the eastern Piedmont was virtually ignored until Parker (1968) described the lithologies, metamorphism and general structural relationships. Parker (1978) characterized the Raleigh belt as exposed continental basement, consisting of eugeosynclinal sediments upon which the rocks of the Carolina Slate belt and the E.C.V.S.B. were conformably deposited. Farrar and Glover (1983) implied that the Raleigh belt was the southern extension of the Grenville-age, Goochland terrane in Virginia. According to Secor and

Snoke (1978), the eastern Piedmont in North Carolina may also be related to the Kiokee and Belair belts in South Carolina, based on similar rock types and metamorphic conditions. Current interpretations suggest that the eastern Piedmont is a tectonically-assembled collage produced by accretion and overthrusting of crystalline terranes (Williams and Hatcher, 1982; Cook, 1983). Farrar (1985a) contends that a decollement surface exists between the E.C.V.S.B. and the Raleigh belt. He suggests that the E.C.V.S.B. is an allochthonous terrane that has been thrust westward over the crystalline basement rocks of the Raleigh belt.

PETROGRAPHY AND MINERAL CHEMISTRY OF THE HOST ROCKS

Samples for petrographic and hand-specimen analysis were collected from five cores from the Portis gold mine. Ninety-six thin sections from PM-27 and 11 thin sections from other cores (PM-7, PM-8, PM-33, PM-37) were prepared and described for mineral and textural relationships. Samples from adjacent cores were used to compare vertical and lateral relationships between lithologic units.

Modal analyses, based on 300 counts per slide for 36 thin sections of rocks used for geochemical analysis, are listed in Appendix A. The modal analyses define four major rock types; 1) metagraywacke, 2) amphibolite, 3) quartz-rich amphibolite, and 4) biotite phyllite. Chemical analyses of the same 36 rock samples group into only three major rock types; 1) metagraywacke, 2) mafic rocks (including amphibolite and biotite phyllite), and 3) quartz-rich amphibolite. Average chemical and modal percentages are provided in Table 1. The ore zone rocks are petrographically and geochemically similar to the metagraywackes but they will be discussed separately.

A non-parametric clustering analysis technique from SAS (Statistical Analysis System), which utilized Ward's minimum variance method (SAS, 1982), was applied to the modal data. Four rock types were delineated using the cubic clustering criterion (CCC) to evaluate Ward's method. If the numerical value for the CCC is greater than two, good clustering is indicated. Values between zero and two imply possible clusters that should be interpreted cautiously (SAS, 1982).

Table 1. Average Chemical and Modal Analyses of Host Rock Types at the Portis Gold Mine

	Metagraywacke n=10	Quartz-Rich Amphibolite n=15	Amphibolite n=6	Biotite Phyllite n=4
Quartz	42.94 (13.1)	20.71 (8.1)	6.35 (4.9)	17.75 (7.0)
Plagioclase	29.13 (7.97)	31.14 (12.2)	24.38 (9.6)	7.53 (11.6)
Hornblende	-----	21.95 (9.8)	59.45 (5.4)	-----
Biotite	5.84 (5.4)	13.96 (7.9)	2.22 (2.8)	49.60 (7.9)
Phengite	13.96 (14.1)	0.09 (0.3)	0.78 (1.9)	-----
Epidote	1.14 (1.2)	3.27 (4.0)	1.88 (1.6)	18.75 (15.7)
Chlorite	5.76 (6.6)	5.04 (9.2)	2.55 (3.5)	0.43 (0.5)
Calcite	0.07 (0.2)	0.39 (0.9)	0.67 (0.9)	5.83 (8.5)
Opagues	1.07 (0.5)	2.40 (1.3)	0.67 (0.6)	0.08 (0.2)
Others	0.09 (0.2)	1.07 (1.1)	0.50 (1.1)	0.08 (0.2)

	Metagraywacke n=10	Quartz-Rich Amphibolite n=16	Mafic Rocks n=10
SiO ₂	71.05 (3.5)	57.60 (2.9)	49.50 (1.8)
TiO ₂	0.75 (0.1)	1.55 (0.3)	1.00 (0.3)
Al ₂ O ₃	14.65 (1.9)	14.65 (1.9)	15.70 (0.9)
Fe ₂ O ₃ *	4.35 (0.7)	12.55 (2.6)	10.10 (1.4)
MgO	1.08 (0.4)	2.40 (0.6)	7.35 (1.3)
MnO	0.07 (0.01)	0.23 (0.05)	0.26 (0.1)
CaO	1.90 (0.6)	6.00 (1.0)	8.45 (1.9)
Na ₂ O	3.20 (1.0)	2.95 (0.7)	1.85 (0.9)
K ₂ O	2.51 (1.1)	1.60 (0.6)	2.45 (1.9)
P ₂ O ₅	0.10 (0.03)	0.28 (0.1)	0.15 (0.05)
Ba	644 (194)	349 (142)	212 (66)
Rb	96 (39)	63 (33)	95 (75)
Sr	135 (71)	182 (59)	219 (83)
Y	31 (8)	37 (8)	21 (6)
Zr	217 (47)	136 (72)	54 (36)

*Total Fe as Fe₂O₃.

Others are accessory phases comprising less than 1%, include sphene, tourmaline, allanite, and apatite.

Major elements in weight %; trace elements in ppm.

n is size of population for each rock type.

one standard deviation from the mean is shown in parentheses.

The value for the Portis data is 1.7, suggesting that the clusters are valid but the variability within the clusters is not totally explained by the independent variables.

Metagraywacke

Metagraywackes are felsic, range from very fine- to coarse-grained (0.01-4 mm), and are typically greenish-gray to gray. Coarse-grained metagraywackes consist primarily of quartz and albite (Plate 2) and are interpreted as metamorphosed volcanoclastic sandstones. A few very coarse metagraywackes contain epidotized rock fragments. Fine-grained metagraywackes are composed mostly of white mica and quartz, and are considered to have been volcanically derived mudstones and siltstones (Plate 3). Mudstones, siltstones, and sandstones are grouped together as metagraywackes on the basis of their similar chemical characteristics.

Stratification in the mudstones, siltstones, and sandstones varies from laminations (<10 mm) to beds up to 1 m. Most sedimentary layers maintain consistent to slightly variable thicknesses. Lenticular bedding (10 mm) is also observed. Normal graded bedding, a common feature of flysch terranes (Stow and Shanmugam, 1980), is a prevalent feature of the metagraywackes. Graded bedding is visible at the hand-specimen and microscopic scale (Plate 4). Complete fining-upward sequences usually grade from sand- and granule-size fragments at the base (sandstones) to clay- or silt-size particles at the top (mudstones). Partial sequences are also recognized. The preponderance of normal graded bedding at the Portis implies that the metagraywackes

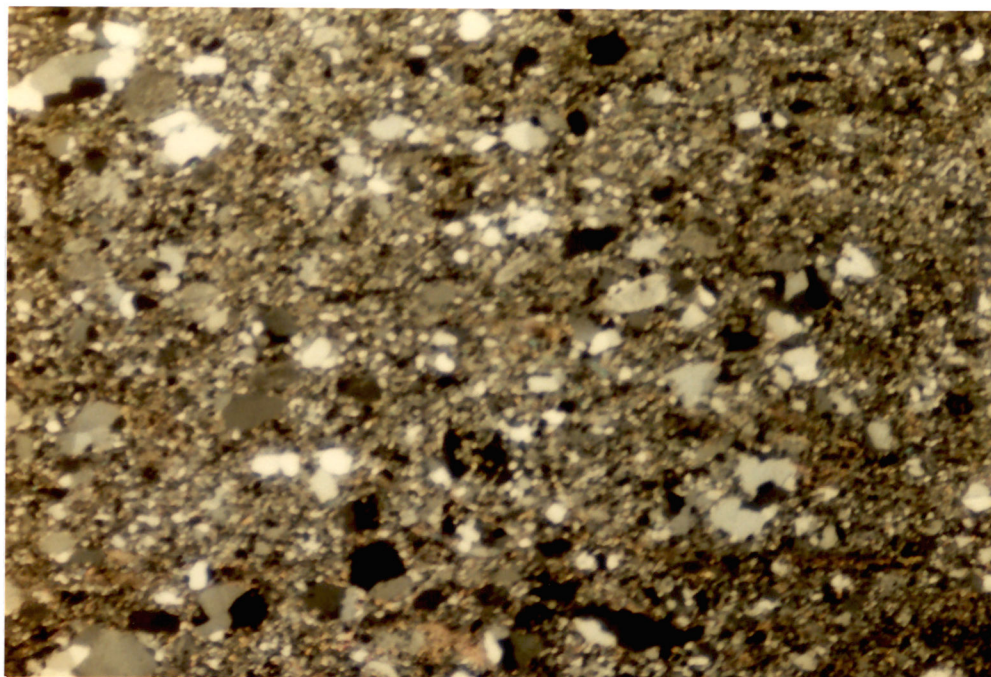


Plate 2. Photomicrograph of coarse-grained metagraywacke, crossed nichols. Untwinned albite porphyroblasts and composite quartz grains in a groundmass of quartz, plagioclase, and micas. Long dimension of plate is 6.9 mm.



Plate 3. Photomicrograph of fine-grained metagraywacke, crossed nichols. Long dimension of plate is 6.9 mm.

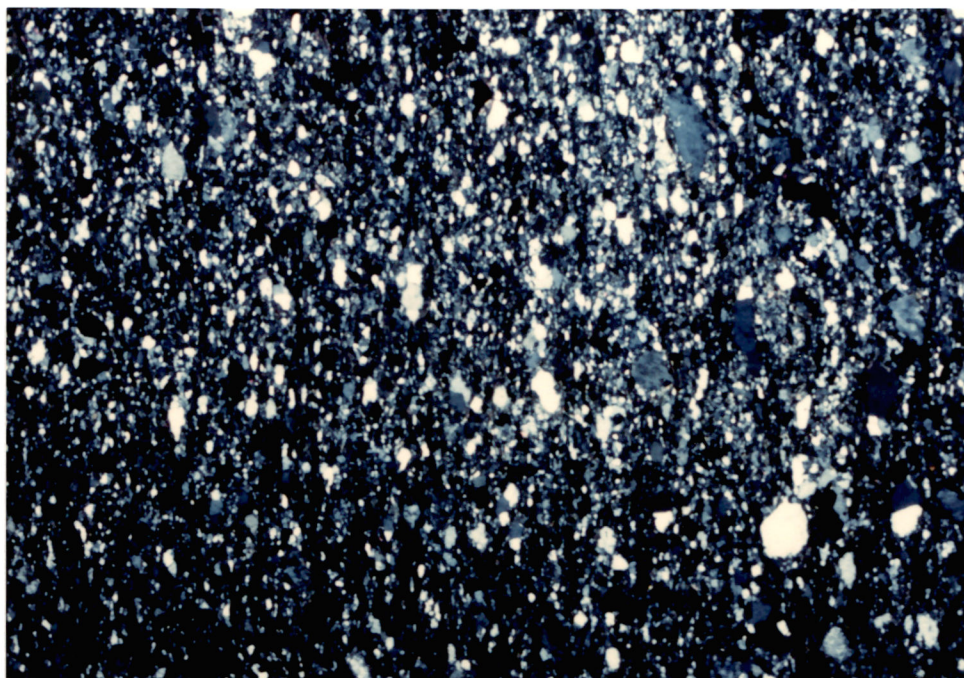


Plate 4. Photomicrograph of normal graded bedding within metagraywackes, crossed nichols. Fining upward sequences are from right to left. Long dimension of plate is 6.9 mm.

are stratigraphically upright. Generally, the base of each unit is characterized by a sharp contact. Truncated sequences and sharp basal contacts suggest an episodic depositional pattern for the sediments. Scour-and-fill structures and cross-laminations, observed in other flysch terranes, occur only rarely in the metagraywackes at the Portis. Microfaults with 1-2 mm displacements are widespread. Stow and Shanmugam (1980) recognized a number of similar small-scale sedimentary structures in Recent Scotian margin sediments, in the Ordovician Sevier shale of Tennessee, and in the flysch sediments of the lower Paleozoic Meguma Group, Nova Scotia. All three localities represent examples of turbidite sedimentation. Many sedimentary features exhibited by these fine-grained rocks are also evident at the Portis, suggesting a turbidite origin for the metagraywackes. These features are summarized in Figure 4.

The constituent mineralogy of metagraywackes is quartz + albite + white mica + opaques +/- biotite +/- chlorite +/- epidote +/- calcite +/- sphene +/- garnet +/- hornblende +/- apatite +/- zircon +/- allanite +/- tourmaline +/- K-feldspar. In thin section, a moderately to well developed S_1 foliation and an S_2 crenulation cleavage are defined by the micas (Plate 5).

Quartz occurs as monocrystalline polygonal groundmass grains (.01 mm), as ellipsoidal composite grains (.2 to 3.5 mm), or as discontinuous stringers. Composite grains and stringers and large groundmass grains are usually aligned parallel to the S_1 foliation.

Granoblastic fine-grained (.1 mm) albite is commonly associated with quartz in the groundmass. Groundmass plagioclase is generally

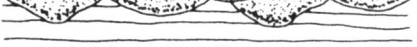
SEDIMENTARY STRUCTURES	SCOTIAN MARGIN	SEVIER SHALE	MEGUMA GROUP	PORTIS GOLD MINE	ILLUSTRATED FEATURES
STRATIFICATION					
REGULAR	C	C	C	C	
IRREGULAR	C	P	C	C	
LENTICULAR	P	P	C	P	
GRADED BEDDING					
NORMAL	C	C	C	C	
REVERSE	R	NF	NF	NF	
NATURE OF CONTACTS					
SHARP	C	C	C	C	
GRADATIONAL	P	P	P	P	
SCOUR AND FILL	P	P	P	P	
INTERNAL LAMINATION					
CROSS-LAMINATION	R	R	C	P	
SECONDARY STRUCTURES					
MICROFAULTS	R	R	R	R	

Figure 4. Sedimentary Features Characteristic of Turbidite Sedimentation Recognized in Flysch Terranes and the Portis Gold Mine, after Stow and Shanmugam, 1980.
(C) commonly observed, (P) present, (R) rare, and (NF) not found.

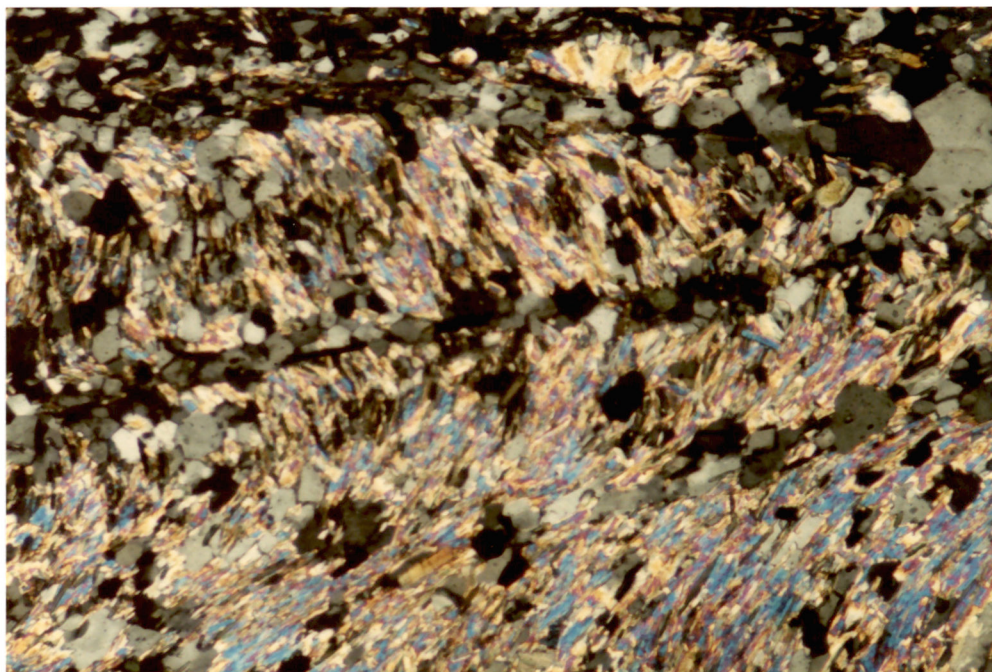


Plate 5. Photomicrograph of S_1 foliation and S_2 crenulation cleavage, crossed nichols. The S_1 foliation is defined by a dimensional-preferred orientation of quartz. S_2 foliation is defined by phengite grains, 30 to 40° to the S_1 foliation. Long dimension of the plate is 1.24 mm.

untwinned, although minor albite twinning was observed. Larger (< 2 mm) anhedral albite porphyroblasts are also untwinned. The lack of twinning in metamorphic plagioclase is well documented (Spry, 1979; Blatt and others, 1972). Most coarse-grained albite is moderately altered to sericite. Phengite, biotite, and chlorite occur as individual laths or clusters that form layered aggregates. Large phengite grains (.1 mm) may be bent when in contact with albite porphyroblasts or ellipsoidal quartz grains. Biotite displays olive brown to yellow pleochroism. Zircon inclusions in biotite are highlighted by pleochroic halos. Felted masses of chlorite are pleochroic green to yellow.

Fine-grained (.05 mm), euhedral to subhedral grains of epidote are dispersed as matrix material. Allanite, a member of the epidote group, is easily identified by strong reddish-brown pleochroism and rims of granular epidote. Isolated hornblende grains are restricted to metagraywacke layers adjacent to massive quartz-rich amphibolite layers. Magnetite, pyrite, hematite, pyrrhotite, sphene, calcite, garnet, and apatite are ubiquitous, but occur in trace amounts.

Tourmaline is common in fine-grained metagraywacke layers. Abundant tourmaline (10%) was found in one distinctive phengite-rich unit near the top of PM-27 (Plate 6). A metasomatic origin for the tourmaline seems unlikely since the tourmaline is restricted to this thin unit and is not observed in the adjacent rocks; instead, tourmaline formed during metamorphism of this volcanically derived (?) boron-rich mud. Turner and Verhoogen (1960) state that argillaceous marine sediments may contain sufficient boron to account for

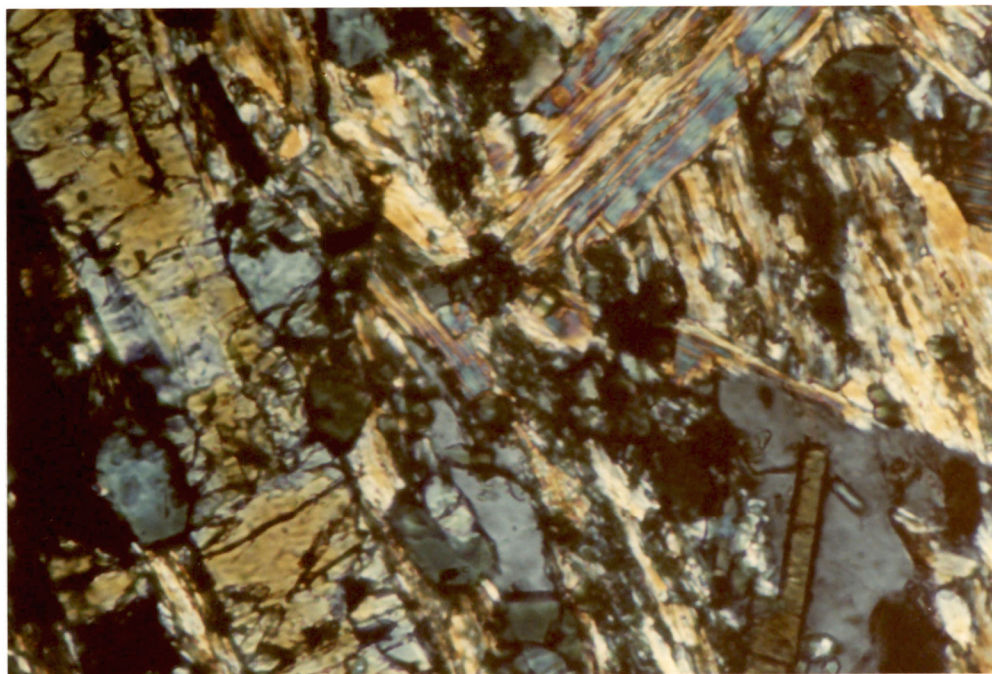


Plate 6. Photomicrograph of phengite-rich layer with tourmaline, crossed nichols. Long dimension of plate is 0.32 mm.

tourmaline. Slack and others (1984) reported that tourmaline is common in Proterozoic and early Paleozoic sequences dominated by clastic metasedimentary rocks.

Amphibolite

Amphibolites are readily distinguished in thin section and hand-specimen because of their dark green color and medium- to coarse-grained porphyroblastic texture (Plate 7). Amphibolite layers are generally less than one meter in thickness, although some may be as thick as two meters. They are massive and exhibit relatively homogeneous compositions consisting of 60% hornblende and approximately 25% plagioclase plus minor quartz (Table 1). These amphibolites are interpreted as mafic pyroclastic units. The thickest amphibolite layers may be pyroclastic flows (?), although most are believed to have formed by submarine fall-out. Some amphibolites are layered. Typically, hornblende layers alternate with layers of quartz and plagioclase (Plate 8). These layered amphibolites are probably transitional between mafic pyroclastic layers and more felsic metagraywackes.

The amphibolites consist of hornblende + plagioclase + quartz + epidote + chlorite + opaques +/- biotite +/- calcite +/- white mica +/- sphene. Foliation is not usually observed in the amphibolites.

Hornblende is medium- to coarse-grained, brown to bluish-green, and subhedral to euhedral. Diverse habits are exhibited, such as randomly oriented clusters and prismatic blades. Quartz and plagioclase grains are commonly enclosed by hornblende, producing

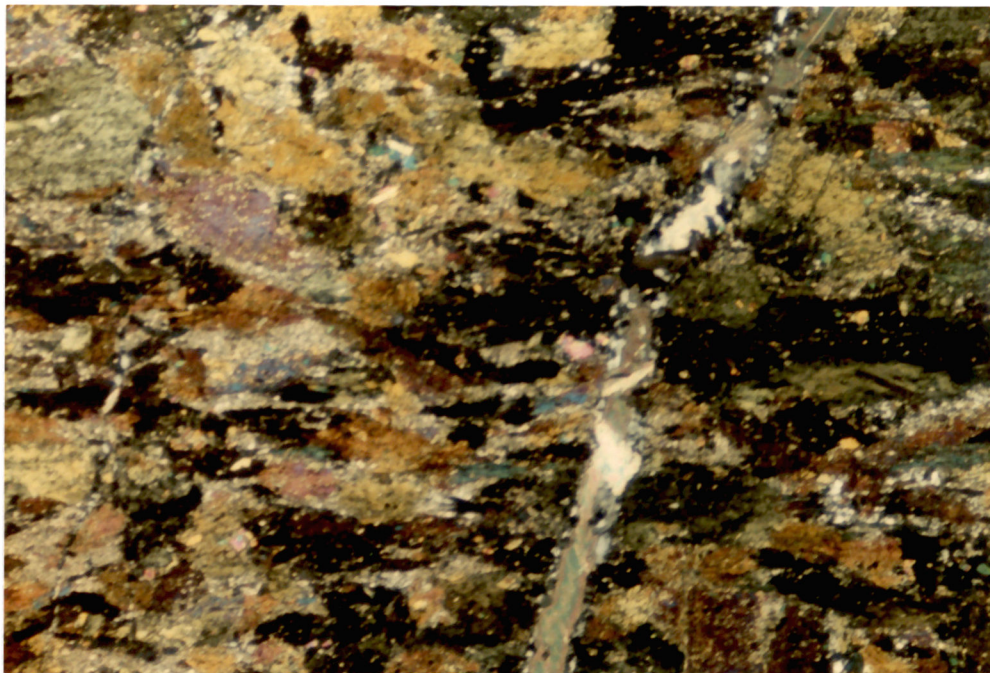


Plate 7. Photomicrograph of massive amphibolite, crossed nichols. Note feathery porphyroblastic texture of Fe-pargasite and Stage 2 vein. Long dimension of plate is 6.9 mm.

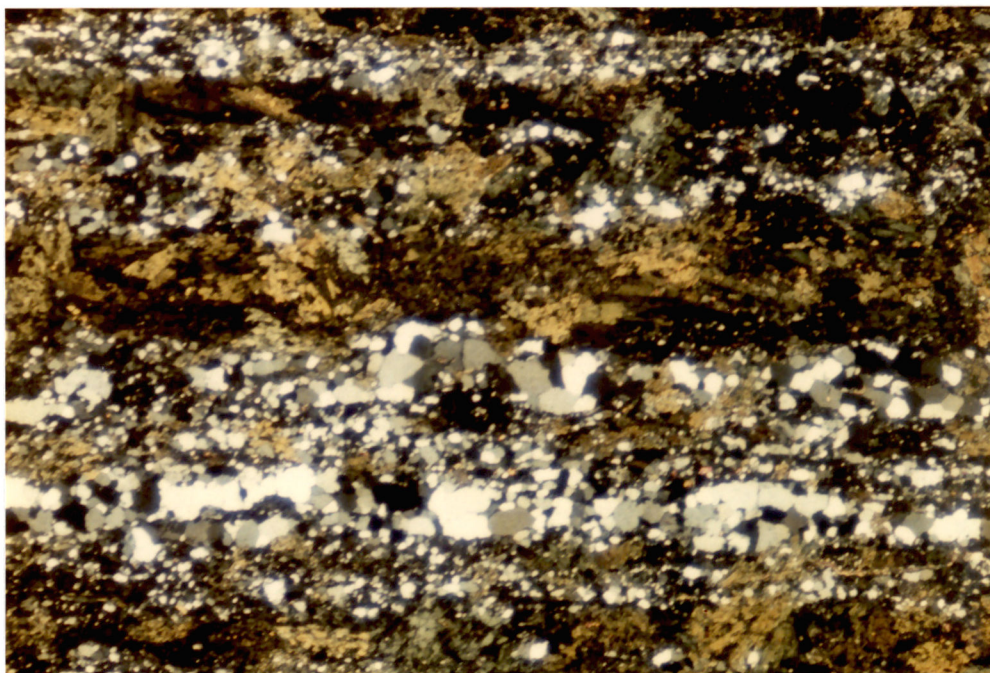


Plate 8. Photomicrograph of layered amphibolite, crossed nichols. Long dimension of plate is 6.9 mm.

poikiloblastic textures. Opaque inclusions (ilmenite ?) are found in nearly all grains. Microprobe analyses indicate that the hornblende is Fe-pargasite (scheme of Papike and others, 1974). A typical microprobe analysis of hornblende is provided in Table 2. Chemical analyses of select mineral phases were performed on the ARL-9 Spectrometer Microprobe at Virginia Polytechnical Institute and State University.

Hornblende occurs in a matrix of granoblastic quartz and plagioclase (.01 to .5 mm). A few composite quartz grains are incorporated in the matrix as well. Microprobe analyses of plagioclase (Table 2) indicate oligoclase/andesine compositions. Plagioclase is strongly sericitized and contains numerous epidote inclusions.

Biotite occurs as euhedral to anhedral stubby plates (.01 to .25 mm) in close association with Fe-pargasite. In the vicinity of veins, most biotite and hornblende alters to chlorite. Epidote is fine- to medium-grained (.05 to .25 mm) and is widely dispersed. A few epidote grains exhibit lime-green to light yellow pleochroism. Microprobe analyses of epidote (Table 2) average 12% Fe_2O_3 . Sphene, ilmenite, and magnetite (?) are accessory phases.

Quartz-rich Amphibolite

Quartz-rich amphibolites are visually the most distinctive host rock at the Portis gold mine. They are characterized by a "clotted" texture whereby hornblende, biotite, chlorite, epidote and opaques are concentrated in sprays and clots segregated from quartz and plagioclase (Plate 9). Unlike the other host rocks, quartz-rich amphibolites display no distinct bedding features.

TABLE 2. Microprobe Analyses of Selected Mineral Phases
from the Portis Gold Mine

Wt. %	Garnet	Amphibole	Albite	Oligoclase/Andesine
SiO ₂	37.95	39.51	68.33	58.26
TiO ₂	0.22	0.50	-----	-----
Al ₂ O ₃	20.77	15.07	20.06	27.56
FeO*	25.69	23.03	0.01	0.22
MgO	0.94	4.28	-----	-----
MnO	9.24	0.68	0.05	0.02
CaO	5.50	10.98	0.71	7.35
Na ₂ O	0.02	1.41	9.84	6.75
K ₂ O	0.03	1.06	0.08	0.10
Total	100.36	96.52	99.08	100.26

Recalculated Data (Anhydrous Basis)

Si	3.05	6.20	3.00	2.59
Al ₄	-----	1.80	1.03	1.44
Al ₆	1.96	0.98	-----	-----
Mg	0.11	1.00	-----	-----
Na	-----	0.43	0.84	0.58
K	-----	0.21	-----	0.01
Ca	0.48	1.85	0.03	0.35
Ti	0.01	0.06	-----	-----
Fe ₂	1.73	2.96	-----	-----
Fe ₃	-----	0.06	-----	-----
Mn	0.63	0.09	-----	-----

*Total Fe as FeO.

Mole % for garnet: Al₅₉ Sp₂₁ Gr₁₆ Py₄ An₀

Mole % for albite: Ab 95.66; An 3.84; Or 0.50

Mole % for oligoclase/andesine: Ab 61.99; An 37.41; Or 0.60

TABLE 2 (Continued)

Wt. %	Phengite	Epidote	Chlorite	Biotite
SiO ₂	48.22	39.20	26.40	36.93
TiO ₂	0.96	0.14	0.05	2.20
Al ₂ O ₃	29.29	24.48	17.95	17.10
FeO*	4.56	11.22	35.39	25.61
MgO	1.67	0.08	10.57	7.79
MnO	0.08	0.34	0.73	0.38
CaO	0.03	22.83	0.06	0.05
Na ₂ O	0.13	0.03	-----	0.12
K ₂ O	8.99	0.03	0.04	9.41
Total	93.93	98.35	91.19	99.59

Recalculated Data (Anhydrous Basis)

Si	6.55	3.05	5.66	5.53
Al ₄	1.45	-----	2.34	2.47
Al ₆	3.23	2.24	2.19	0.54
Mg	0.34	-----	3.38	1.75
Na	0.03	-----	-----	0.03
K	1.56	-----	0.01	1.80
Ca	-----	1.90	0.01	0.01
Ti	0.10	0.01	0.01	0.25
Fe ₂	-----	-----	6.34	3.20*
Fe ₃	0.52	0.73	-----	-----
Mn	-----	0.02	0.13	0.05

*Total Fe as FeO.

Fe/Fe+Al ratio for epidote: 0.245

Fe/Fe+Mg ratio for chlorite: 0.652

Fe/Fe+Mg ratio for biotite: 0.646

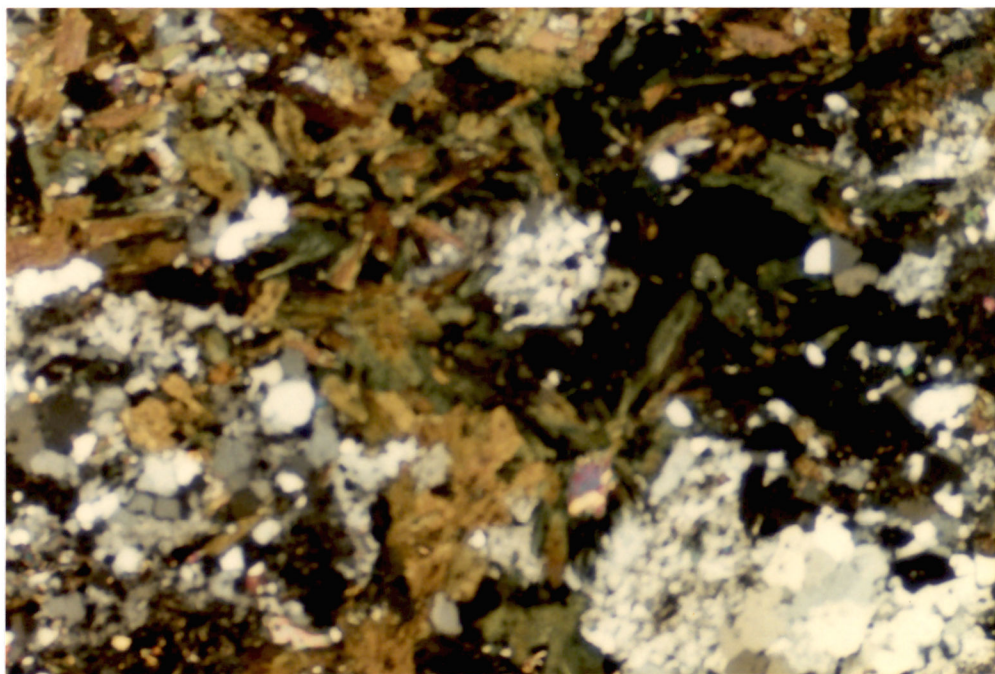


Plate 9. Photomicrograph of quartz-rich amphibolite, crossed nichols. Mafic clots consist of Fe-pargasite sprays with epidote, opaques and some biotite. Long dimension of plate is 3.08 mm.

Quartz-rich amphibolite layers are usually at least three meters thick, and they are conformably interbedded with metagraywackes, biotite phyllites and ore zone rocks. Quartz-rich amphibolites usually lie stratigraphically above and below the ore zone.

The constituent mineralogy of quartz-rich amphibolites is hornblende + biotite + quartz + plagioclase + opaques + epidote + apatite +/- sphene +/- chlorite +/- phengite +/- garnet +/- calcite +/- allanite +/- zircon. The assemblage is similar to, but modal percentages are slightly different (Table 1) from those of amphibolites.

Hornblende porphyroblasts form radiating clusters, bow-ties or poikiloblastic grains. Maximum grain size varies from 0.25 to 2 mm. Hornblende in quartz-rich amphibolites is also classified as Fe-pargasite, based on microprobe analyses (Papike and others, 1974).

Biotite generally forms subhedral to euhedral plates less than 0.5 mm in length. Chlorite is fine- to medium-grained and has an Fe/Fe+Mg ratio of 0.65. These chlorites plot in the brunsvigite field (Deer and others, 1962). Epidote associated with mafic clots is less than 0.25 mm in diameter and occurs as equant, blocky grains or inclusions. Sphene is present as rounded blebs or subhedral rhombs. Blebs are frequently cored by ilmenite. Anhedral to subhedral opaque grains are widely dispersed but tend to occur as inclusions in mafic clots. Farrar (1985b) reported the presence of opaque inclusions in amphiboles from rocks from the Smithfield Formation. He interpreted these opaques as having exsolved from primary pyroxenes.

Subrounded quartz grains (.05 to .5 mm) exhibit a granoblastic-

polygonal texture, with well-developed triple junctions. Larger polycrystalline grains range up to 0.75 mm. These grains occasionally display undulatory extinction and some are slightly elliptical, similar to composite quartz grains observed in the metagraywackes and layered amphibolites. Subhedral to anhedral oligoclase/andesine laths range from 0.25 to 2 mm in length. Oligoclase occurs as twinned and untwinned varieties. Carlsbad twins are the most common type, but albite and pericline (?) twins have been noted in several smaller grains. Most grains are moderately to highly sericitized and contain inclusions of epidote, chlorite, biotite, calcite, and apatite.

Common accessory phases of quartz-rich amphibolites include apatite, garnet, and zircon. Apatite occurs as acicular, prismatic inclusions in oligoclase and quartz. Garnet occurs as pink, anhedral porphyroblastic grains. Zircon is present as inclusions in pargasite and biotite, and the inclusions are highlighted by pleochroic halos.

Hydrothermal alteration has affected the texture and chemistry of a three-meter-wide zone in the lowermost quartz-rich amphibolite unit of PM-27. Biotite and pargasite in mafic clots are partially to completely altered to chlorite. Oligoclase is extensively altered to sericite. Symplectic intergrowths of vermicular quartz and plagioclase are very common in these alteration zones (Plate 10). Some quartz-feldspathic areas are pink from hematite staining. Localized lime-green colors are due to epidotization in the vicinity of hydrothermal veins. Epidote occurs as a grain-to-grain replacement of oligoclase and pargasite. Plate 11 illustrates the incipient growth of epidote inclusions in oligoclase and pargasite and the development of

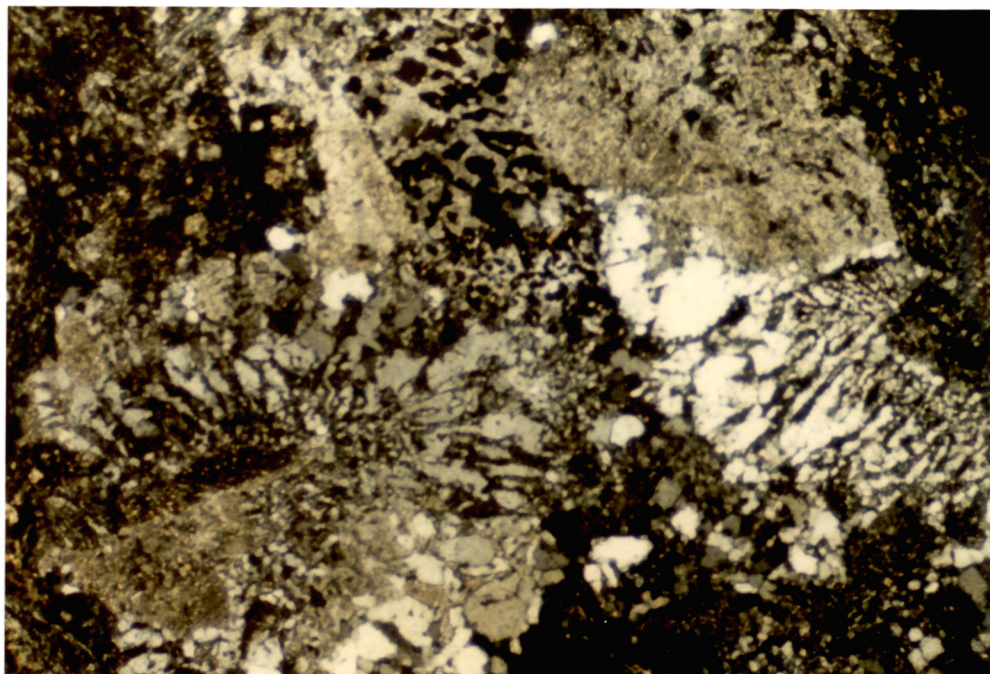


Plate 10. Photomicrograph of symplectic intergrowths of quartz and plagioclase, crossed nichols. This texture is common in altered portions of quartz-rich amphibolite. Long dimension of plate is 3.08 mm.

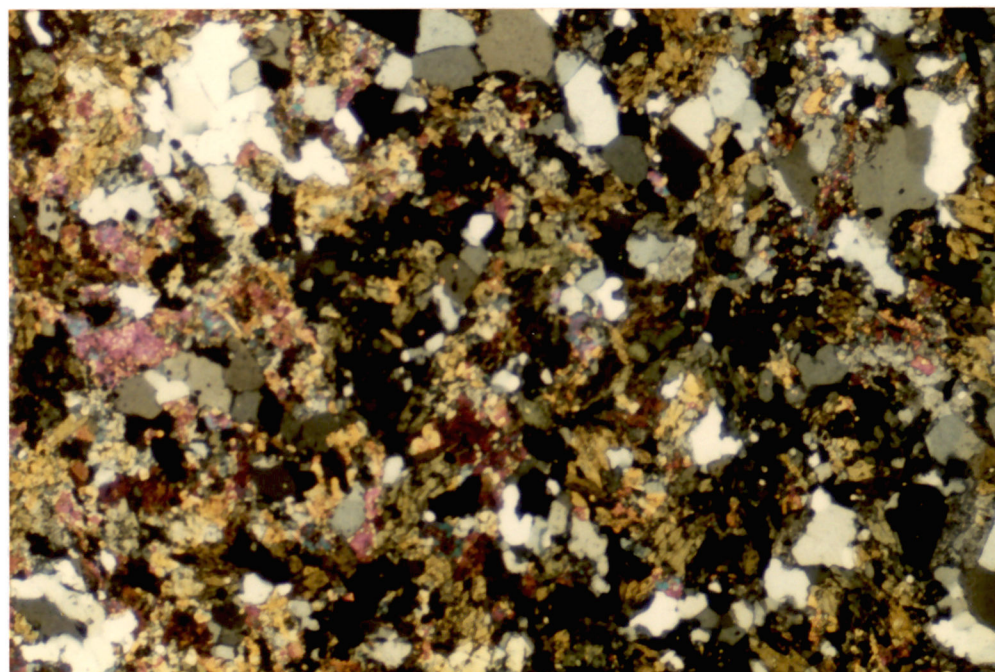


Plate 11. Photomicrograph of plagioclase altering to epidote, crossed nichols. Partial to near-complete alteration is observed from right to left of plate. Note epidote mimics the shape of the plagioclase. Long dimension of plate is 3.08 mm.

epidote pseudomorphs.

Biotite Phyllite

Biotite phyllite is the least abundant rock type found at the Portis gold mine. Thin beds, less than 0.5 meters, are scattered throughout the stratigraphic sequence and are in contact with all other rock types, including the ore zone. The fine- to medium-grained biotite phyllites are dark brown to black, soft, and thick to thinly laminated.

Biotite phyllites consist biotite + quartz + calcite + epidote + plagioclase + opagues +/- chlorite +/- garnet. Generally, quartz and plagioclase occur together as thin layers alternating with biotite (Plate 12). A strong S_1 foliation is defined by parallel alignment of biotite grains.

Dark brown biotite (.05 to .25 mm) occurs as subhedral to euhedral, tabular laths. Quartz and plagioclase (oligoclase/andesine) display a granoblastic-polygonal texture in layers segregated from biotite. Epidote is present as euhedral, prismatic grains (.25 mm) or as anhedral, rounded granular masses. These masses seem to be relict clasts, perhaps Ca-rich plagioclase that was replaced by epidote. Anhedral calcite blebs are spatially related to quartz-plagioclase layers, but they also occur in biotite layers. Occasionally, calcite forms thin bands, parallel to the foliation. Trace amounts of pink, subhedral to euhedral garnets are common.

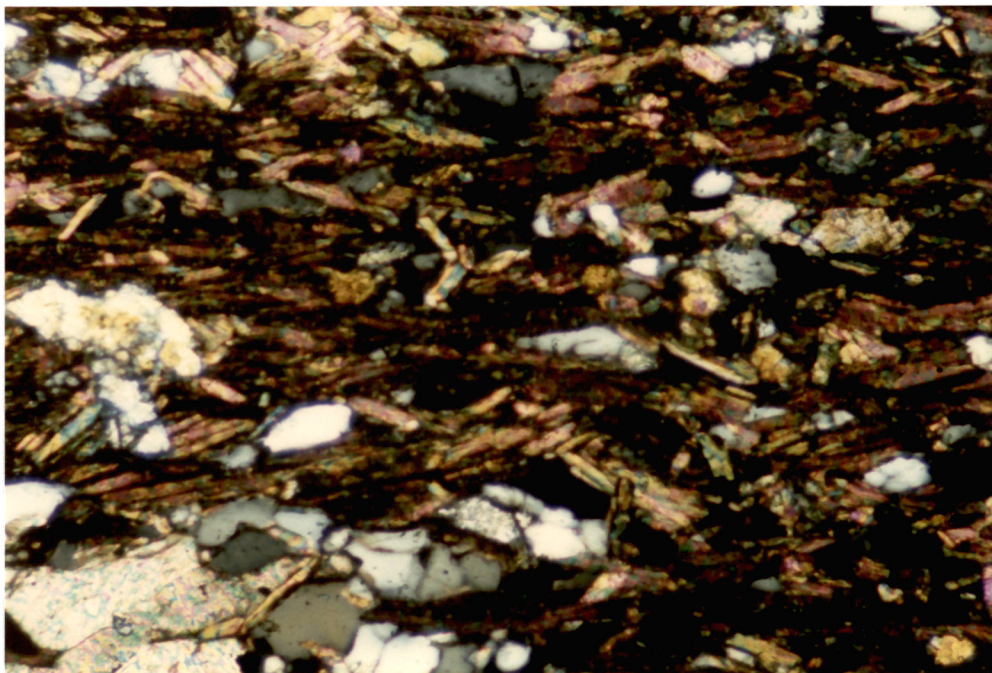


Plate 12. Photomicrograph of biotite phyllite, crossed nichols. Note well-developed S₁ foliation defined by biotite. Long dimension of plate is 1.24 mm.

Ore Zone Rocks

The two meter-thick ore zone layer in core PM-27 is interbedded with the quartz-rich amphibolites. Fresh samples are gray, very hard, and exhibit a dense, compact texture which may be attributed to silicification and stockwork quartz veins. In outcrop, the ore zone is termed the "White Belt" (Bryson, 1936) and it weathers to a bleached white, blocky, quartzo-feldspathic clay. Although hematite staining is common in the saprolite, it was not noted in fresh material.

The major components of the ore zone are albite + quartz + opaques. Accessory phases include biotite + phengite +/- chlorite +/- calcite +/- allanite +/- epidote +/- K-feldspar +/- zircon. Gold is found within and adjacent to stockwork quartz veins contained in the ore zone (Waltman, 1985). These quartz veins extend into the adjacent quartz-rich amphibolites. Foliation is not evident in the ore zone, but biotite occasionally forms thin discontinuous bands.

The ore horizon rocks consist of fine- to medium-grained, relatively equigranular groundmass of albite, quartz, and opaques (Plate 13). Quartz and albite grain textures vary from granoblastic-polygonal to interlobate. Quartz occurs as mono- to polycrystalline, subrounded grains ranging from 0.01 to 2.5 mm. Some composite grains display undulatory extinction. Groundmass albite is untwinned. Coarser albite (1 to 2.5 mm) generally exhibits carlsbad twinning. These larger albite laths commonly display irregular boundaries with matrix quartz.

Fine-grained biotite is olive-brown to reddish-brown with minute zircon inclusions. Chlorite occurs as individual grains in the matrix

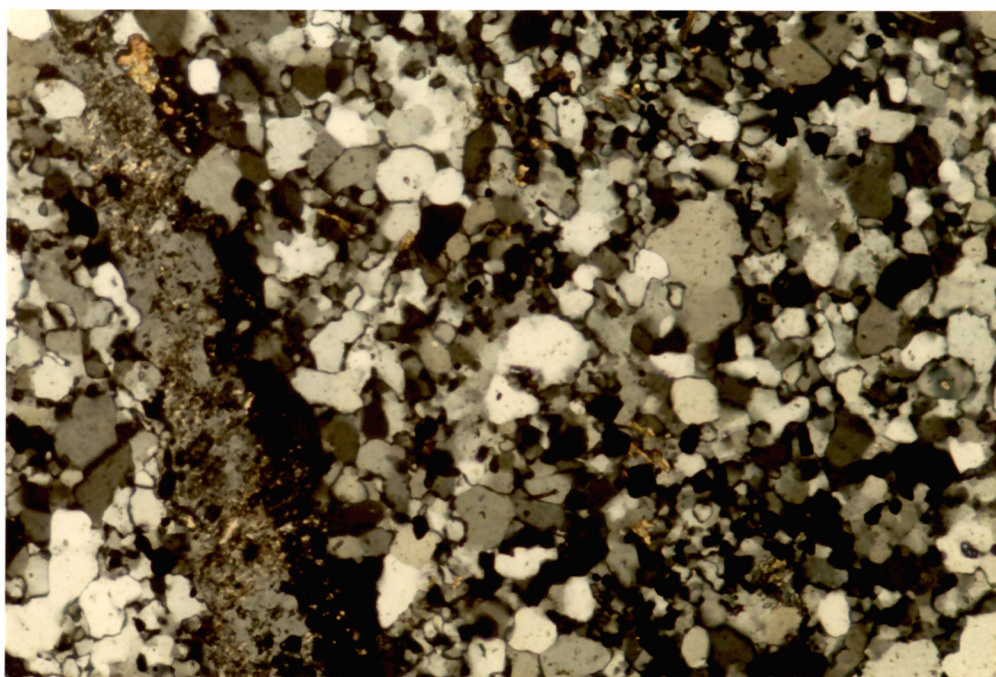


Plate 13. Photomicrograph of the ore zone rocks, crossed nichols. Note coarse-grained albite lath. Long dimension of plate is 1.24 mm.

or felted masses in contact with pyrite. Chlorite and biotite also occur together as parallel intergrowths. Phengite is typically medium-grained (.1 to .5 mm). Discrete phengite grains are subhedral and poikiloblastic, commonly enclosing quartz. White mica combined with opaques and plagioclase also forms aggregates or clots. These clots may be recrystallized fragments and/or xenoliths. Calcite forms anhedral blebs with embayed boundaries. K-feldspar is recognized by grid twinning in a few widely dispersed grains. Opaques consist of pyrite, pyrrhotite, magnetite, and ilmenite (?).

METAMORPHISM

Metamorphic conditions within the E.C.V.S.B. range from greenschist to amphibolite facies (Farrar, 1985a). At the Portis gold mine, regional metamorphism has produced a mineral assemblage typical of epidote-amphibolite facies. Metamorphic assemblages in pelitic rocks include quartz + albite + phengite +/- biotite +/- chlorite +/- garnet +/- hornblende +/- tourmaline +/- apatite +/- epidote +/- sphene +/- opaques. Metamorphic assemblages in mafic rocks contain epidote + hornblende + oligoclase/andesine + chlorite + biotite +/- garnet +/- calcite +/- quartz +/- apatite +/- phengite +/- sphene +/- opaques.

Protolith phases have undergone extensive metamorphic recrystallization. Grain boundaries of fine-grained quartz and plagioclase commonly intersect at triple points, indicative of a granoblastic-polygonal texture (Spry, 1979). Coarser-grained quartz is found as stringers and granoblastic ellipsoidal polycrystalline grains. Porphyroblastic textures are commonly found in all rock types. Phases such as garnet, biotite, hornblende and some plagioclase tend to develop as large grains during prograde reactions. Although apatite normally occurs as inclusions, porphyroblastic apatite was observed in one biotite-rich layer. Ilmenite, pyrite and allanite have rims of sphene, chlorite and epidote, respectively.

A pervasive S_1 foliation is parallel to the relict bedding (S_0) of the volcanoclastic sediments. In the pelitic rocks, the S_1 foliation

is defined by parallel alignment of mica plates and by a dimensional-preferred orientation of groundmass quartz and plagioclase grains. Most ellipsoidal quartz grains and stringers are also parallel to the S_1 foliation. In mafic units, the S_1 foliation is typically parallel to the compositional layering (S_0). The S_1 foliation is strongly developed in biotite-rich zones, but is less pronounced in amphibole-rich layers where amphibole clusters and coarse-grained plagioclase are randomly oriented. In some amphibole-rich layers, streaks of ilmenite and coarse-grained biotite display a weakly developed foliation parallel to S_1 . A less pronounced crenulation cleavage (S_2) occurs at a 30° angle to the relict bedding. The S_2 foliation occurs in both pelitic and mafic rocks and is marked by a parallel alignment of biotite, chlorite and phengite grains and by bent S_1 mica grains. In some of the mafic units discontinuous streaks of ilmenite are wrapped into "S-shaped" patterns perhaps as a result of development of the crenulation cleavage. The S_1 and S_2 foliations represent two distinct deformational events which may relate to the Taconic (?) and Alleghanian orogenies.

Chemical analyses of select mineral phases are shown in Table 2. Plagioclase compositions are primarily albite (An_{0-10}) for pelitic rocks and oligoclase-andesine (An_{25-40}) for mafic rocks. Garnets are almandine-rich (Al59 Sp21 Gr16 Py4 An0) and are compositionally zoned. From core to rim, they exhibit a decrease in MnO and an increase in FeO and MgO. Amphiboles are mostly Fe-pargasite and epidote exhibits an average Fe/Fe+Al ratio of 0.22 indicating very little Fe-enrichment. White mica occurs as sericite alteration of plagioclase and as discrete

grains or masses of phengite. Fe-rich chlorite and biotite occur in all rock types, but they are most commonly associated with mafic units.

Epidote-amphibolite facies metamorphic conditions are strongly supported by the chemical compositions of the mineral phases present at the Portis mine. The coexistence of two plagioclase compositions at the Portis suggests either the development of a peristerite gap as metamorphic conditions approach amphibolite facies, or it may simply reflect different bulk compositions before metamorphism. Many of the plagioclase grains in the mafic rocks contain epidote inclusions suggesting that calcium held within the structure of the precursor plagioclase was released to form epidote during metamorphism. Spessartine-rich garnets are commonly found in greenschist terranes, such as the Carolina Slate belt (Fodor and others, 1981; Campbell, 1984), but at the Portis, garnets are Fe-enriched and relatively depleted in manganese suggesting that metamorphic conditions were approaching amphibolite facies. This chemical zonation patterns suggest that the garnets are prograde phases. The existence of Fe-pargasite, an aluminous hornblende, and the absence of actinolite at the Portis are indicative of epidote-amphibolite to amphibolite facies. Fe-enrichment in the hornblende was probably a reflection of high iron contents in the protolith. Although Fe content in epidote is not a good metamorphic grade indicator, low Fe/Fe+Al ratios are typical of epidote in epidote-amphibolite grade rocks. In the pelites, phengite or iron-enriched muscovites typically grow during epidote-amphibolite facies conditions (Ernst, 1963). Based on these data the metamorphic

assemblage probably corresponds with the M_2 regional metamorphic event as recognized by Farrar (1985a).

Hydrothermal Alteration

Two stages of vein development are evident at the Portis mine. Relative age differences between the two periods of vein formation are based on crosscutting relationships and on textural features attributed to deformation.

Stage 1 or older veins consist almost entirely of granoblastic quartz with traces of intergranular calcite (Plate 14). Quartz grains commonly display undulatory extinction and deformation lamellae. Grain boundaries are often sutured or crenulated. These features are the result of strain (Spry, 1979). Associated minerals include amphibole, epidote, biotite, chlorite, sphene, white mica, magnetite, and pyrite.

Stage 1 quartz veins are often associated with alteration haloes which may extend for several centimeters into the host rocks. Alteration haloes may be zoned. Generally, coarse-grained phases are located along the edge of the vein as a vein-wall lining. Adjacent to these contact zones lie "bleached" portions of wall rock that are usually epidotized and depleted in ferro-magnesian minerals. Biotite is absent in the "bleached" zones. Apparently, minerals situated along the vein contact grew at the expense of ferro-magnesian phases from the now depleted "bleached" zone.

Randomly oriented Stage 1 quartz veins occur in all rock types at the Portis mine. Highest concentrations of Stage 1 veins occur in the

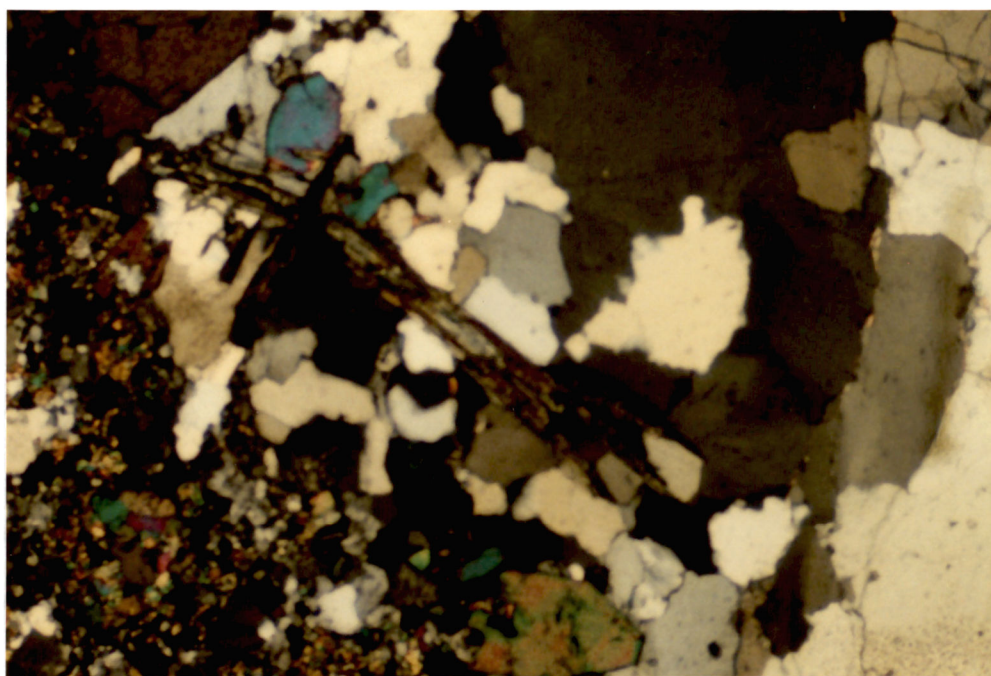


Plate 14. Photomicrograph of Stage 1 vein with wall-rock contact, crossed nichols. Note sutured boundaries of quartz grains. Long dimension of plate is 0.32 mm.

ore zone and immediately adjacent rock units. Some Stage 1 quartz veins are oriented parallel to the original bedding (S_0) and the individual grains have textural characteristics similar to the ellipsoidal quartz grains. Other Stage 1 quartz veins are folded with their axial planes parallel to the S_1 foliation.

Stage 2 or younger veins contain varying amounts of potassium feldspar ($Or_{>95}$), calcite, chlorite, epidote and a Ca-Al zeolite, possibly stilbite. The potassium feldspar is believed to be adularia, a common constituent of hydrothermal veins (Rose and Burt, 1979). The zeolite occurs as sheaf-like aggregates (Plate 15), a characteristic habit of stilbite (Hurlbut and Klein, 1977). A simple paragenetic sequence is defined by the Stage 2 vein components. Adularia and chlorite developed first. These phases usually line vein walls. Calcite was next, followed by stilbite. Sparse epidote is considered to have formed early in the paragenetic sequence with chlorite and adularia.

Wall rocks in contact with Stage 2 veins are strongly altered. Alteration zones range from less than a millimeter to 2 meters and may be brecciated. One particular zone near the bottom of PM-27 contains vermicular symplectic intergrowths of plagioclase and quartz. These intergrowths are only found in altered rock suggesting that this texture is a product of the alteration. Typically, biotite and hornblende are partially to completely altered to chlorite. Chlorite that formed during the Stage 2 hydrothermal event can be distinguished from metamorphic chlorite by the presence of minute Ti-oxide (?) grains along the fringes of the chlorite flakes. Alteration also involves

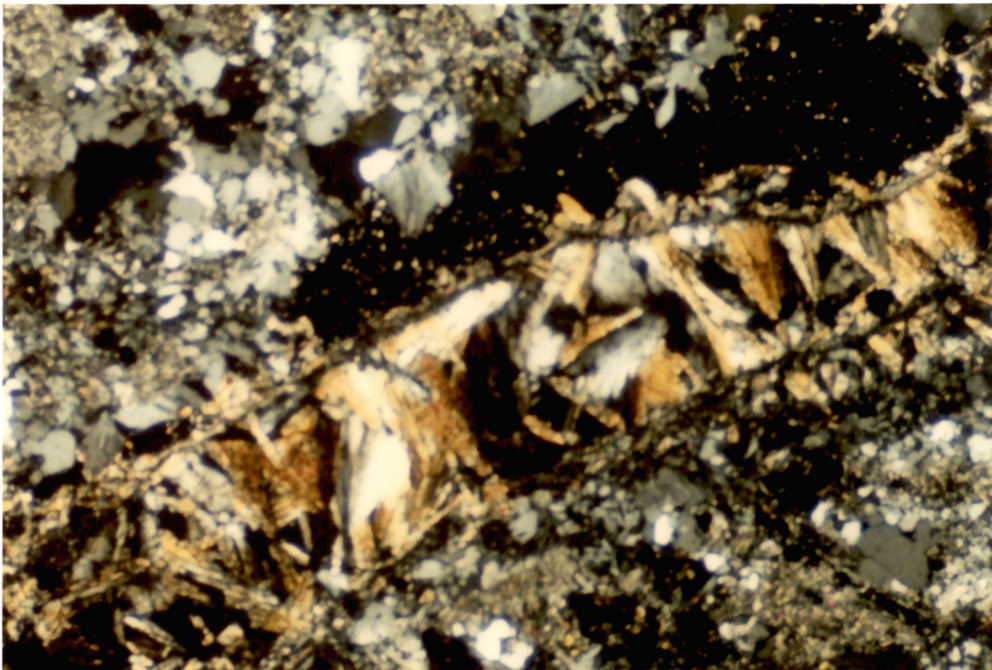


Plate 15. Photomicrograph of Stage 2 vein, crossed nichols. Note sheaf-like aggregates of stilbite (?). Long dimension of plate is 0.32 mm.

plagioclase grains which are heavily sericitized and epidotized.

Stage 2 veins are randomly oriented and crosscut the S_1 foliation at high angles. They also crosscut and offset Stage 1 quartz veins and ellipsoidal quartz grains. The Stage 2 veins probably represent post-metamorphic hydrothermal activity which produced a localized zeolite facies overprint on the host rocks at the Portis gold mine.

HOST ROCK GEOCHEMISTRY

Thirty seven samples from the Portis gold mine were analyzed for major and trace element (Rb, Sr, Y, Zr, and Ba) abundances. Chemical analyses are provided in Appendix B. Sample locations are illustrated in Figure 2. Descriptions of sampling and sample preparation, analytical procedures and parameters, and accuracy and precision estimates are reported in Appendix C.

A non-parametric factor analysis technique utilized by SAS (Statistical Analysis System) was applied to the chemical data. Clustering, based on a geochemical data matrix (37 samples x 15 variables) was used to designate rock types. The fifteen variables represent the major and trace element concentrations for each geochemical sample. Factor analysis yielded three chemically distinct groups, named on the basis of rock terms defined by the modal data: 1) metagraywackes; 2) mafic rocks; and 3) quartz-rich amphibolites. Biotite phyllites which are recognized as a distinct rock type on the basis of modes, cluster with amphibolites as mafic rocks. Rocks from the ore zone will be discussed separately although they cluster geochemically with the metagraywackes. Two anomalous samples (27-72, -85) cluster with the quartz-rich amphibolites. Average chemical analyses are provided in Table 3.

Harker variation plots of the major elements (Fig. 5), especially MgO, separate the three geochemical clusters determined by factor analysis. Fe_2O_3 , MgO, Al_2O_3 , CaO, and MnO are negatively correlated

with SiO_2 in all rock types. Although trends for CaO and MgO in mafic

Table 3. Average Chemical Analyses of Host Rock Types at the Portis Gold Mine.

	Metagraywacke n=10	Quartz-rich Amphibolite n=16	Mafic Rocks n=10
SiO_2	71.05 (3.5)	57.60 (2.9)	49.50 (1.8)
TiO_2	0.75 (0.1)	1.55 (0.3)	1.00 (0.3)
Al_2O_3	13.67 (1.5)	14.65 (1.9)	15.70 (0.9)
Fe_2O_3^*	4.35 (0.7)	12.55 (2.6)	10.10 (1.4)
MgO	1.08 (0.4)	2.40 (0.6)	7.35 (1.3)
MnO	0.07 (0.01)	0.23 (0.05)	0.26 (0.05)
CaO	1.90 (0.6)	6.00 (1.0)	8.45 (1.9)
Na_2O	3.20 (1.0)	2.95 (0.7)	1.85 (0.9)
K_2O	2.51 (1.1)	1.60 (0.6)	2.45 (1.9)
P_2O_5	0.10 (0.03)	0.28 (0.1)	0.15 (0.05)
Ba	644 (194)	349 (142)	212 (66)
Rb	96 (39)	63 (33)	95 (75)
Sr	135 (71)	182 (59)	219 (83)
Y	31 (8)	37 (8)	21 (6)
Zr	217 (47)	136 (72)	54 (36)

*Total Fe as Fe_2O_3 .

Major elements in weight %; trace elements in ppm.

n is size of population for each rock type.

one standard deviation from the mean is shown in parentheses.

rocks are not distinct. TiO_2 values for quartz-rich amphibolites and metagraywackes are negatively correlated, but mafic rocks show a very poor correlation. K_2O and Na_2O display no trends which may be due to their high mobility and alteration. A negative trend is apparent for P_2O_5 in the metagraywackes, but moderate positive trends are found in the mafic rocks and the quartz-rich amphibolites. Correlation coefficients (r), displayed in Table 4, were calculated for each element vs. silica for each rock type.

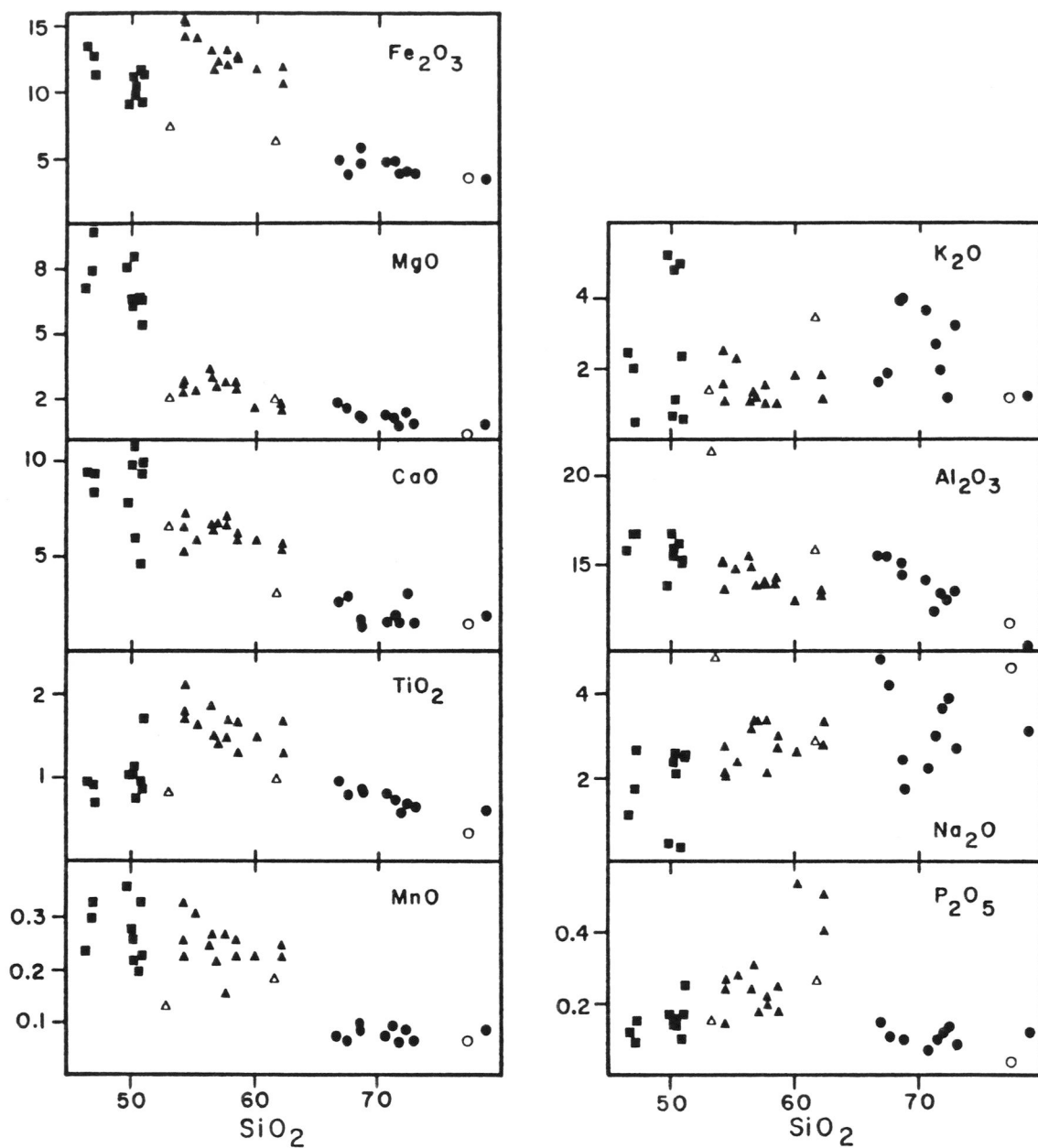


Figure 5. Major Element Harker Diagrams for the Rocks of the Portis Gold Mine.

Symbols for the rock types are; metagraywacke (●), mafic rocks (■), quartz-rich amphibolite (▲), ore zone rocks (○), and the anomalous samples (△). All analyses are in weight percent.

Metagraywacke

SiO₂ content of metagraywackes from the Portis gold mine ranges

Table 4. Correlation Coefficients (r) for the Major Elements vs. Silica.

	Metagraywacke	Quartz-Rich Amphibolite	Mafic Rocks
TiO ₂	-0.82	-0.26	0.40
Al ₂ O ₃	-0.98	-0.51	-0.40
Fe ₂ O ₃	-0.65	-0.42	-0.66
MgO	-0.87	-0.52	-0.56
MnO	-0.10	-0.16	-0.24
CaO	-0.31	-0.55	-0.17
Na ₂ O	0.38	-0.07	0.09
K ₂ O	-0.46	0.15	0.20
P ₂ O ₅	-0.37	0.65	0.50

from 61.74 to 78.85 weight %. The average silica content (71.05 Wt.%) is slightly higher than typical Carolina Slate belt graywackes (Allen and Wilson, 1968; Butler and Daniel, 1969; Seiders, 1978; and Green and others, 1982). Table 5 compares the average major element geochemistry of the Portis metagraywackes with graywackes from other regions.

Two subdivisions (A and B) of metagraywackes have been recognized on the basis of geochemistry. Metagraywackes comprising subgroup A (27-73, -76, -79, -80, -84, -86) contain Na₂O concentrations greater than 3.0 weight % and K₂O values less than 3.0 weight %. Subgroup B metagraywackes (27-81, -83, -89, -91) exhibit Na₂O contents less than 3.0 weight % and K₂O values greater than 3.0 weight %. Trace element concentrations in subgroup A are characterized by higher Sr and lower Ba, Rb, and Y than subgroup B. Texturally, subgroup A samples are quartzo-feldspathic metagraywackes (sandstone) and subgroup B samples

Table 5. Comparison of Major Element Geochemistry of Metagraywackes from the Portis Gold Mine and other Graywackes

Wt. %	PGM	YF	OCNC	RENG	PET	CMVR
SiO ₂	71.05	65.82	64.50	70.59	66.70	68.20
TiO ₂	0.75	1.11	0.85	0.64	0.60	0.38
Al ₂ O ₃	13.65	16.78	15.80	12.59	13.50	16.10
Fe ₂ O ₃ *	4.35	6.15	7.20	4.97	5.10	3.13
MgO	1.10	1.52	1.80	1.51	2.10	1.10
CaO	1.90	1.60	0.91	1.61	2.50	3.20
MnO	0.07	0.08	0.18	0.08	0.10	----
K ₂ O	2.50	2.20	3.00	2.19	2.00	2.33
Na ₂ O	3.20	3.03	2.40	2.76	2.90	3.80
P ₂ O ₅	0.10	----	0.06	----	0.20	0.08
K ₂ O/Na ₂ O	0.78	0.73	1.25	0.79	0.69	0.61

*Total Fe as Fe₂O₃.

PGM; Average Portis gold mine metagraywacke.

YF; Aver. Yadkin graywacke, Albemarle, NC (Butler and Daniel, 1969).

OCNC; Orange County, NC graywacke (Allen and Wilson, 1968).

RENG; Aver. Rensselaer graywacke, Troy, NY (Ondrick and Griffiths, 1969)

PET; Aver. of 61 graywackes (Pettijohn, 1963).

CMVR; Dacitic crystal tuff, Moore County, NC (Green and others, 1982).

are micaceous metagraywackes (mudstone/siltstone). Variations among major and trace element concentrations in subgroups A and B reflect modal differences in Na-rich plagioclase (albite) and K-rich micas (phengite). Barium and Rb readily substitute for K in micas where they are adsorbed on clays via ion exchange. A $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{CaO}$ plot (Fig. 6) shows the chemical diversity of subgroups A and B. Subgroup A metagraywackes cluster in the field of felsic nonalkalic volcanic rocks of the Piedmont as proposed by Rankin (1975). Subgroup B metagraywackes plot outside the field of felsic nonalkalic volcanic rocks closer to the K_2O apex of Figure 6.

Mafic Rocks

Mafic rocks from the Portis gold mine contain 46.63 to 51.12 weight % SiO_2 . These rocks are chemically similar to amphibolites found throughout the Carolina Slate belt (Table 6). Mafic rocks are subdivided into two groups (A and B) based on major and trace element geochemistry. Subgroup A correlates with modal amphibolites containing nearly 60% hornblende. Subgroup B correlates with biotite phyllites with 50% modal biotite and no amphibole.

Subgroup A (27-70, -71, -74, -75, -78, -82, and 37-7) is characterized by higher CaO and by lower K_2O concentrations than Subgroup B (27-87, -88, and 37-3) (Figure 6). Barium, Rb, and Sr correlate with K_2O and CaO in subgroups A and B. Strontium ($r=0.40$) exhibits a moderately positive correlation with CaO in subgroup A while Ba ($r=0.45$) shows a similar correlation with K_2O in subgroup B. Rubidium ($r=0.99$) displays a very strong positive correlation with K_2O

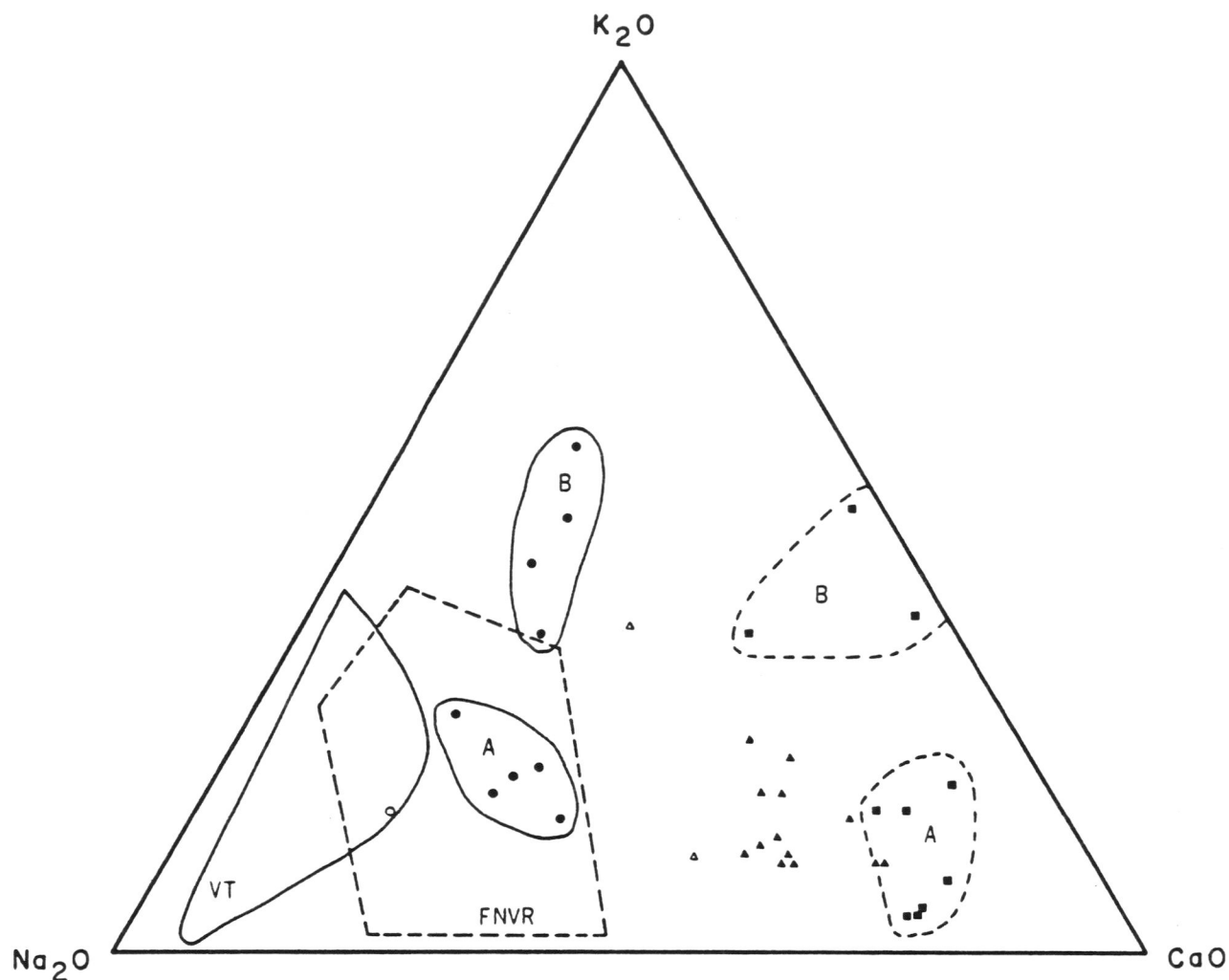


Figure 6. K_2O - Na_2O - CaO Diagram for the Portis Gold Mine Rocks. Field marked VT represents Na-enriched vitric tuffs, from Butler and Ragland, 1969. Note the ore zone sample (○) plots within this field. Dashed line pentagon marked FNVR represents the field of felsic nonalkalic volcanic rocks, from Rankin, 1975. Irregular solid line fields (A,B) correspond to metagraywacke (●) subgroups A and B. Irregular dashed line fields (A,B) are mafic rock (■) subgroups A and B, also quartz-rich amphibolite (▲), and anomalous samples (△).

Table 6. Geochemical Comparison of Mafic Rocks from the Portis Gold Mine and other Amphibolites

Wt. %	PGM-A	PGM-B	HG	VIRG	GL
SiO ₂	49.10	50.35	49.40	47.41	49.29
TiO ₂	1.00	1.05	1.24	0.56	1.33
Al ₂ O ₃	15.95	15.05	15.10	14.96	15.19
Fe ₂ O ₃ *	11.35	10.15	12.19	9.85	11.17
MgO	7.45	7.05	6.26	7.35	8.14
CaO	9.45	6.05	10.80	7.25	10.06
MnO	0.27	0.25	0.18	0.23	0.23
K ₂ O	1.35	4.93	0.30	1.85	0.57
Na ₂ O	2.15	1.15	2.92	3.33	1.82
P ₂ O ₅	0.15	0.14	0.17	0.15	0.14
K ₂ O/Na ₂ O	0.63	4.29	0.10	0.56	0.31
Ba	188	267	71	297	122
Rb	55	188	13	60	---
Sr	239	172	198	---	152
Y	22	17	25	19	30
Zr	59	40	72	---	128

*Total Fe as Fe₂O₃.

PGM-A; Average Portis gold mine amphibolite, subgroup A.

PGM-B; Average Portis gold mine amphibolite, subgroup B.

HG; Average Hillabee greenstone, AL (Tull and Stow, 1982).

VIRG; Aver. Chopawamsic amphibolite, VA (Pavlidis and others, 1982).

GL; Average Gossan Lead amphibolite, NC/VA (Gair and Slack, 1984).

in subgroup B.

Mafic rocks from subgroup A and B are interpreted as metamorphosed mafic pyroclastic units. The significantly higher K_2O and lower CaO concentrations found in subgroup B suggest that these rocks may have been altered. Mafic rocks from the Portis mine plot on an AFM diagram (Fig. 7) in the field of basalts from the Carolina Slate belt (Feiss, 1982). Mafic volcanic rocks from the slate belt typically straddle the boundary between the calc-alkaline and tholeiitic fields, but AFM diagrams may not be valid for characterizing mafic rocks from the Carolina Slate belt due to the highly mobile nature of K_2O , Na_2O , and MgO in altered terranes (Feiss, 1982). The mobility of alkalis also precludes the usage of the total alkalis vs. silica diagram; however, amphibolites from subgroup A are for the most part subalkaline and subgroup B samples are slightly alkalic (diagram not shown).

Volcanogenic suites may be characterized through use of plots of incompatible elements which are less affected by alteration (Jakes and White, 1972; Black, 1980; Rogers, 1982; and Feiss, 1982). According to Feiss (1982), most rocks from the Carolina Slate belt plot in the calc-alkaline field on a Ti-Zr-Y diagram. Mafic rocks from the Portis gold mine are distinctly calc-alkaline (Fig. 8). Titanium concentrations of less than 1.3 weight % from Carolina Slate belt volcanic rocks (Fig. 9) are indicative of magmas generated in a subduction-related environment (Feiss, 1982). Mafic rocks from the Portis average 1.00 weight % TiO_2 . Sample 27-75 (1.70 weight % TiO_2) is anomalously high.

Major and trace elements in mafic to intermediate volcanic rocks have been used in recent studies (Jakes and White, 1972; Whitney and

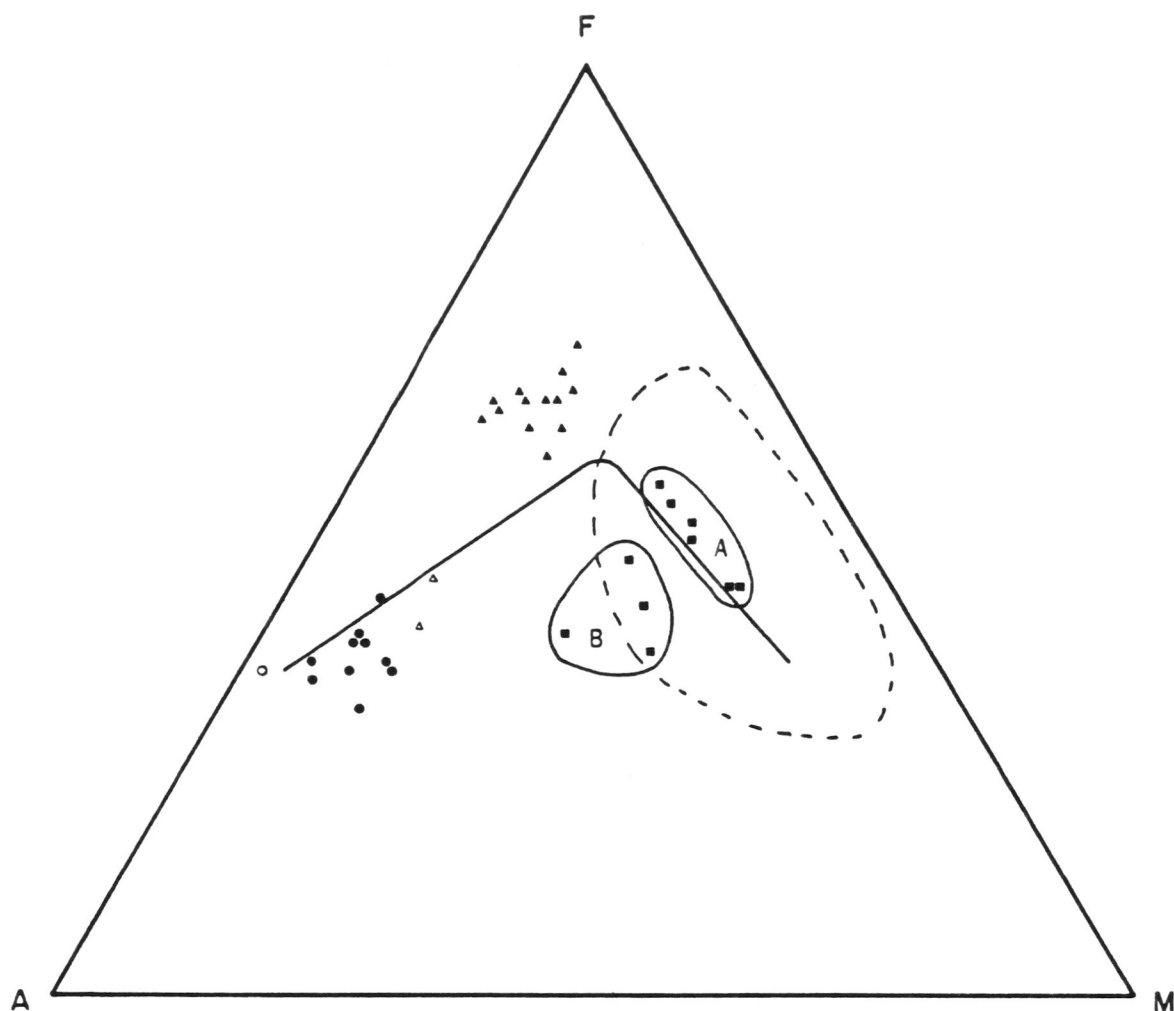


Figure 7. AFM Diagram of the Host Rocks from the Portis Gold Mine. Solid line represents a calc-alkaline/tholeiitic trend for volcanic rocks (Irvine and Barager, 1971). Dashed line encloses mafic volcanic rocks from the Carolina Slate belt, after Feiss (1982). Solid-line fields (A,B) represent subgroups A and B for mafic rocks (■). Other rock types included are quartz-rich amphibolite (▲), ore zone rocks (○), metagraywacke (●), and the anomalous samples (△) which plot with the metagraywackes.

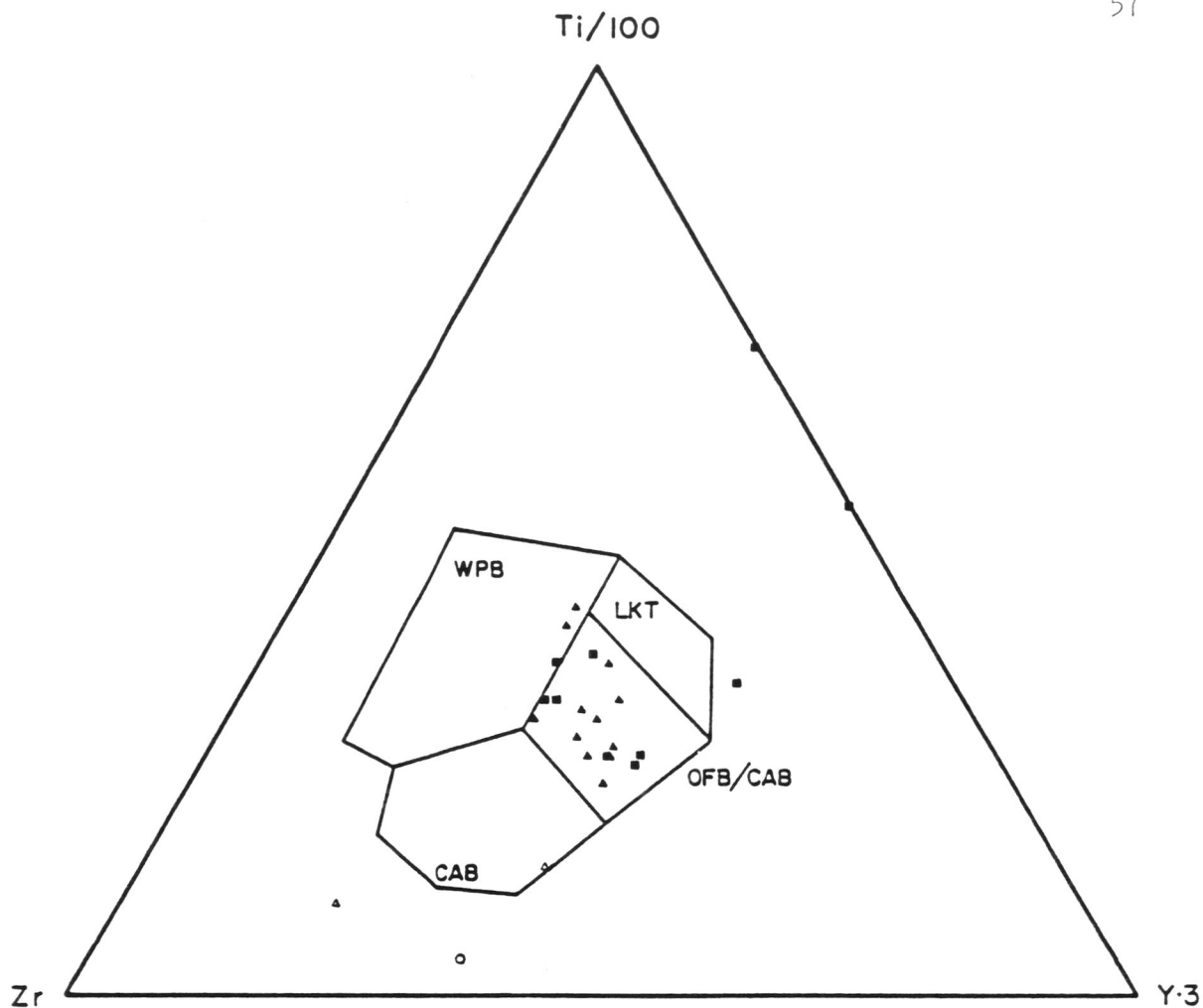


Figure 8. Ti-Zr-Y Diagram of the Mafic Rocks and Quartz-Rich Amphibolites from the Portis Gold Mine. Discriminant fields are from Pearce and Cann (1973), WPB = within plate basalts, OFB = ocean floor basalts, CAB = calc-alkaline basalts, and LKT = low potassium tholeiites. Symbols for rock types are mafic rocks (■), quartz-rich amphibolites (▲), ore zone rocks (○), and the anomalous samples (△).

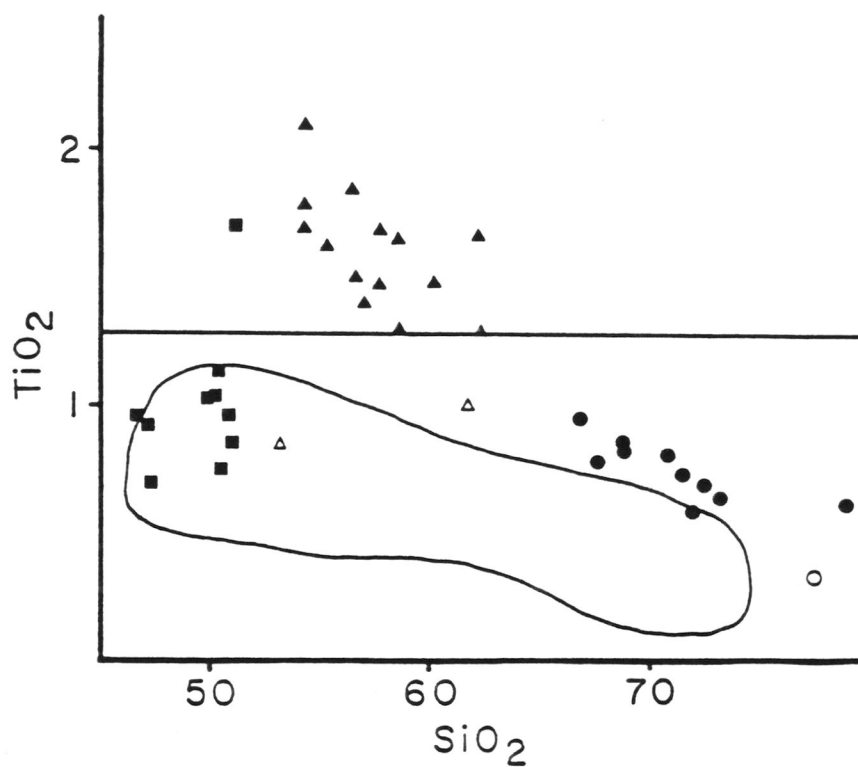


Figure 9. TiO_2 vs. SiO_2 Diagram of Host Rocks from the Portis Gold Mine. Horizontal line represents 1.3 weight % TiO_2 . Irregular solid-line field encloses Carolina Slate belt volcanics, after Feiss (1982). Rocks from the Portis are mafic rocks (■), metagraywackes (●), quartz-rich amphibolites (▲), ore zone rocks (○), and the anomalous samples (△).

others, 1978; Black, 1980; and Rogers, 1982) to determine the composition of crustal material underlying island arc terranes. Rogers (1982) suggested that the Carolina Slate belt probably lies on continental margin crust thin enough to produce calc-alkaline volcanics. He based his conclusions on trends of major and trace elements observed in basalts and andesites. Major and trace element contents of mafic pyroclastic units at the Portis are similar to those reported by Rogers (1982). TiO_2 and Ba suggest that a relatively thin (?) wedge of continental margin material may lie beneath the slate belt (Table 7). K_2O and Rb concentrations of the Portis mafic rocks are much higher than the values reported by Rogers (1982) for mafic igneous rocks (Table 7). The anomalously high values of K_2O and Rb may be a reflection of their mobile nature. Similar trends are apparent in the quartz-rich amphibolites; however, TiO_2 is much higher than the values observed by Rogers.

Quartz-rich Amphibolite

The SiO_2 content of quartz-rich amphibolites varies from 54.36 to 62.34 weight % and averages 57.6 %. Table 8 compares quartz-rich amphibolites with igneous rocks of similar intermediate composition. Quartz-rich amphibolites are characterized by much higher Fe_2O_3 and TiO_2 concentrations, higher K_2O , and slightly lower Na_2O and Al_2O_3 values than typical andesitic rocks from the Carolina Slate belt. Significant modal quantities of magnetite, ilmenite, and sphene are a reflection of the high iron and titanium contents observed in most quartz-rich amphibolites.

Table 7. Average Chemical Content of Calc-Alkaline Rocks from Island Arcs and Continental Margins compared with the Portis Mine.

	Continental Margin*	Island Arc*	Portis Mine
Mafic Rocks			A / B
K ₂ O	0.85	0.51	1.35 / 4.93
TiO ₂	1.29	0.87	1.00 / 1.05
Ba	274	167	188 / 267
Rb	20	7	55 / 188
Sr	501	344	239 / 172
Zr	---	49	59 / 40
Y	---	12	22 / 17
Quartz-rich Amphibolites			
K ₂ O	2.00	1.00	1.60
TiO ₂	0.90	0.70	1.55
Ba	500	300	349
Rb	50	15	63
Sr	600	400	182
Zr	200	100	136
Major elements in Wt.%, Trace elements in ppm.			
*Data from Rogers (1982).			

Samples (27-72 and -85) do not plot as typical quartz-rich amphibolites on some plots. Sample 85 is considered to be transitional to more felsic rock types. Although C27-72 clusters geochemically with the quartz-rich amphibolites, it is characterized by lower silica (53.14 wt.%) and Fe₂O₃ (7.59 wt.%) and higher Al₂O₃ (21.07 wt.%) and Na₂O (4.92 wt.%) concentrations than the other quartz-rich amphibolites. Sample 72 is associated with a tourmaline-rich horizon near the top of PM-27 that is suspected of being a chemical sediment.

Table 8. Major Element Content of Quartz-rich Amphibolites from the Portis Mine Compared to other Rocks of Intermediate Composition

Wt. %	PGM	NOCK	MCNC	VIRG	AND	AT
SiO ₂	57.60	54.20	54.57	59.10	56.86	65.80
TiO ₂	1.55	1.31	0.79	0.67	0.88	0.74
Al ₂ O ₃	14.65	17.17	16.90	14.80	17.22	15.90
Fe ₂ O ₃ *	12.55	9.52	9.33	9.45	7.98	6.39
MgO	2.40	4.36	6.43	4.10	3.40	1.61
CaO	6.00	7.92	4.77	3.40	6.87	2.37
MnO	0.23	0.15	----	0.14	----	0.09
K ₂ O	1.60	1.11	0.24	1.10	1.67	0.96
Na ₂ O	2.95	3.67	4.47	3.90	3.54	3.47
P ₂ O ₅	0.28	0.28	0.13	0.10	----	----
K ₂ O/Na ₂ O	0.54	0.30	0.05	0.28	0.47	0.28

*Total Fe as Fe₂O₃.

PGM; Average Portis gold mine quartz-rich amphibolite.

NOCK; Average andesite composition (Nockolds, 1954).

MCNC; Average Moore County, NC andesite (Green and others, 1982).

VIRG; Chopawamsic Formation, VA andesite (Pavlides and others, 1982).

AND; Average andesite composition (Le Maitre, 1976).

AT; Average andesitic tuff (Butler and Ragland, 1969).

On an AFM diagram (Fig. 7), quartz-rich amphibolites plot in a tight cluster near the total iron apex. Samples 27-72 and -85 plot with the metagraywackes.

Barium, Rb, Y, and Zr concentrations of the quartz-rich amphibolites are typical of calc-alkaline andesitic rocks (Jakes and White, 1972). Anomalously low strontium values in quartz-rich amphibolites from the Portis gold mine do not conform to calc-alkaline rocks. Jakes and White (1972) reasoned that the complexity of Sr variation due to strong fractionation by feldspar resulted in vague trends among calc-alkaline rocks. On a Ti-Zr-Y triangular diagram (Fig. 8), quartz-rich amphibolites cluster in the calc-alkaline field proposed by Pearce and Cann (1973). Subduction-related volcanic rocks from the Carolina Slate belt generally contain less than 1.3 weight % TiO_2 (Feiss, 1982). Quartz-rich amphibolites plot outside of the subduction-related field (Fig. 9).

Ore Zone Rocks

The single analyzed sample from the ore horizon (Sample 27-95) exhibits high SiO_2 (77.44 wt.%), high Na_2O (4.62 wt.%), and low K_2O (1.15 wt.%) concentrations. The ore zone is chemically similar to felsic tuffs from the Carolina Slate belt, as shown in Table 9. On a Na_2O - K_2O - CaO ternary diagram (Fig. 6), sample 27-95 lies within the field of Na-rich vitric tuffs (Butler and Ragland, 1969), and exemplifies the highly sodic nature of the ore zone.

The ore horizon is also characterized by an extremely low Rb (4 ppm) value and the highest Y (57 ppm) content of any rock at the

Table 9. Chemical Analyses of the Ore Zone and Rocks of Similar Composition

Wt. %	PGM	VT	QKT	BCFT	RHYL
SiO ₂	77.44	73.70	70.60	74.90	74.43
TiO ₂	0.33	0.45	0.40	0.33	0.26
Al ₂ O ₃	11.54	14.60	13.25	13.70	13.18
Fe ₂ O ₃ *	3.53	2.81	4.35	1.34	2.09
MgO	0.19	0.77	1.18	0.16	0.37
CaO	1.36	0.59	2.10	0.68	1.34
MnO	0.06	0.09	0.07	0.02	0.07
K ₂ O	1.15	1.40	0.65	0.21	3.66
Na ₂ O	4.62	4.02	4.75	7.40	4.05
P ₂ O ₅	0.04	----	0.08	0.06	0.06
Rb (ppm)	4	53	<5	----	105
Sr	73	----	110	----	107
Y	57	----	42	----	----
Zr	294	----	114	----	----

*Total Fe as Fe₂O₃.

PGM; Ore horizon, Portis gold mine.

VT; Average vitric tuff, Albemarle, NC (Butler and Ragland, 1969).

QKT; Average quartz keratophyre (Hyndman, 1985).

BCFT; Average Buck Creek felsic tuff, OR (Butler and Ragland, 1969).

RHYL; Average rhyolite (Hyndman, 1985).

Portis. Barium, Zr, and Sr concentrations are typical of calc-alkaline felsic rocks (Jakes and White, 1972).

According to Butler and Ragland (1969), Na-enriched, K-depleted felsic tuffs in the Carolina Slate belt have been altered by metasomatic processes. The metasomatic process is viewed as an exchange reaction whereby Na enters the system while K, Rb, Ba, and other mobile elements are removed. The $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratio (4.02) for the ore zone is much higher than corresponding unaltered calc-alkaline felsic volcanic rocks (Nockolds, 1954) indicating that the ore zone may be extensively altered. Low Rb concentrations (<5 ppm) are usually observed in Na-metasomatized rocks, ie. keratophyres (Barker, 1983; and Hyndman, 1985). The selective removal of Rb and Ba relative to K during metasomatism accounts for anomalous K/Rb and K/Ba ratios (Ragland and others, 1968). The K/Rb ratio for the ore zone is 1193, an order of magnitude greater than the ratio for unaltered felsic volcanic rocks from the Carolina Slate belt (Butler and Ragland, 1969), and the K/Ba ratio is 150 compared to an average of 9 for the other rocks at the Portis.

Geochronology

The E.C.V.S.B. has undergone at least two major episodes of metamorphism. The M_1 event occurred during the Taconic (?) orogeny (475-425 ma) and was responsible for pervasive greenschist facies conditions in the Carolina Slate belt and the E.C.V.S.B. (Farrar, 1985a). A K-Ar whole rock age from phengite-rich metasediments in the Carolina Slate belt yielded an age of 483 ± 15 my (Kish and others, 1979). The date is believed to represent the approximate time of metamorphism in the Carolina Slate belt because temperatures associated with greenschist facies metamorphism should not significantly exceed the blocking temperature for muscovite (350° C).

The subsequent M_2 metamorphic event generated an amphibolite facies assemblage in the Raleigh belt and adjacent portions of the E.C.V.S.B. (Farrar, 1985a). The elevated temperatures of the M_2 event apparently overprinted the M_1 greenschist facies assemblage of the E.C.V.S.B. in the vicinity of the Raleigh belt. The thermal maximum for the Raleigh belt probably accompanied the intrusion of several granitic plutons from 315 to 285 ma (Farrar, 1985a). Russell and others (1985) propose an Alleghanian (325-275 ma) age for M_2 .

A biotite mineral separate from core PM-27 at the Portis gold mine yielded a K-Ar age of 269 ± 6 my (Table 10). This age coincides with cooling at the end of the Alleghanian event. A description of sample preparation is provided in Appendix C.

Cooling ages from other K-Ar biotite mineral separates (Parker,

Table 10. K-Ar Data for a Biotite Separate from the Portis Gold Mine

%K	Radiogenic ^{40}Ar $\times 10^{-12}$ m/g	^{40}Ar % atm	Age(my)
7.360 (7.313)	3701 (3694)	1.6 (1.6)	269 +/- 6
7.350	3686	1.7	
7.243			
7.298			
Average values (in parentheses)			
Analysis was performed at the Isotope Geochemistry Laboratory at the University of Arizona.			

1968; Mauger and others, 1983; and Moncla, pers. comm., 1986) and Rb-Sr whole rock and mineral isochrons (Stirewalt and others, 1981; Wedemeyer, 1981; and Russell and others, 1985) in the eastern Piedmont (Table 11) increase from the Raleigh belt to the E.C.V.S.B. (Fig. 10). The increase in cooling ages from west to east suggests that uplift and cooling occurred significantly earlier in the E.C.V.S.B. than in the Raleigh belt. The areal extent of M_2 metamorphic conditions is not known, but Glover and others (1983) and Farrar (1985a) suggest that the entire E.C.V.S.B. was not affected by the thermal event.

The reported K-Ar minimum age of biotite from the Portis mine supports the cooling age trend exhibited in Figure 10. Rocks from the Portis mine cooled more rapidly than rocks from the Raleigh belt. The cooling age of the Portis and an epidote-amphibolite facies assemblage suggest that the Portis mine probably lies in the extreme western portion of the E.C.V.S.B., very near the boundary with the Raleigh belt.

Table 11. Reported Cooling Ages from the Eastern Piedmont

LOCATION	AGE (Ma)	Rb-Sr/K-Ar	REF.
<u>RALEIGH BELT</u>			
Buckhorn Granodiorite (1)	242	Rb-Sr	E
Lake Gresham Gneiss (3)	238	K-Ar	C
Greystone Quarry (5)	259	K-Ar	C
Falls Leucogneiss (4)	238,242	Rb-Sr	D
Raleigh Gneiss (2,6)	246,241	Rb-Sr	D
Wise Granite (7)	247	Rb-Sr	D
average	244		
<u>E.C.V.S.B. WEST OF HOLLISTER SHEAR ZONE</u>			
Portis Gold Mine (9)	269	K-Ar	
Sims Granite (8)	285	Rb-Sr	F
Butterwood Creek Granite (10) (foliated)	251	Rb-Sr	D
average	268		
<u>E.C.V.S.B. EAST OF HOLLISTER SHEAR ZONE</u>			
Rocky Mount Quarry (12)	337	K-Ar	B
Fountain Quarry (11)	309	K-Ar	A
Butterwood Creek Granite (nonfoliated) (13,14)	286,287,293	Rb-Sr	D
average	302		
Numbered map locations for Figure 10 (in parentheses)			
<u>REFERENCES</u>			
A) Mauger and others, 1983	D) Russell and others, 1985		
B) Moncla, pers. comm., 1986	E) Stirewalt and others, 1981		
C) Parker, 1968	F) Wedemeyer, 1981		

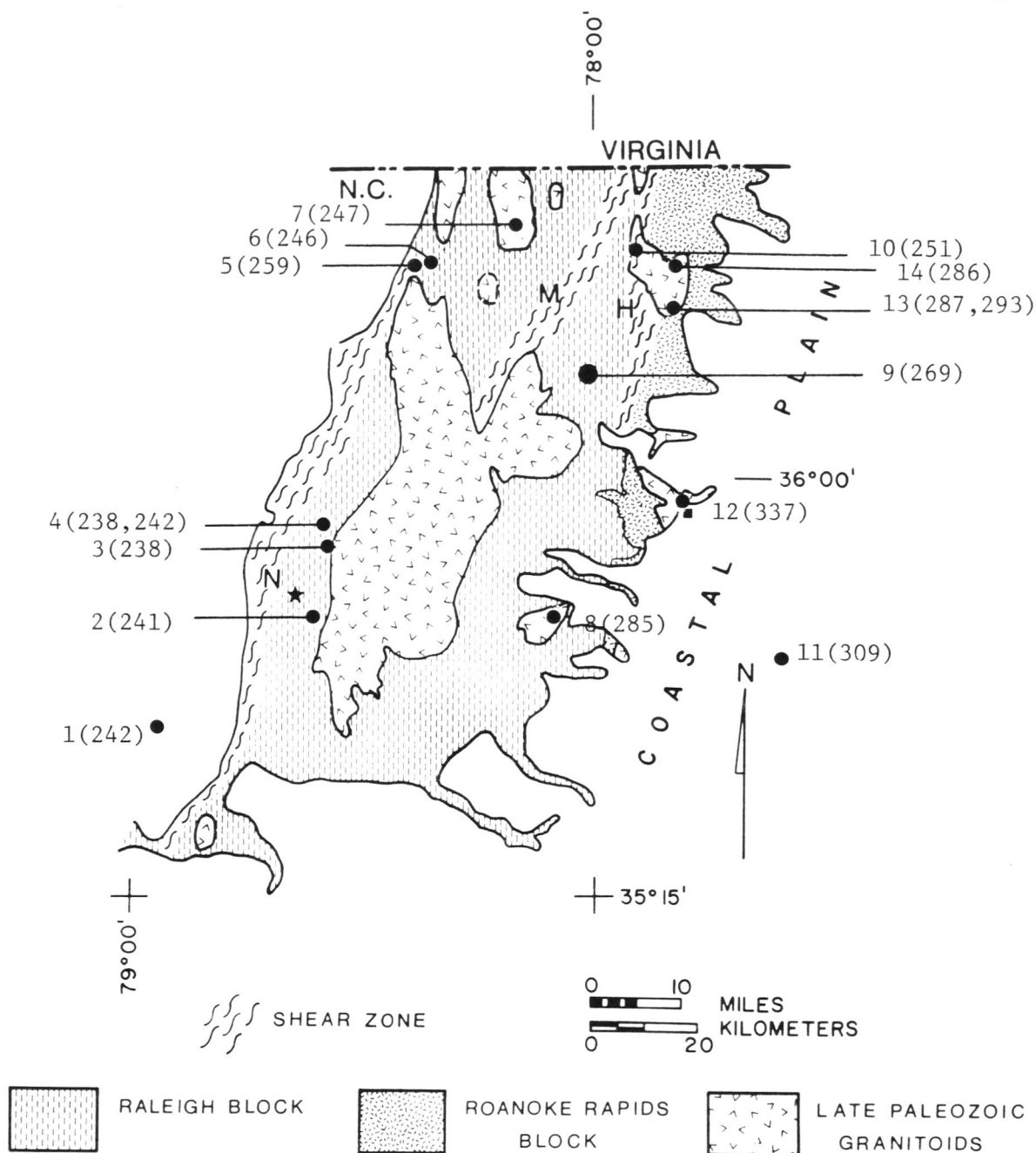


Figure 10. Location map of K-Ar cooling ages and Rb-Sr whole-rock mineral isochron ages within the eastern Piedmont, NC. Reported ages are referenced in Table 11. Age dates in parentheses, (★) Raleigh, (■) Rocky Mount, (N) Nutbush Creek shear zone, (M) Macon shear zone, and (H) Hollister shear zone.

DISCUSSION

The Portis gold mine is a low-grade gold deposit located in the northwestern portion of the Eastern Carolina Volcanic Slate belt. The various lithologies were deposited in a distal (?) submarine environment on the flanks of a volcanic arc terrane, presumably during the late Precambrian to early Cambrian. Trace element concentrations within the amphibolites and quartz-rich amphibolites suggest that the volcanic and volcanoclastic rocks may have developed upon a thin (?) wedge of continental crust.

Volcanically-derived metasediments consist of felsic turbidite-deposited metagraywackes. Layered to massive amphibolites represent metamorphosed mafic pyroclastic units deposited as flows (?) or as submarine fall-out. Biotite phyllites are interpreted as altered equivalents to the amphibolites. These felsic and mafic rocks reflect the bimodal composition of the volcanic rocks deposited in the slate belt. Massive quartz-rich amphibolites are interpreted as possible primary or slightly reworked pyroclastic units. Quartz-rich amphibolites are typically non-foliated and have a relatively uniform geochemical signature. The texture of quartz-rich amphibolites is unique, whereby sprays and clots of pargasite, biotite, epidote, sphene, and ilmenite are segregated from concentrations of quartz and plagioclase. These clots may have been mafic fragments incorporated within a felsic glassy (?) or clastic (?) matrix. The ore horizon is considered to be a vitric tuff layer, based on its chemical

similarities to Na-enriched felsic tuffaceous units found in the Carolina Slate belt. The ore zone has been enriched by sodium metasomatic alteration.

Epidote-amphibolite facies regional metamorphism has produced widespread recrystallization and neomineralization of the lithologies at the Portis gold mine. A K-Ar cooling age of 269 ± 6 my for a biotite mineral separate implies that temperatures at the Portis mine were greater than 300°C during the Alleghanian thermal event (325-275 ma). A later period of hydrothermal alteration produced a zeolite facies overprint exhibited by stage 2 veins containing stilbite (?) and calcite. Retrograde (?) alteration of biotite to chlorite is common in the vicinity of these veins.

Many of the gold deposits in the southeastern US were formed by exhalative processes (Worthington and Kiff, 1970; Spence and others, 1980; and Butler, 1981). These deposits are usually associated with extensive high-alumina alteration zones and stockwork quartz vein systems. At the Portis mine, there is no evidence of high-alumina alteration, but stockwork quartz veins are locally present. The Portis gold mine lacks many of the critical features recognized at other epithermal or exhalative-type deposits and therefore it is not considered to be exhalative in origin.

Gold at the Portis mine is associated with Stage 1 quartz veins concentrated within the ore zone and adjacent quartz-rich amphibolite layers (Waltman, 1985). Based on textural evidence, Stage 1 quartz veins represent an early hydrothermal event which occurred either prior to or during M_1 metamorphism. The formation of quartz veins during

metamorphic dewatering of thick volcano-sedimentary sequences has been documented in the Meguma Group of Nova Scotia (Boyle, 1979; Mawer, 1985; and O'Brien, 1985). The lithologies and tectonic history of the Meguma Group are similar to those of the Carolina Slate belt in the southeastern US (Schenk, 1970; Keppie and Dostal, 1979), suggesting that gold deposition in the Meguma Group may also serve as a model for some gold deposits in the southeastern US. Thornton and Seyfried (1985) suggest that the movement of silica, base metals, and gold in connate waters may begin as early as diagenesis under acidic, oxidizing conditions. Waltman (1985) suggested that the conditions responsible for depositing the Stage 1 quartz veins and the gold exhibited an increased oxygen fugacity. Silica and gold were transported in solution from the source rocks (quartz-rich amphibolites, mafic rocks and volcanically-derived sediments) and deposited in favorable sites. At the Portis, the ore zone represents a favorable host which allowed silica and gold to precipitate in fractures that formed during compaction of the volcano-sedimentary sequence. Fractures were more prevalent in the ore zone and adjacent quartz-rich amphibolites because they were fairly rigid indurated units surrounded by more ductile sedimentary layers.

In contrast to a metamorphic origin, Waltman (1985) suggested that the gold at the Portis mine was deposited hydrothermally as pore fluids were heated by quartz keratophyre and quartz diorite subvolcanic intrusives. He further states that dilatant fractures which formed during cooling of the intrusives served as conduits for the hydrothermal fluids. Ultimately these silica-filled tension fractures

became preferred sites for gold mineralization. The absence of any effects attributed to injection of hot magma into wet sediments (Williams and McBirney, 1979) and the conformable nature of the stratigraphic units suggest that the ore zone and the quartz-rich amphibolites were not emplaced as subvolcanic intrusives, but that they were conformable deposits in a submarine volcano-sedimentary sequence on the flanks of a volcanic arc terrane.

CONCLUSIONS

- 1) Host rocks at the Portis gold mine are a sequence of subaqueous volcanoclastic and epiclastic sediments conformably interlayered with several tuffaceous units.
- 2) Reworked (?) volcanoclastic sediments (metagraywackes) were deposited as turbidite flows.
- 3) Amphibolites are interpreted as mafic pyroclastic units deposited as submarine flows (?) (massive amphibolites) or by submarine fall-out (?) (layered amphibolites).
- 4) Biotite phyllites are interpreted as altered mafic pyroclastic units.
- 5) Massive quartz-rich amphibolites are interpreted as submarine andesitic tuffs and/or slightly reworked tuffs.
- 6) Trace element concentrations of amphibolites and quartz-rich amphibolites suggest that the volcanic sequence may have been built on a thin (?) wedge of continental crust.
- 6) The ore zone rocks are geochemically similar to Na-enriched

metasomatized vitric tuffs found in the Carolina Slate belt.

- 7) Epidote-amphibolite facies (Barrovian ?) metamorphism has affected the Portis gold mine lithologies. Late-stage (post-metamorphic) hydrothermal activity produced a localized zeolite facies overprint.
- 8) At least two periods of deformation are evident; a penetrative foliation is parallel to the original bedding and a less prominent crenulation cleavage is inclined at 30° to the bedding.
- 9) The K-Ar cooling age of the Portis gold mine (269 ± 6 my) and an epidote-amphibolite facies assemblage suggest that the Portis gold mine probably lies in the extreme western portion of the E.C.V.S.B. very near the boundary with the Raleigh belt.

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APPENDIX A

Modal and Geochemical Sample Numbers
Grouped According to Rock Types

<u>Amphibolite</u>	<u>Quartz-rich Amphibolite</u>	<u>Metagraywacke</u>
C27-70	C27-72	C27-73
C27-71	C27-77	C27-76
C27-74	C27-85	C27-79
C27-75	C27-90	C27-80
C27-78	C27-92	C27-81
C27-82	C27-93	C27-83
C37-7	C27-94	C27-84
	C27-96	C27-86
	C27-97	C27-89
<u>Biotite Phyllite</u>	C27-98	C27-91
C27-87	C27-99	
C27-88	C27-100	<u>Ore Zone</u>
C37-3	C27-101	C27-95

Mineral Abbreviations Used in the Modal Analysis

Qtz:Quartz	Phe:Phengite	Opq:Opaques	Tou:Tourmaline
Plg:Plagioclase	Epi:Epidote	Apt:Apatite	Zir:Zircon
Amp:Amphibole	Chl:Chlorite	All:Allanite	Ksp:K-Feldspar
Bio:Biotite	Cal:Calcite	Sph:Sphene	

Appendix A (continued)
 Modal Percentages of the Rock Samples
 (acc equals less than 1%)
 (--- is not observed)

Sample	Qtz	Plg	Amp	Bio	Phe	Epi	Chl	Cal	Opq	Apt	Spn			
C27-70	12	17	57	5	5	2	1	---	1	---	---			
C27-71	2	27	63	acc	---	acc	7	acc	acc	---	acc			
C27-74	3	26	63	6	---	2	acc	acc	acc	---	acc			
C27-75	12	26	55	acc	acc	1	3	acc	3	acc	---			
C27-78	3	11	66	2	---	5	7	2	acc	---	acc			
C27-82	6	38	52	acc	---	1	acc	1	2	acc	acc			
C37-7	5	13	41	22	---	16	acc	1	acc	---	acc			
Sample	Qtz	Plg	Bio	Phe	Epi	Chl	Cal	Opq	Apt	Spn	Tou	Zir	All	Ksp
C27-73	45	38	12	acc	3	acc	acc	1	acc	acc	---	---	---	---
C27-76	41	42	13	---	acc	2	acc	acc	acc	acc	acc	---	---	---
C27-79	45	23	8	10	3	9	---	1	acc	acc	acc	acc	acc	---
C27-80	37	37	acc	21	acc	4	---	2	acc	---	acc	---	acc	---
C27-81	31	23	---	40	acc	4	acc	2	acc	---	---	---	acc	---
C27-83	34	31	---	24	acc	9	acc	1	acc	---	---	---	acc	---
C27-86	75	17	3	acc	2	3	acc	1	acc	---	---	acc	acc	acc
C27-89	28	30	14	27	---	---	acc	1	acc	acc	acc	acc	---	---
C27-91	47	27	4	16	acc	4	---	acc	---	---	acc	---	---	---
C27-95	40	54	acc	2	acc	2	acc	2	---	---	---	---	acc	acc

Appendix A (continued)
 Modal Percentages of the Rock Samples
 (acc equals less than 1%)
 (--- is not observed)

Sample	Qtz	Plg	Amp	Bio	Phe	Epi	Chl	Cal	OPq	Apt	Spn	Tou	All
C27-72	3	63	---	16	1	9	2	---	4	---	---	acc	---
C27-77	23	37	21	2	---	acc	14	acc	3	---	acc	---	---
C27-85	46	23	---	5	1	2	22	acc	acc	---	acc	---	acc
C27-90	22	13	27	acc	acc	1	35	acc	3	---	acc	---	---
C27-92	16	32	30	17	---	3	acc	acc	1	---	---	---	---
C27-93	14	29	28	25	---	acc	---	---	2	acc	acc	---	---
C27-94	27	36	21	12	---	acc	---	---	3	acc	acc	---	---
C27-96	28	33	13	17	---	4	acc	acc	2	acc	acc	---	---
C27-97	28	34	10	19	---	2	3	1	4	acc	---	---	---
C27-98	32	19	24	20	---	2	1	---	2	---	---	---	---
C27-99	24	38	17	acc	---	4	11	3	2	acc	acc	---	---
C27-100	19	36	15	10	---	4	9	acc	5	acc	acc	---	---
C27-101	22	38	27	11	---	acc	acc	acc	2	acc	---	---	acc
C37-4	29	18	33	16	---	3	---	acc	acc	acc	acc	---	acc
C37-8	19	29	24	23	---	acc	acc	acc	3	acc	acc	---	---
Sample	Qtz	Plg	Bio	Epi	Chl	Cal	Opq						
C27-87	13	2	60	7	---	18	acc						
C27-88	18	4	49	23	1	5	acc						
C37-3	12	---	49	39	---	---	---						

APPENDIX B

Chemical Analyses of the Rock Samples

	C27-70 (MR)	C27-71 (MR)	C27-74 (MR)	C27-75 (MR)	C27-78 (MR)
SiO ₂	50.23	47.23	50.45	51.12	47.12
TiO ₂	1.04	0.70	0.75	1.70	0.92
Al ₂ O ₃	16.64	16.64	15.82	15.12	16.64
Fe ₂ O ₃ *	11.12	11.27	10.41	11.32	12.69
MgO	6.67	9.71	8.58	5.41	7.96
CaO	9.68	9.25	10.71	9.82	8.22
MnO	0.27	0.32	0.21	0.22	0.29
K ₂ O	0.63	0.45	1.09	0.53	1.98
Na ₂ O	2.39	2.65	2.10	2.53	1.74
P ₂ O ₅	0.14	0.15	0.16	0.25	0.09
H ₂ O ⁻	0.01	0.08	0.03	0.01	0.07
LOI	1.40	2.14	2.28	1.45	3.83
TOTAL	100.22	100.59	102.59	99.48	101.28
Ba	141	94	242	132	277
Rb	26	13	47	21	74
Sr	254	221	244	371	193
Y	20	23	22	31	8
Zr	74	56	63	122	---
K/Rb	100.0	146.2	96.2	104.7	111.0
Ba/Rb	5.42	7.23	5.15	6.29	3.74
Rb/Sr	0.102	0.059	0.193	0.057	0.383

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(MR) represents mafic rocks.

APPENDIX B (continued)

	C27-82 (MR)	C27-87 (MR)	C27-88 (MR)	C37-3 (MR)	C37-7 (MR)
SiO ₂	50.99	49.87	50.36	50.85	46.63
TiO ₂	0.86	1.03	1.13	0.96	0.96
Al ₂ O ₃	15.04	13.64	15.41	16.11	15.70
Fe ₂ O ₃ *	9.24	9.05	9.65	11.68	13.40
MgO	6.62	8.10	6.31	6.73	7.16
CaO	9.24	7.72	5.90	4.55	9.35
MnO	0.32	0.35	0.25	0.19	0.23
K ₂ O	2.34	5.15	4.73	4.91	2.45
Na ₂ O	2.50	0.44	2.60	0.34	1.12
P ₂ O ₅	0.17	0.17	0.14	0.10	0.12
H ₂ O ⁻	0.06	0.16	0.10	0.08	0.09
LOI	2.81	6.36	3.29	1.33	1.97
TOTAL	100.19	102.04	99.87	97.83	99.18
Ba	218	274	268	258	212
Rb	104	201	232	130	99
Sr	251	156	285	76	140
Y	27	17	18	17	26
Zr	66	52	68	---	35
K/Rb	93.4	106.3	84.6	156.7	102.7
Ba/Rb	2.10	1.36	1.16	1.99	2.14
Rb/Sr	0.414	1.288	0.814	1.711	0.707

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(MR) represents mafic rocks.

APPENDIX B (continued)

	C27-72 (QA)	C27-77 (QA)	C27-85 (QA)	C27-90 (QA)	C27-92 (QA)
SiO ₂	53.14	54.41	61.74	54.36	55.36
TiO ₂	0.86	2.10	1.00	1.79	1.63
Al ₂ O ₃	21.07	13.51	15.74	15.08	14.67
Fe ₂ O ₃ *	7.59	15.32	6.19	14.25	14.12
MgO	1.95	2.82	1.97	2.67	2.35
CaO	6.58	7.17	3.01	6.48	5.79
MnO	0.13	0.22	0.17	0.32	0.30
K ₂ O	1.44	1.08	3.40	1.57	2.27
Na ₂ O	4.92	2.05	2.89	2.16	2.41
P ₂ O ₅	0.16	0.27	0.27	0.15	0.28
H ₂ O ⁻	0.02	0.09	0.08	----	0.09
LOI	0.94	3.09	2.47	1.90	1.35
TOTAL	98.80	102.13	98.93	100.73	100.62
Ba	228	170	729	291	426
Rb	81	55	154	62	91
Sr	234	230	202	129	133
Y	36	41	54	40	37
Zr	373	177	208	106	113
K/Rb	73.8	81.5	91.6	105.1	103.5
Ba/Rb	2.82	3.09	4.73	2.27	4.68
Rb/Sr	0.346	0.239	0.762	0.481	0.684

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(QA) represents quartz-rich amphibolites.

APPENDIX B (continued)

	C27-93 (QA)	C27-94 (QA)	C27-96 (QA)	C27-97 (QA)	C27-98 (QA)
SiO ₂	54.36	62.34	62.29	60.17	57.78
TiO ₂	1.70	1.31	1.67	1.49	1.69
Al ₂ O ₃	15.16	13.13	13.43	12.86	13.72
Fe ₂ O ₃ *	15.57	10.64	11.86	11.76	12.12
MgO	2.28	1.41	1.72	1.56	2.73
CaO	5.20	5.61	5.31	5.77	7.04
MnO	0.25	0.22	0.24	0.22	0.15
K ₂ O	2.51	1.14	1.81	1.79	1.01
Na ₂ O	2.77	3.34	2.81	2.65	2.14
P ₂ O ₅	0.24	0.41	0.51	0.54	0.20
H ₂ O ⁻	0.07	0.05	0.09	0.08	0.10
LOI	0.95	0.74	0.74	1.45	0.73
TOTAL	101.06	100.31	102.48	100.34	99.41
Ba	543	317	388	426	319
Rb	104	23	75	64	59
Sr	173	166	181	166	338
Y	37	37	41	42	36
Zr	120	126	134	116	120
K/Rb	100.2	205.7	100.2	116.1	71.0
Ba/Rb	5.22	13.78	5.17	6.66	5.41
Rb/Sr	0.601	0.139	0.414	0.386	0.175

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(QA) represents quartz-rich amphibolites.

APPENDIX B (continued)

	C27-99 (QA)	C27-100 (QA)	C27-101 (QA)	C37-4 (QA)	C37-5 (QA)
SiO ₂	58.65	58.60	56.50	57.76	57.05
TiO ₂	1.31	1.66	1.85	1.48	1.41
Al ₂ O ₃	14.17	13.80	15.45	13.99	13.72
Fe ₂ O ₃ *	12.57	12.73	13.18	13.23	12.30
MgO	2.46	2.77	3.41	2.78	2.59
CaO	6.15	5.84	6.60	6.58	6.67
MnO	0.22	0.25	0.24	0.26	0.21
K ₂ O	1.00	1.01	1.05	1.52	1.15
Na ₂ O	3.02	2.74	3.18	3.38	3.36
P ₂ O ₅	0.18	0.25	0.24	0.22	0.18
H ₂ O ⁻	0.06	0.08	0.09	0.08	0.02
LOI	1.14	1.56	0.86	0.79	0.88
TOTAL	100.93	101.29	102.65	102.04	99.54
Ba	330	427	177	293	250
Rb	39	28	45	34	36
Sr	192	145	242	149	143
Y	37	21	39	27	19
Zr	108	71	130	77	70
K/Rb	106.4	149.7	96.8	185.5	132.6
Ba/Rb	8.46	15.25	3.93	8.62	6.94
Rb/Sr	0.203	0.193	0.186	0.228	0.252

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(QA) represents quartz-rich amphibolites.

APPENDIX B (continued)

	C37-8 (QA)	C27-73 (MG)	C27-76 (MG)	C27-79 (MG)	C27-80 (MG)
SiO ₂	56.68	72.43	66.87	71.44	71.90
TiO ₂	1.51	0.69	0.95	0.73	0.58
Al ₂ O ₃	14.83	12.82	15.37	13.23	13.19
Fe ₂ O ₃ *	11.68	4.00	4.80	4.79	3.91
MgO	3.02	1.24	1.72	1.00	0.62
CaO	6.34	2.86	2.53	1.81	1.41
MnO	0.26	0.08	0.07	0.09	0.06
K ₂ O	1.32	1.19	1.59	2.66	1.92
Na ₂ O	3.37	3.91	4.81	3.02	3.68
P ₂ O ₅	0.31	0.14	0.15	0.10	0.12
H ₂ O ⁻	0.04	0.05	0.10	0.07	0.08
LOI	0.86	1.27	1.53	2.07	1.81
TOTAL	100.22	100.68	100.49	100.98	99.28
Ba	277	310	490	739	642
Rb	53	57	78	104	50
Sr	83	203	188	159	66
Y	42	33	36	29	20
Zr	134	299	191	211	179
K/Rb	103.4	86.6	84.6	106.1	159.4
Ba/Rb	5.23	5.44	6.28	7.11	12.84
Rb/Sr	0.639	0.281	0.415	0.654	0.758

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(QA) represents quartz-rich amphibolites.

(MG) represents metagraywackes.

APPENDIX B (continued)

	C27-81 (MG)	C27-83 (MG)	C27-84 (MG)	C27-86 (MG)	C27-89 (MG)
SiO ₂	68.81	70.76	67.63	78.85	68.76
TiO ₂	0.82	0.81	0.78	0.61	0.86
Al ₂ O ₃	14.30	13.93	15.32	10.19	14.95
Fe ₂ O ₃ *	5.76	4.70	3.77	3.40	4.56
MgO	1.09	1.11	1.47	0.68	1.16
CaO	1.21	1.49	2.80	1.75	1.58
MnO	0.08	0.07	0.06	0.08	0.09
K ₂ O	3.97	3.60	1.84	1.21	3.90
Na ₂ O	1.77	2.23	4.23	3.11	2.43
P ₂ O ₅	0.10	0.07	0.11	0.12	0.10
H ₂ O ⁻	0.06	0.04	0.05	0.07	0.04
LOI	2.99	2.37	2.19	1.90	2.36
TOTAL	100.96	101.18	100.25	101.95	100.79
Ba	839	885	595	393	792
Rb	156	128	75	49	133
Sr	88	126	279	88	85
Y	45	36	34	19	28
Zr	239	211	223	145	281
K/Rb	105.6	116.7	101.8	102.5	121.7
Ba/Rb	5.38	6.91	7.93	8.02	5.96
Rb/Sr	1.773	1.016	0.269	0.557	1.565

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(MG) represents metagraywackes.

APPENDIX B (continued)

	C27-91 (MG)	C27-95 (OZ)
SiO ₂	73.10	77.44
TiO ₂	0.64	0.33
Al ₂ O ₃	13.35	11.54
Fe ₂ O ₃ *	3.84	3.53
MgO	0.72	0.19
CaO	1.39	1.36
MnO	0.06	0.06
K ₂ O	3.18	1.15
Na ₂ O	2.73	4.62
P ₂ O ₅	0.09	0.04
H ₂ O ⁻	0.01	0.05
LOI	1.70	0.97
TOTAL	100.81	101.28
Ba	750	602
Rb	130	4
Sr	70	73
Y	34	57
Zr	187	294
K/Rb	101.5	1193.1
Ba/Rb	5.77	150.1
Rb/Sr	1.857	0.055

*Total Fe as Fe₂O₃.

Major elements, H₂O⁻, and LOI in Weight %.

Trace elements in ppm.

(MG) represents metagraywackes.

(OZ) represents the ore zone.

APPENDIX C

SAMPLING AND SAMPLE PREPARATION

Thirty-seven lithologically diverse samples were selected from drill holes PM-27 and PM-37 (Fig. 2). Average sample length of 2-inch diameter split core is approximately five inches (12.7 cm). Weathered rock, brecciation zones and areas where veins are concentrated were avoided during selection of geochemical samples.

Thin sections were made from each sample. The remaining material was passed through a precontaminated jaw crusher and pulverizer. A 25 gram split of each sample was milled in a tungsten carbide SPEX ballmill to produce a finely-ground homogeneous powder suitable for geochemical analysis.

An HF-HBO₃ dissolution technique (Bernas, 1968) was utilized to develop a 500 ppm aqueous solution for atomic absorption and UV-vis spectrophotometric analyses. Boric acid backed, pressed-powder pellets were used in X-ray fluorescence analyses.

ANALYTICAL PROCEDURES

Major and Trace Element Geochemistry

K₂O, Na₂O, MgO, Fe₂O₃ and Al₂O₃ analyses were performed on an Instrumentation Laboratories Model 457 Atomic Absorption Spectrophotometer. SiO₂ concentrations were determined by colorimetry

using a technique modified after Shapiro (1974) on an Hitachi Model 100-60 Spectrophotometer. CaO , TiO_2 , MnO , P_2O_5 , Ba, Rb, Sr, Y, and Zr were analyzed by X-ray Fluorescence Spectrometry (XRF) on a wavelength dispersive General Electric Model XRD-6 vacuum spectrometer. Standard procedures were employed for all XRF analyses, according to Hutchinson (1974) and Kikkert (1983). Adsorbed water (H_2O^-) was determined gravimetrically (Maxwell, 1968) and loss on ignition (LOI) was performed using a procedure outlined by Hutchinson (1974).

Instrumental parameters for each analysis are provided in Table A.

When necessary, XRF analyses were corrected for machine drift and background interferences. Mass absorption corrections for barium were calculated utilizing a computer program. A Mo X-ray tube was used to determine Rb, Sr, Y, and Zr concentrations according to the method described by Drez (1977) after Wilband (1975). Raw data from atomic absorption and UV-vis spectrophotometry analyses were not corrected for machine drift. Calibration curves for all analyses were calculated by linear or cubic regression programs, based on results from certified international rock standards.

Accuracy of the chemical analyses was estimated by averaging the the differences between the calculated and accepted values for the known standards. Accuracy estimates are listed in Table B.

Precision for each analysis was achieved by replicate analysis of 10 percent of the samples. Four samples (27-79, -86, -94, and 37-4) were chosen randomly. Average precision estimates are shown in Table C.

Geochronology

Biotite from PM-37 (444 ft, 135 m) was selected for determining the K-Ar cooling age. Analysis of a thin section of the biotite indicated that it was unaltered. The remaining material was crushed, pulverized, sieved, and washed. Heavy liquids (methylene iodide and tetrabromethane) and a "shaker" table were used to separate biotite from a sieve fraction (75 to 180 μm) of biotite, epidote and plagioclase. The biotite separate was also hand-picked to remove extraneous grains. The analysis was performed by the Isotope Geochemistry Laboratory at the University of Arizona.

Table A. Instrumental Parameters for Major and Trace Element Analyses

A.A. SETTINGS (Instrumentation Laboratories Model IL-457)

Element	Wavelength (nanometers)	Lamp Current	Bandpass	Photo- Multiplier	Oxidant
Mg	285.5	3ma	1.0	530	Air
Na	585.3	8ma	0.5	460	Air
Fe	248.3	8ma	0.3	480	Air
K	762.3	7ma	1.0	620	Air
Al	309.9	8ma	1.0	570	N ₂ O

UV-VISIBLE SETTINGS (Hitachi Model 100-60)

Element	Wavelength (nanometers)	Lamp	Deuterium Background	Mode	Response
Si	640.0	W	Yes	Abs	Fast

X.R.F. SETTINGS (General Electric XRD-6)

Element	Line	Peak 2θ	Tube	Crystal	KV/MA	Detector	Vacuum
Ca	K α	113.03	Cr	LiF 200	45/8	Gas Prop	Yes
Ti	K α	86.26	Cr	LiF 200	45/10	Gas Prop	Yes
Mn	K α	63.74	W	LiF 200	50/15	Gas Prop	Yes
P	K α	141.32	Cr	Germanium	45/34	Gas Prop	Yes
Ba	L β ₂	116.08	Cr	LiF 220	50/48	Gas Prop	Yes
Rb	K α	38.49	Mo	LiF 220	50/45	Scint	No
Sr	K α	36.37	Mo	LiF 220	50/45	Scint	No
Y	K α	34.40	Mo	LiF 220	50/45	Scint	No
Zr	K α	32.58	Mo	LiF 220	50/45	Scint	No

Table B. Accuracy Estimates for Geochemical Analyses

MAJOR ELEMENTS

Element	Average Δ (wt.%)	Number of Standards	Correlation Coefficient
SiO ₂	0.345	18	0.9986
TiO ₂	0.061	11	0.9980
Al ₂ O ₃	0.129	14	0.9991
Fe ₂ O ₃	0.178	12	0.9986
MgO	0.090	12	0.9993
CaO(1)	0.185	15	0.9989
CaO(2)	0.118	13	0.9994
MnO	0.017	16	0.9940
K ₂ O	0.080	20	0.9995
Na ₂ O	0.041	16	0.9996
P ₂ O ₅	0.019	15	0.9970

TRACE ELEMENTS

Element	Average Δ (ppm)	Number of Standards	Correlation Coefficient
Ba	45	9	0.9980
Rb	6	12	0.9972
Sr	11	13	0.9981
Y	3	8	0.9910
Zr	8	9	0.9905

Average Δ is the average of the differences between the known and calculated values of standards used in the analysis. Correlation coefficients were determined from standards curves generated for each analysis. Major elements, H₂O⁻, and LOI are in Weight %. Trace elements are in ppm.

Table C. Precision Estimates for the Geochemical Analyses

MAJOR ELEMENTS

Element	Avg. Coeff. of Variation
SiO ₂	0.56
TiO ₂	4.11
Al ₂ O ₃	1.40
Fe ₂ O ₃	3.12
MgO	2.10
CaO(1)	0.24
CaO(2)	0.59
MnO	3.65
K ₂ O	2.48
Na ₂ O	3.12
P ₂ O ₅	10.45
H ₂ O ⁻	43.10
LOI	7.98

TRACE ELEMENTS

Ba	1.13
Rb	28.18
Sr	4.35
Y	24.09
Zr	12.62

Coefficient of Variation is a statistical estimate of the degree of variability of replicate analyses defined as $100(s)/x$ where s is the standard deviation and x is the mean (Till, 1974). Major elements, H₂O⁻, and LOI are in Weight %. Trace elements are in ppm.