DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

The geology and hydrothermal alteration centers of the Snow Camp Mine-Major Hill area, Central Carolina slate belt, Alamance and Chatham Counties, North Carolina

by

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Open-File Report 87-180

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1987

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ABSTRACT

The Snow Camp Mine-Major Hill area is located in the north-central portion of the Carolina slate belt in the Piedmont of North Carolina. Hydrothermally altered metavolcanic rocks outcrop along a northeast trend throughout the field area (approximately 32 km^2). Snow Camp Mine Ridge and Major Hill are prominent ridges of siliceous rocks representing two centers of extensive hydrothermal alteration, and a third unnamed highland northeast of Major Hill forms another center.

The three altered areas have distinct zones of silicic (quartz, pyrite, iron oxides), advanced argillic (pyrophyllite, andalusite, kaolinite, chloritoid, pyrite, iron oxides), and sericitic (sericite, paragonite, chlorite, iron oxides) alteration, with the silicic alteration being the most intense and the sericitic alteration the least intense. Smaller clusters of altered rocks occur northeast, east, and south of these three centers.

The protoliths of the altered rocks are Late Precambrian to Early Cambrian felsic volcanic rocks which have been metamorphosed to the chlorite zone of the greenschist facies, creating a metamorphic overprint that masks the alteration mineral assemblage.

Several small mines and prospects were operated in earlier times (19th century), and minor amounts of gold and base metals have been found in the field area. Pyrophyllite and sericite have been mined from several localities, including the Snow Camp Mine.

The linear nature of the individual alteration centers and the orientation of the overall alteration system in the Snow Camp Mine-Major Hill area suggests that the centers may mark fractures along a major northeast-trending lineament. A succession of similar localities extends along a northeast trend for 180 km in the Carolina slate belt.

INTRODUCTION

The Snow Camp Mine-Major Hill area is located in the Carolina slate belt of north-central North Carolina in southern Alamance County about 24 km west of Chapel Hill (Figure 1). The map area, approximately 32 km^2, is in a region of cultivated fields, pastures, and woodlands. Areas of rock outcrop are mostly limited to crests of hills, steep slopes, and creek beds. The region was settled in the 18th century by a community of Quakers; their descendents now use the land primarily for dairy farming.

The major reason for studying the area in detail is the widespread presence of hydrothermally altered volcanic and subvolcanic rocks that occur as separate alteration centers and can be divided into distinct alteration zones. Three large areas of alteration, the Snow Camp Mine ridge, Major Hill, and a highland northeast of Major Hill, are present in the map area, along with smaller clusters which may also be centers of alteration. These and many similar altered areas occur along a northeast trend for 180 km in the Carolina slate belt (Figure 2). Several of these areas have been described by Hughes (1985), Hughes et al. (1986), McKee (1985), Sexauer (1983), and Feiss (1985). The high-alumina alteration centers appear to have resulted from the activity of meteoric waters that were part of an active hydrothermal system (Feiss and Weslowski, 1986; and Criss and Klein, 1986).

The protoliths of the altered rocks are primarily metamorphosed Late Precambrian or Early Cambrian felsic crystal and crystal-lithic tuffs, lava flows, and shallow felsic intrusions. Andesitic rocks and minor exposures of granodiorite are also located in the map area. Abrupt transitions from unaltered to altered rocks are present in several places.

The altered rocks are highly siliceous and tend to form hills resistant to erosion. The rocks occur in zones as follows: central silicic ridge of altered rocks containing pods of advanced argillically altered rocks (pyrophyllite, kaolinite, and minor andalusite). The most widespread and least intense alteration results in sericitically altered rocks, which surround the silicic and argillic rocks. Propylitic (chloritic) alteration, though probably present, is not recognizable, because all of the rocks in the field area have been subjected to low-grade metamorphism to the chlorite zone of the greenschist facies. The paragenesis of the alteration mineral assemblage is complicated and partially masked by the metamorphic mineral assemblage.

Objectives

The purpose of this project was to map the Snow Camp Mine-Major Hill area in detail to address the following problems:

1) What are the protoliths of the altered systems?
2) What is the geometry of the systems?

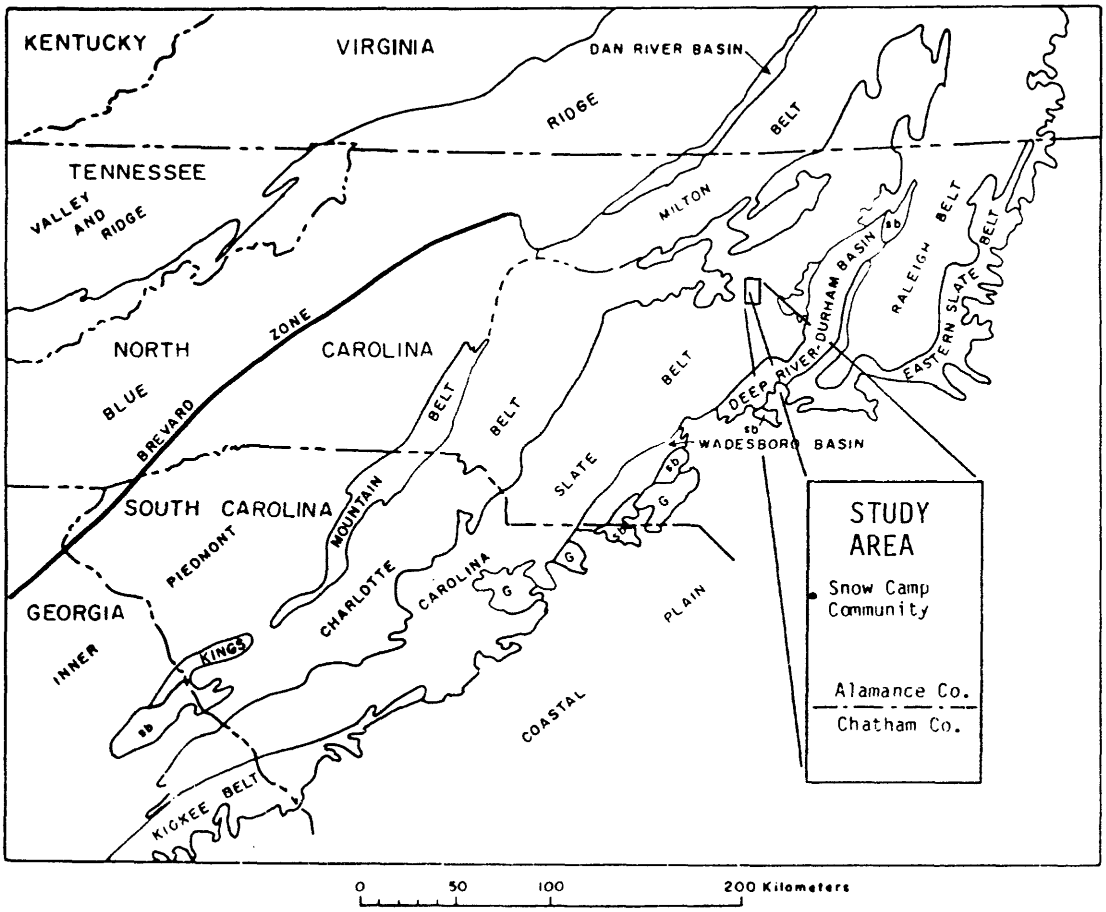


Figure 1. Location of Snow Camp Mine-Major Hill study area.

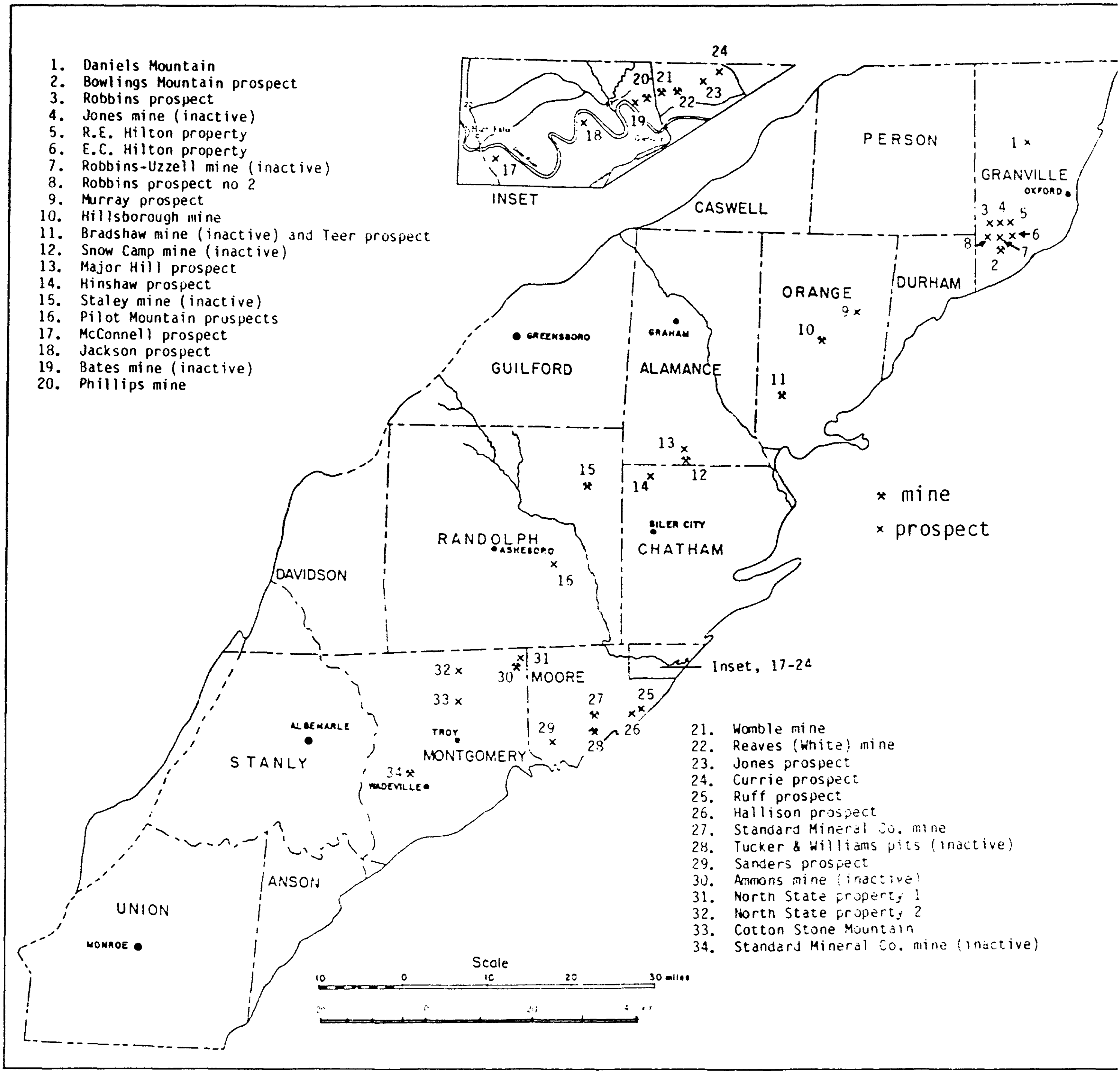


Figure 2. Pyrophyllite deposits in the Carolina slate belt, North Carolina. (from Stuckey, 1967).

3) Do unaltered rocks stratigraphically overlie the altered rocks?
4) Are the altered rocks located along major fractures or other structural controls?
5) What is the heat source for the alteration system?
6) Is there precious metal or base metal mineralization associated with the altered systems?
7) How does the intrusive activity in the area relate to the alteration?

Possible relationships between altered and unaltered rocks are proposed, and as a result of this study, a model of occurrence of the alteration systems is suggested.

Methods

This study is primarily a mapping project which was undertaken to try to better understand the relationships between the altered and unaltered rocks in the Snow Camp Mine-Major Hill area. The field area has been mapped on the scale 1:24,000 (Plate 1). The Snow Camp Mine pyrophyllite pit was sketched at 1"=50' (Figure 3). X-ray diffraction (XRD) was used to determine the alteration mineral assemblages and thin sections were made for textural studies and for mineral identification of the unaltered rocks. The results of whole rock geochemistry on a suite of unaltered volcanic rocks from the Snow Camp Mine-Major Hill area are listed in Table 1. Four pyritic quartz-pyrophyllite rocks from the Snow Camp Mine pyrophyllite pit were analyzed by fire assay for their gold content with a lower detection limit of 0.075 ppm (Table 2).

Previous Work

Detailed geologic maps for the Snow Camp Mine-Major Hill area have not been published, but several authors have described the major alteration centers within the area. Carpenter (1982), in his regional map covering the six counties to the north and west of Alamance County, included most of the field area in a felsic volcanic unit of crystal tuffs and felsic crystal-lithic tuffs. He has distinguished some units of intermediate crystal tuffs in the central portion of the map area. Carpenter (1982) interpreted felsic lava flow rocks east of the Snow Camp Mine alteration center as corresponding to the felsite portion of the Uwharrie Formation in the Asheboro Quadrangle further southwest. However, Harris and Glover (1985) include the Snow Camp Mine-Major Hill area in the Hyco Formation which underlies the Uwharrie Formation. Three samples from the upper part of the Hyco Formation, between Roxboro, North Carolina, and Christie, Virginia, approximately 70-100 km to the northeast, have been dated at 620 +/- 20 Ma (Glover and Sinha, 1973). Age determinations of selected samples in the Snow Camp Mine-Major Hill area should help to clear up some of this uncertainty.

Wilkinson (1978) mapped the northeast quarter of the Silk Hope quadrangle, about 10 km east of the Snow Camp Mine pit, and her work characterizes the geologic environment of much of the slate belt in central North Carolina. Wilkinson (1978) describes three Late Precambrian volcaniclastic units, and suggests that they were deposited in the vent facies of a volcanic arc. Most of these units she believes were deposited in a subaerial environment with local waterlain volcanic units. The stratigraphy of this area consists of felsic tuffs and lava flows which grade upwards to laharic breccias overlain by interbedded andesitic flows and felsic pyroclastic rocks. These units were intruded by the Chatham granite and were later subjected to greenschist facies metamorphism and deformation resulting in a northeast-trending slaty cleavage.

Hauck (1977) mapped the northwest quarter of the Bynum quadrangle, just east of the Silk Hope quadrangle. He distinguished nine volcaniclastic units of andesitic to dacitic lava flows and pyroclastic tuffaceous rocks. These were intruded by granite before being metamorphosed and deformed.

The Snow Camp Mine alteration center was examined by Schmidt (1985) who found the pyrophyllite deposit to be similar to many of the others in the Carolina slate belt. Schmidt (1985) noted the weakly metamorphosed felsic to intermediate volcanic rocks in his reconnaissance of the area and gave a brief description of the alteration system and the pyrophyllite pit. He described a crystal-rich unit on the east side of the Snow Camp Mine ridge which he interprets to be a subvolcanic intrusion that may have caused the alteration of the volcanics.

Results from oxygen isotopic investigations by Criss and Klein (1986) and Feiss and Weslowski (1986) in the high-alumina alteration systems in the Carolina slate belt suggest that meteoric waters, as part of an active hydrothermal system, were involved in the alteration of the volcanic rocks at the Snow Camp Mine and elsewhere in the slate belt.

Stuckey (1967) described the Snow Camp Mine pyrophyllite deposit and discussed production at the pyrophyllite mine. He reported coarse-grained andalusite which occurs in minor amounts in the deposit. Espenshade and Potter (1960) described the Snow Camp Mine deposit as a lenticular body of pyrophyllite and fine-grained quartz about 107 m (350 ft) long and 76 m (250 ft) wide. They also mentioned the silicic ridge which runs south from the deposit. Stuckey (1967) summarized the occurrences of pyrophyllite on Major Hill in what he described as an area of fine- to medium-grained felsic tuffs. Several pyrophyllite and sericite localities are included in his report on Major Hill. Stuckey (1967) mentioned the sericite quarry located 0.45 km north on S.R. 2351 from the intersection of S.R. 1005, where sericite was mined to be mixed with pyrophyllite (Plate 1).

D'Agostino and Schmidt (1986) reported evidence of gold mineralization in the Major Hill-Sutphin area (Plate 1). They discovered visible gold in seven panned stream sediment and five soil concentrations and detectable gold in two samples taken from the dumps of old prospects during a reconnaissance sampling program in the area. From these gold occurrences and their close association with hydrothermally altered rocks, D'Agostino and Schmidt (1986) concluded that the Major Hill-Sutphin area has enough potential to merit further economic mineral evaluation.

Carpenter (1976) discussed base metal mineralization at the Foust Copper Mine near the base of Bass Mountain; a black rhyolitic ridge in the northwest corner of the Snow Camp Mine-Major Hill map area (Plate 1). Diorite crops out in a small area near the mine, but the mineralization occurs in a rhyolite porphyry. The ore is described as a massive to sheared quartz vein containing chlorite, calcite, limonite, sericite, and feldspar along with ore minerals of native silver, sphalerite, chalcopyrite, galena, malachite, and traces of pyrrhotite and bornite which occur in fractures and cavities in the vein. The vein was worked to a depth of 78 feet in the late 1800s. The shaft is now almost completely filled with dump materials.

The pit of the Robeson Gold Mine, which is associated with a mineralized quartz vein described by Carpenter (1976) and located about 1 1/2 kilometers northeast of the Snow Camp intersection on S.R. 1004, has been filled with garbage. There is no visible evidence of a mine in this area. Several other mineralized quartz veins have been described by local residents in the Snow Camp Mine-Major Hill area.

Acknowledgements

This project would not have been possible without the generous support provided by Robert G. Schmidt from the U.S.G.S. in Reston, Virginia. This report has been enhanced by his ideas and suggestions, and his contributions are greatly appreciated. Thoughts originating from stimulating discussions with J. Robert Butler and P. Geoffrey Feiss from the University of North Carolina at Chapel Hill are also reflected in this report. The whole-rock geochemical data was kindly provided by Terry L. Klein from the U.S.G.S. in Reston, Virginia.

GEOLOGIC SETTING

Regional Geology

The study area is located in the Carolina slate belt which extends approximately 600 km from northern Georgia northeastward to southern Virginia. The belt consists of Late Precambrian to Early Cambrian submarine and subaerial volcanic and sedimentary rocks which have been intruded by Late Precambrian to Late Paleozoic granitic to gabbroic intrusions. The dating of the slate belt is based on rare fossil finds (Gibson et al., 1984; Secor et al., 1983; St. Jean, 1973) and on the isotopic (U-Pb and Rb-Sr) ages of the igneous rocks. At least two distinct periods of deformation occurred in the slate belt from the Late Precambrian into the Paleozoic. The older event, the Virgilina deformation, represented by folding and faulting in the northern slate belt, is bracketed between 575 and 620 Ma. The younger (Taconic?) event produced a northeast-trending, nearly vertical slaty cleavage which parallels the strike of the axial planes of a series of open folds (Butler, 1963). During the later deformational period, the entire belt was metamorphosed to low-grade greenschist facies over a period 440-480 Ma (Glover et al., 1983). Glover and Sinha (1973) suggest that 150-220 Ma may separate the structural deformation at Virgilina from the regional metamorphic event. The few reliable age dates which are available do not adequately explain the long and complex history of the slate belt.

During Mesozoic time, the Carolina slate belt underwent an extensional tectonic period which created several depositional basins throughout the belt. Normal faulting occurred during this period along with the intrusion of mafic dikes.

The northern slate belt is characterized by Late Precambrian volcanic and intrusive rocks (Glover and Sinha, 1973). Laney (1917) subdivided the Virgilina sequence of the northern slate belt into three formations, the oldest of which is the Hyco Formation (620 +/- 20 Ma). The Hyco Formation is up to 4900 m thick and consists of andesitic to rhyodacitic volcanic rocks and abundant shallow intrusions. Harris and Glover (1985) include the Snow Camp Mine-Major Hill area in the Hyco Formation. They suggest that the Flat River Subvolcanic Complex, exposed in the northern slate belt, may have been the source of the overlying primarily pyroclastic Hyco Formation.

Just southwest of the map area, in central to southern North Carolina, the rhyolitic Uwharrie Formation outcrops. These rocks are 6 to 13 km thick and are thought to be younger (approximately 520 to 570 Ma; Butler, 1979) than the Virgilina sequence farther north. The primarily subaerial Uwharrie Formation is overlain by submarine volcanogenic mudstones and sandstones of the Albemarle Group (Feiss and Weslowski, 1986). Fewer felsic intrusive rocks occur southwestward in the slate belt. The southernmost major pluton in central North Carolina is the Parks Crossroads granodiorite, between Siler City and Asheboro, dated at 566 +/- 46 Ma by Tingle (1982).

Several possibilities have been suggested for the tectonic setting of the Carolina slate belt. Butler and Ragland (1969) interpreted the belt to be an ancient island arc based on its geochemistry and its similarity to much younger tectonic-volcanic environments. Long (1979) proposed a rifting environment to explain the bimodal nature of the rocks in the slate belt. The slate belt appears to have formed in a shallow volcanic basin isolated from North America (Secor et al., 1983). The basin is characterized by primarily shallow marine to subaerial volcanism and shallow sedimentation and lacks mature clastics and carbonates (Feiss, 1985).

Local Geology

The Snow Camp Mine-Major Hill map area contains many outcrops of unaltered or only slightly altered volcanic rocks (Plate 1). Due to the abundance of pyroclastic textures, the volcanic rocks are interpreted as being deposited in a predominantly subaerial environment. Based on petrography and whole-rock geochemistry (Table 1), the dominant rock types in the field area are described as pyroclastic felsic crystal and crystal-lithic dacitic to rhyodacitic tuffaceous rocks, dacitic subvolcanic rocks, and black fine-grained rhyolitic lava flows. Green, fine-grained andesitic flow rocks occur in several areas of the field area. Hornblende-bearing diorite, in a small outcrop consisting of several large boulders, has been mapped southeast of the Snow Camp Mine. Portions of a complex quartz diorite pluton lies within the northeast corner of the field area.

Rock Units

Felsic Volcanic Rocks

The felsic volcanic rocks are generally light-gray crystal and crystal-lithic dacitic and rhyodacitic tuffs and lava flows with abundant feldspar crystals, primarily plagioclase but also including some potassium feldspar. Metamorphism has altered all of the plagioclase so that only albite remains, but some of the grains were originally more calcic, as indicated by epidote within them. The matrix of many of the rocks is fine-grained and rich in quartz and plagioclase. Chlorite, which formed from biotite during metamorphism, is common. The tuffs contain lithic fragments, which indicates their pyroclastic nature (sites 5003, 5005, 5008, 5028, 5030, and 5067) (see Plate 1). One outcrop south of the Snow Camp Mine alteration center (site 5074) contains large lithic fragments and appears to be a volcanic debris flow.

Some of the light gray, crystal-rich dacitic rocks contain intergrown feldspar crystals which might have been destroyed in an explosive pyroclastic event (sites 5004 and 5036). These rocks are similar to the felsic tuffs in the field but may be subvolcanic intrusions.

Several outcrops of black, rhyolitic lava flows occur in the field area (sites 5007, 5026, 5029, 5051, and 5055). These rocks contain potassium feldspar and albite, along with abundant pyrite, magnetite and/or hematite crystals. Some well-preserved flow banding (site 5069) is found on Major Hill. The rhyolitic rocks may have been part of a dome in the central vent facies of the volcanic center.

Andesitic Volcanic Rocks

An area north of Major Hill and several other localities in the field area contain large outcrops of green, fine-grained andesitic rocks (sites 5011, 5012, and 5076). Some are interbedded with the felsic volcanic rocks, but near Major Hill the andesitic rocks form a mappable unit. These rocks have been altered by greenschist facies metamorphism and are very chloritic. Some of the andesites in the field area may be hydrothermally altered, particularly the andesites outcropping just north of Major Hill (site 5076).

Hornblende-Bearing Dioritic Rocks

Hornblende-bearing diorite is present in a small outcrop (site 5072) and in float about 1 km south and southeast of the Snow Camp Mine pyrophyllite pit. The rocks are intensely saussuritized; the mafic minerals have altered to chlorite and epidote, and the feldspars have altered to sericite. The intrusive rocks may be both hydrothermally altered and metamorphosed. The diorite may represent a plug from a subvolcanic intrusion, but it was not possible to determine the exact relationship of the diorite to the other rocks found in the field area. Schmidt (personal communication, 1986) believes that this diorite is similar to the quartz diorite bodies found cropping out close to the centers of alteration at Pilot and Fox mountains in Randolph County, North Carolina, and the Hillsborough Mine in Orange County, North Carolina, where the exact relationships are also unclear.

Complex Felsic Plutonic Rocks

Areas of pre- and post-metamorphic felsic plutonic rocks outcrop in the northeast corner of the map area. These rocks have been examined in the field by Schmidt and Payás (personal communication, 1986). They described the intrusive rocks as quartz diorite and porphyritic quartz diorite.

Proposed Geologic History

The complex geologic history of the field area has involved several major events. The entire area, excluding a felsic pluton in the northeast corner of the map area described by Schmidt and Payas (personal communication, 1986), has experienced at least one period of metamorphism, and portions of the original group of volcanic rocks have undergone hydrothermal alteration. There is field evidence for at least one episode of deformation, resulting in a northeast-trending slaty cleavage. Intense weathering has further altered the rocks and has destroyed all but the most resistant outcrops. McConnell and Glover (1982) examined an area about 100 km north of the Snow Camp Mine-Major Hill area, and have proposed the following history for the northern slate belt:

1. Calc-alkaline volcanism and some intrusive activity, 620 +/- 20 Ma (Hyco Formation).
2. Hydrothermal alteration of the volcanic rocks from geothermal activity in the area during and following volcanism.
3. Pre-metamorphic folding and faulting, Virgilina deformation, 575-620 Ma.
4. Mid-Paleozoic low-grade metamorphism and deformation creating a pervasive northeast-trending slaty cleavage in the slate belt, 440-480 Ma.
5. Later local folding and formation of some cleavage.
6. Mesozoic rifting, creating the extensional basins and causing some intrusive activity resulting in mafic dikes.
7. Intense weathering.

No field evidence was identified that would support a separate Virgilina deformation in the Snow Camp Mine-Major Hill area, but this portion of the slate belt contains field evidence for all of the other events proposed by McConnell and Glover (1982) for the northern slate belt.

ALTERATION CENTERS

Zonation

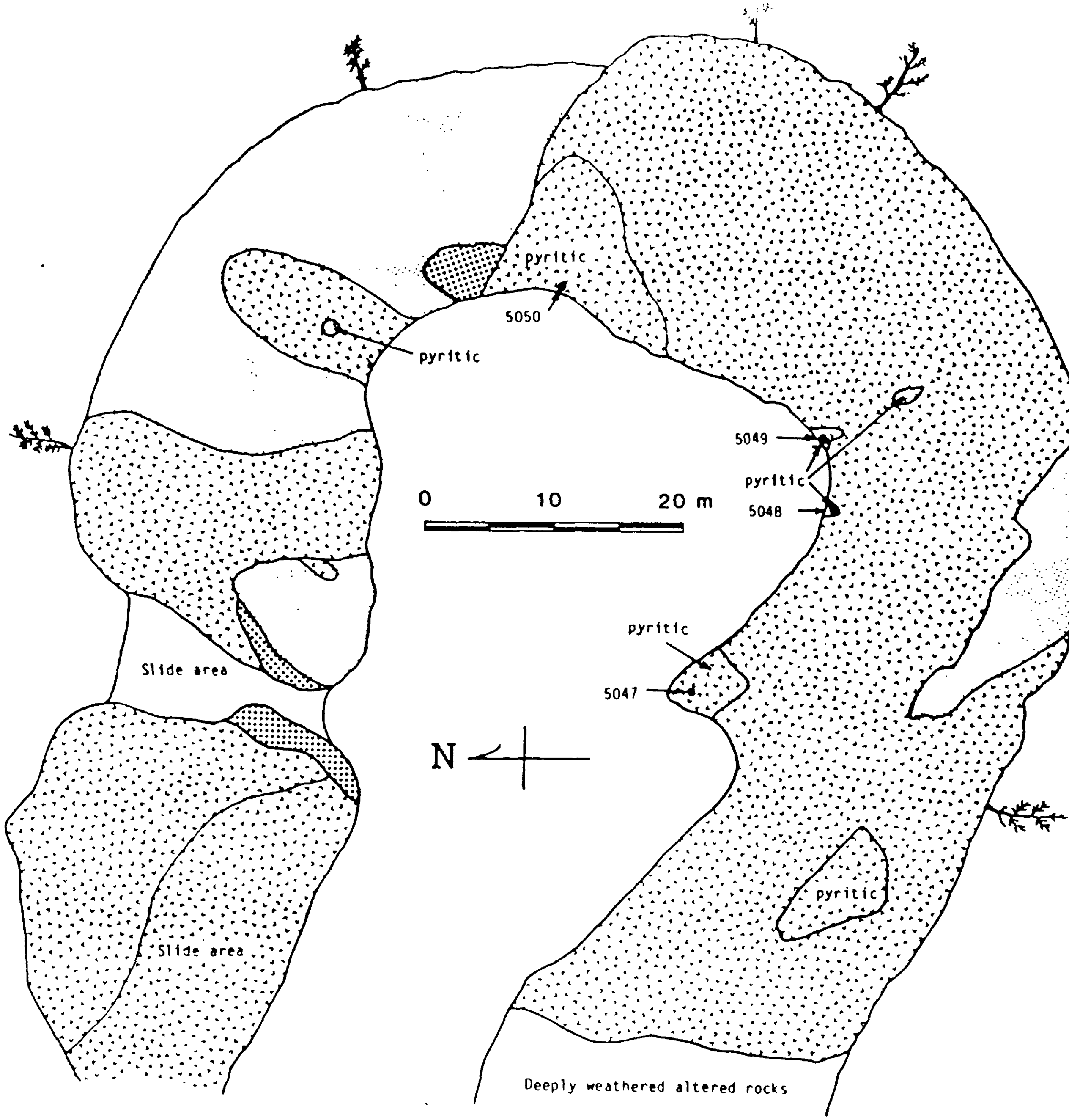
The alteration systems in this field area are mapped as general zones according to the most prominent alteration mineral found in the rock, but the zones are necessarily interpretive and grade into each other. The altered rocks have been studied optically and by x-ray diffraction (XRD) to determine the alteration mineral assemblages. These zones are, in order of decreasing intensity of alteration, silicic, advanced argillic, and sericitic (and paragonitic) (Rose and Burt, 1979). Zones of propylitically altered rocks were not separately delineated in the field, because the regional chlorite-zone greenschist-facies metamorphism creates the same mineral assemblage in rocks of andesitic composition.

Snow Camp Mine Area

The Snow Camp Mine alteration area is located about 5 km southeast of the Snow Camp commmunity intersection (Plate 1). The Snow Camp Mine pyrophyllite deposit was mined for pyrophyllite beginning in 1935 and resulted in an open three-sided pit with steep walls up to 30 m high (Figure 3). At present the pyrophyllite pit is not being worked, and it provides a good three-dimensional view of an alteration system in felsic volcanic rocks. The alteration assemblages in the pit include quartz-pyrophyllite +/- kaolinite +/- andalusite rocks, quartz-pyrophyllite-paragonite rocks, quartz-chlorite-paragonite-sericite rocks, quartz-paragonite +/- hematite rocks, and quartz-pyrophyllite-chloritoid rocks. Several pyritic pods occur within the pit and some are gold-bearing (Table 2). A central pyrophyllite-bearing silicic ridge runs through the pit where it is in contact with less-altered sericitic rocks. This ridge may represents a fluid conduit in a larger alteration system.

Alteration has taken place in rhyodacitic to dacitic volcanic and subvolcanic rocks, and part of the altered rock forms the highly silicic resistant ridge trending north-northeast for about 2 km. On the west side of the pond at Snow Camp Mine, crystal-lithic rhyodacites are well exposed and do not appear to be altered (sites 5028 and 5071). The contact between the altered and unaltered rocks appears to parallel the stream and lake in the mine area. It may be a fault contact, with the original stream course marking the contact between the altered and unaltered rocks. The large pyrophyllite deposit occurs northeast of the lake, and it is capped by quartz-chloritoid-pyrophyllite rocks. At the south end of the ridge more of the pyrophyllite-rich rocks occur, associated with quartz-chloritoid-pyrophyllite rocks (site 5037).

East from the Snow Camp Mine ridge, the rocks retain some relict textures but are sericitically altered. The pyroclastic nature of the rocks can be seen on the weathered surface which suggests that the dacitic to rhyodacitic rocks are the protoliths for the altered rocks. Some



Quartz-pyrophyllite rocks, +/- kaolinite, andalusite, chloritoid, sericite, paragonite, and iron oxides.

Quartz-sericite rocks, +/- paragonite, K-feldspar and iron oxides. Some rocks in this unit are not intensely altered but are crystal tuffs with a quartz-sericite matrix and sericite veinlets crosscutting the feldspars.

Quartz-chloritoid-chlorite rocks, +/- sericite and hematite.

•← 5050 Sample site

Figure 3. Sketch of mine walls, Snow Camp pyrophyllite pit (not a map). Very steep mine walls are shown as viewed from the center of the pit floor, approximately at location of north arrow.

rhyodacitic subvolcanic intrusions outcrop on the east side of the central altered ridge (site 5036). South of the Snow Camp Mine ridge, there are outcrops of a volcaniclastic debris flow (site 5074) surrounded by sericitically altered rocks (site 5075). Outcrops of altered rocks continue to the south and southwest, where pods of highly siliceous rock and quartz-pyrophyllite-pyrite rock probably represent other smaller alteration centers.

Major Hill

The Major Hill alteration center occurs in the central section of the map area between S.R. 2348 and S.R. 2351 and extends northeast at least 2 km (Plate 1). The series of altered hills is not restricted to a central ridge as at the Snow Camp Mine. The system is approximately 1.5 km wide.

The outcrops along S.R. 2348 are sericitically altered rhyodacitic crystal tuffs and subvolcanic intrusions (site 5005). These rocks are exposed further up the hill to the north (site 5066); beyond that a zone of quartz-pyrophyllite rocks (site 5062) is present along with some quartz-chloritoid rocks (site 5063). The central ridge along the top of Hill 797 runs east-west and consists of black silicic-hematitic rocks, some of which retain volcaniclastic textures. Quartz-pyrophyllite rocks occur on the knob east of Hill 797, and some isolated patches occur on the knobs to the north. The northwestern edge of the system from Hill 717 to Hill 678 is marked by flow-banded rhyolitic rocks which are well exposed and unaltered (site 5069). Just north of this unit, fine-grained intermediate volcanic rocks crop out (site 5076). These rocks also appear to be unaltered. Some pods of unaltered rocks occur within the altered sequence, possibly faulted into place.

Highland Area Northeast of Major Hill

The rocks in the highland area northeast of Major Hill, north and south of S.R. 1005 and south of S.R. 2335, are hydrothermally altered (Plate 1). The hills south of S.R. 1005, just northeast of Major Hill, contain fault blocks of pyrophyllite and outcrops of siliceous-hematitic rocks. Going from west to east along the ridge north of S.R. 1005, the mineral assemblage ranges from quartz-sericite +/- chloritoid +/- hematite rocks (sites 5014, 5015, 5016) to quartz-pyrophyllite-iron oxide rocks (site 5017) on the first hilltop. The second hill, 0.7 km to the northeast, contains a similar assemblage (sites 5018 and 5019) with knobby quartz-pyrophyllite +/- andalusite rocks forming the crest (site 5020).

Hydrothermally-altered volcanic rocks crop out in a series of northwest-trending hills just north of S.R. 2335 and west of Marys Creek in the northeastern corner of the field area. These are foliated quartz-sericite +/- paragonite +/- hematite rocks (sites 5023, 5024, and 5025) which are only well exposed on the top of the hills. No evidence for more intense alteration was found in this area.

Schmidt and Payás (personal communication, 1986) constrained the contact to 300 m between outcrops of altered rocks in the northeast part of the field area and a felsic pluton on the eastern edge of the area (Plate 1). The intrusive rocks include porphyritic quartz diorite and subvolcanic porphyritic dacites.

Other Alteration Centers

The area east of the Snow Camp Mine, near the eastern edge of tne map area, was described as a zone of quartz and quartz-sericite-pyrite rocks by Schmidt (personal communication, 1986). Pyrophyllite-rich rocks are found in float in this cultivated low-lying area, and outcrops are sparse.

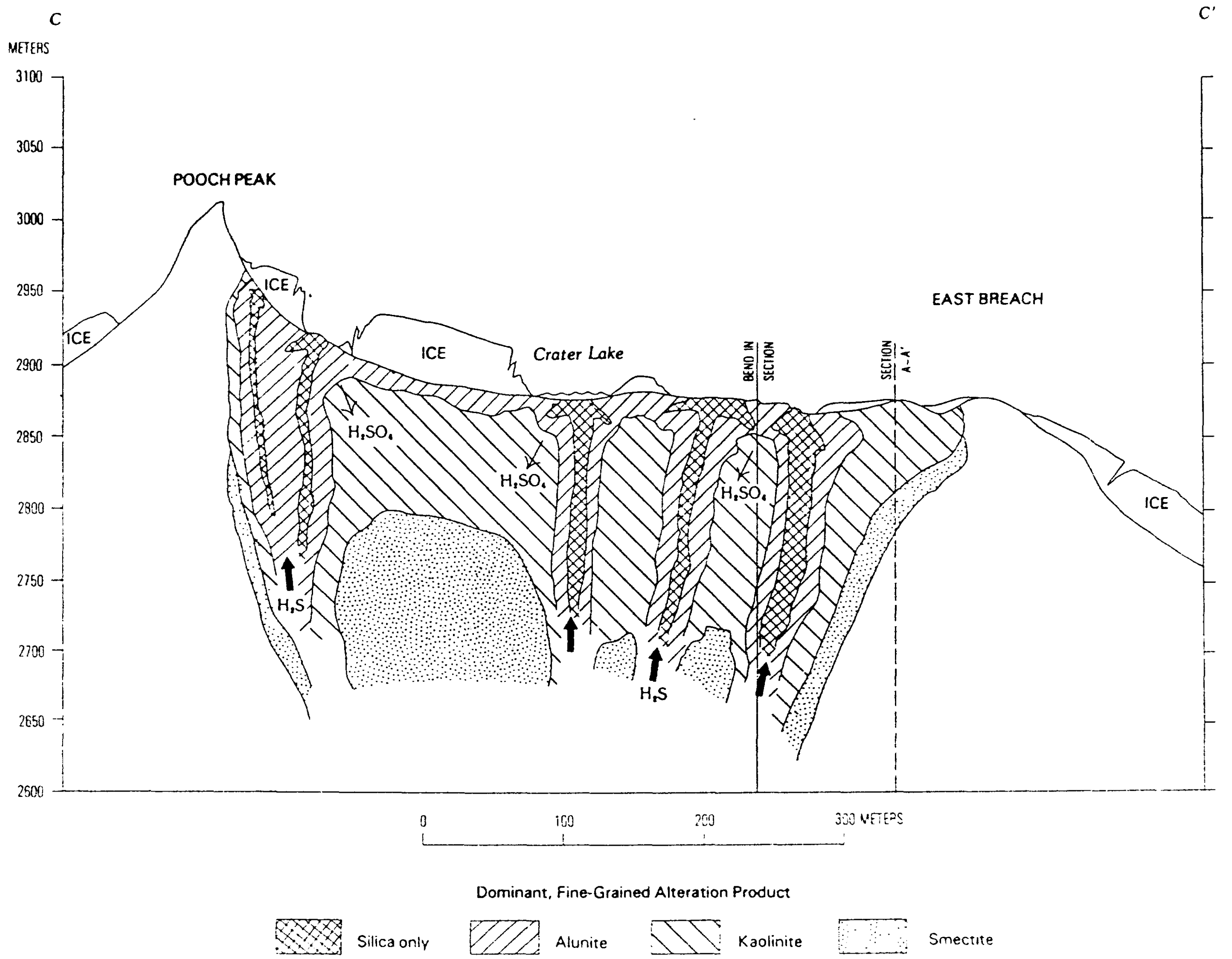
MODELS AND INTERPRETATIONS

The alteration centers in the study area are part of a succession of similar localities extending along a northeast trend for 180 km in the Carolina slate belt (Figure 2). The individual Snow Camp Mine and Major Hill areas occur along a narrow (1-2 km) northeast trend, although the altered hills within the systems are not always oriented in this direction (Plate 1). The linear nature of the individual alteration centers and the northeast trend of the alteration system suggests that the centers may be along individual fractures which follow a major northeast-trending lineament (Figure 2). This lineament parallels the orientation of the Carolina slate belt and may mark a major fault system, although geologic manifestations (i.e., fault breccias, stratigraphic offsets, etc.) other than the alignment of the alteration centers have not been recognized in the field.

The felsic volcanic rocks which host the alteration centers are similar to the surrounding rocks, and may be from the same unit. However, due to the lack of bedding in the volcanic rocks, the stratigraphy is poorly defined and it is not possible, at this point, to determine absolutely whether the alteration parallels or crosscuts the stratigraphy.

Proposed Analog To The Snow Camp Mine-Major Hill Alteration Centers

There are many young volcanic terrains in which geothermal activity alters the volcanic rocks with hot acidic waters, resulting in rocks similar to those in the Snow Camp Mine-Major Hill alteration centers. One such analog occurs in the northern Cascade Range of northwestern Washington State where the volcanic rocks at Mount Baker have been hydrothermally altered in several places to silica and clay minerals along near vertical fluid conduits marked by silicic rocks (Frank, 1983) (Figure 4). This Pleistocene calc-alkaline dacitic to andesitic stratovolcano is still thermally active. In this geothermal area, hydrogen metasomatism of the volcanic rocks associated with sulfurous fumaroles has created large amounts of kaolinite and montmorillonites along with illite, alunite, jarosite, pyrophyllite, pyrite, gypsum and silica minerals. A highly leached surficial zone is dominated by acid-sulfate waters derived from the oxidation of hydrogen sulfide (H_2S) gas from fumarole conduits to sulfuric acid (H_2SO_4) in condensing steam around the fumaroles. At Mount Baker, kaolinite is not abundant in surficial debris but is commonly found in tephra and fumarole ejecta. This suggests that a surficial silica-alunite zone of alteration is underlain and surrounded by a silica-kaolinite-alunite zone which is, in turn, underlain by a montmorillonite zone. In this case, a highly leached surficial zone results in a siliceous residue which extends to the water table where a transition into a zone rich in alunite and kaolinite occurs. Below this, the pH increases and less leaching occurs, resulting in a montmorillonite zone. The sequence also varies laterally, creating zones of decreasing intensity of alteration moving away from the fumarole conduit. The central zone is silicic; this



SULFUR OXIDATION NEAR THE GROUND SURFACE

$$H_2S + \tfrac{1}{2}O_2 \rightleftharpoons H_2O + S^\circ$$
$$S^\circ + O_2 \rightleftharpoons SO_2$$
$$SO_2 + \tfrac{1}{2}O_2 \rightleftharpoons SO_3$$
$$SO_3 + H_2O \rightleftharpoons H_2SO_4$$

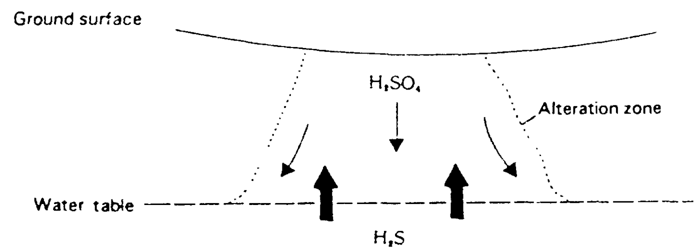


Figure 4. Inferred alteration zones at Mount Baker, Washington, from Frank (1983, Fig. 18 and 19). Section is in Sherman Crater. Hydrogen sulfide from fumarole conduits is oxidized to sulfuric acid, which then proceeds to alter surrounding rock by hydrogen metasomatism. The dominant, fine-grained alteration product in zones of decreasing intensity ranges from silica alone to alunite, kaolinite, and smectite. Suggested sulfur oxidation reactions and the possible solution flow model are also from Frank (1983), who modified them after Schoen, White, and Hemley (1974).

is surrounded by successive concentric zones of alunite, kaolinite, and montmorillonite. This zonation corresponds to that proposed by Rose and Burt (1979) where the alteration consists of silicic (silica and alunite), advanced argillic (pyrophyllite and kaolinite), and sericitic and intermediate argillic (kaolinite, illite, and montmorillonite) zones.

Alteration Conditions Proposed for Snow Camp Mine-Major Hill Centers

Geometry and Paragenesis

The Snow Camp Mine-Major Hill alteration centers are generally silicic along the central ridge of alteration and grade outwards into sericite and paragonite-rich rocks (Plate 1). Pyrophyllite and minor andalusite occur within the silicic zone of alteration. Before greenschist facies metamorphism, the assemblages may have been silica, silica-alunite, silica-pyrophyllite +/- andalusite, silica-kaolinite-montmorillonite, similar to the assemblages at Mt. Baker. Metamorphism may have altered the hydrothermal assemblages to quartz, quartz-sericite, quartz-pyrophyllite-andalusite, and quartz-sericite-paragonite. Iron sulfides and iron oxides occur throughout the zones.

Timing and Mechanism

The resistant ridges marking northeast-trending alteration centers in the Snow Camp Mine-Major Hill area may represent the traces of geothermal conduits, similar to the vertical fluid conduits at Mt. Baker, along which hot acidic alteration fluids would have been concentrated. This shallow geothermal system was probably active during the waning stages of volcanism and possibly for thousands of years before the thermal activity generated by an underlying cooling magma body died down. The altering fluids were meteoric waters which became very acidic from the oxidation of volcanic gases (i.e., H_2S, HF, and HCl). The intensity of the alteration depended on the proximity to the fluid conduit, with the most intense alteration close to the conduit. The conduits were probably fracture controlled, but they may have been more abundant in certain stratigraphic horizons as well.

Interpretations

Giles and Nelson (1983) propose that epithermal hydrothermal systems associated with hot-spring precious-metal deposits are generally found in felsic to intermediate volcanic rocks produced in convergent plate margins. The source of the volcanic and subvolcanic rocks may have been the source of heat for the hydrothermally altering fluids. The ascending fluids in these systems penetrate the pyroclastic and other permeable rock units and produce a mushroom-shaped cap of intensely leached and silicified rock. The silicic zone which marks the most intense alteration grades outward into envelopes of alunite, kaolinite, and montmorillonite. Advanced argillic alteration occurs within the silicic zone. Precious-metal mineralization may occur as the silicified rocks are brecciated by the release of confined hydrothermal fluids, thus providing a possible host for gold ores. In the Snow Camp Mine-Major Hill area, the felsic volcanic and subvolcanic rocks were altered by acidic hot fluids along a northeast trend, resulting in alteration zones which, before low-grade metamorphism, were probably similar to those described by Giles and Nelson (1983).

Schmidt (1985) suggests that the widespread alteration systems in the Carolina slate belt are variations of porphyry copper and/or gold porphyry systems and should be evaluated for their mineral-resource potential. He interprets subvolcanic intrusions as providing the heat source for the hydrothermal circulation system which altered the volcanic rocks in the slate belt. Schmidt (1985) proposes that alteration systems in the slate belt may be analogous to the high-alumina alteration associated with subvolcanic types of porphyry-copper deposits.

The alteration system represented by resistant hills in the Snow Camp Mine-Major Hill area does not contain any exhalative surficial sediments such as siliceous sinter. The magma which produced the volcanic and subvolcanic rocks in this area may have worked as a heat engine for the circulating hot acidic fluids which altered the host rocks, with the alteration that is seen in the field area occurring at an intermediate zone above the heat source. The geothermal system probably caused extensive hydrothermal alteration in the rocks over a long period of time. Based on the amount of iron sulfide in the system, the alteration probably occurred in a reducing environment.

Gold metal content was low in the few samples analysed from the Snow Camp Mine vicinity. A broader evaluation by D'Agostino and Schmidt (1986), based on panned concentrates from streams, indicated that some gold is present in the streams northeast and southeast from Major Hill. They detected no gold in streams close to or extending southwest from the Snow Camp Mine.

SUMMARY

The mineral assemblages and zonations of the alteration centers in the Snow Camp Mine-Major Hill area are similar to those of the other high-alumina alteration centers in the Carolina slate belt. The differences between the centers results from minor chemical variations within the deposits. These variations probably reflect the chemical diversity of the altering fluids which caused hydrogen metasomatism of the host rocks. All of the centers have been extensively leached by H_2SO_4 but some also have been affected by fluorine- and boron-rich fluids resulting in topaz, tourmaline, and other alteration minerals.

The zonation of the alteration centers represents a repetitive sequence of silicic and advanced argillic rocks enclosed by sericitic rocks and some propylitic rocks, with the silicic zone marking the fluid conduit for the altering fluids. The zones are concentrated along possible fractures and have an overall northeast trend throughout portions of the Carolina slate belt.

The protoliths for the alteration system in the Snow Camp Mine-Major Hill area are Late Precambrian to Early Cambrian felsic and intermediate volcanic to subvolcanic rocks with the most commonly altered protolith being rhyodacitic to dacitic pyroclastic rocks. The shallow intrusions in the field area may have intruded before or during the active geothermal period and appear to have been altered along with the volcanic rocks.

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TABLE 1: Whole rock geochemistry data. Analyses by x-ray fluorescence (XRF). Analyst; J. Jackson.

	Sample #				
	5003	5004	5005	5007	5008
Sample Description	Light gray crystal-lithic dacite	Light gray crystal-lithic dacite	Light gray crystal-lithic dacite	Black crystal-lithic magnetic andesite	Light gray crystal-lithic dacite
(%)					
SiO_2	66.19	66.01	67.58	60.70	76.31
TiO_2	.45	.46	.44	1.18	.24
Al_2O_3	17.51	18.08	18.74	15.44	13.29
Fe_2O_3	2.83	2.84	2.94	9.82	<1.89
MnO	.05	.05	.04	.17	.06
MgO	<1.52	<1.52	>1.52	>1.52	>1.52
CaO	2.16	1.92	2.27	4.95	1.74
K_2O	3.88	3.97	2.87	2.06	2.21
(ppm)					
Sn	<2	<2	<2	3	2
Ba	1106	1061	977	900	687
Rb	106	126	70	37	52
Sr	419	361	390	480	449
Y	17	16	16	40	14
Zr	220	229	227	295	169
Nb	4	5	4	6	8
Mo	<10	<10	<10	<10	<10
Ni	12	14	10	20	6
Cu	6	18	10	287	64
Zn	58	69	49	124	29
Cr	<20	<20	<20	<20	<20
La	16	18	32	39	31
Ce	57	50	85	92	50

TABLE 1: (continued) Whole rock geochemical data. (XRF).

	Sample #				
	5011	5026	5028	5029	5030
Sample Description	Green fine-grained magnetic andesite	Black fine-grained pyritic rhyolite	Light gray crystal-lithic dacite	Black fine-grained magnetic rhyolite	Light gray crystal lithic rhyodacite
(%)					
SiO_2	51.48	80.05	66.36	69.08	67.65
TiO_2	1.11	<0.13	0.44	0.42	0.46
Al_2O_3	15.78	9.69	17.79	14.56	18.39
Fe_2O_3	11.73	<1.89	2.90	4.79	2.74
MnO	0.22	<0.03	0.07	0.03	0.05
MgO	4.07	<1.52	<1.52	<1.52	<1.52
CaO	5.91	0.55	2.39	<0.55	2.02
K_2O	<0.24	3.53	3.42	<0.24	4.05
(ppm)					
Sn	<2	<2	<2	4	<2
Ba	106	1180	991	138	1683
Rb	4	48	98	20	92
Sr	725	88	418	85	446
Y	19	58	16	44	14
Zr	98	236	226	287	212
Nb	3	7	5	11	6
Mo	<10	41	<10	<10	<10
Ni	15	12	13	10	8
Cu	140	40	11	8	12
Zn	120	111	67	27	54
Cr	<20	<20	<20	<20	<20
La	10	25	25	23	15
Ce	31	59	51	49	49

TABLE 1: (continued) Whole rock geochemistry data. (XRF).

	Sample #				
	5036	5046	5051	5055	5067
Sample Description	Light gray crystal-lithic rhyodacite	Green fine-grained pyritic mafic dike	Black fine-grained rhyolite	Black fine-grained magnetic rhyolite	Light gray crystal-lithic silicified rhyodacite
(%)					
SiO_2	69.05	46.07	72.78	71.46	73.13
TiO_2	0.37	1.72	0.20	0.43	0.33
Al_2O_3	15.96	17.84	12.16	13.93	14.37
Fe_2O_3	2.47	12.23	3.24	3.47	<1.89
MnO	0.06	0.20	0.05	0.09	0.06
MgO	<1.52	7.67	<1.52	<1.52	<1.52
CaO	2.00	8.02	0.74	1.17	0.88
K_2O	3.46	<0.24	4.18	1.84	2.80
(ppm)					
Sn	<2	2	7	2	<2
Ba	880	421	150	499	1015
Rb	77	15	112	28	61
Sr	419	497	85	182	294
Y	15	22	73	44	16
Zr	202	137	547	252	181
Nb	6	4	21	10	7
Mo	<10	<10	<10	<10	<10
Ni	6	115	20	10	10
Cu	7	56	14	6	6
Zn	56	116	109	84	47
Cr	<20	58	<20	<20	<20
La	22	10	65	20	34
Ce	38	42	125	52	66

TABLE 1: (continued) Whole rock geochemistry data. XRF.

	Sample #			
	5069	5070	5071	5072
Sample Description	Black flow-banded rhyodacitic	Black pyritic andesite	Light gray crystal-lithic rhyodacite	Equigranular hornblende-bearing diorite
(%)				
SiO_2	68.49	56.65	68.77	61.82
TiO_2	0.73	2.42	0.45	1.06
Al_2O_3	14.02	16.56	15.22	16.97
Fe_2O_3	3.50	15.70	2.83	5.63
MnO	0.07	0.09	0.05	0.13
MgO	<1.52	3.79	<1.52	2.23
CaO	1.72	0.71	2.19	3.46
K_2O	4.54	2.19	4.03	3.02
(ppm)				
Sn	<2	2	<2	<2
Ba	1056	508	1087	943
Rb	94	49	88	69
Sr	306	70	433	556
Y	31	33	15	35
Zr	335	192	223	247
Nb	10	6	6	6
Mo	<10	<10	<10	<10
Ni	13	36	16	23
Cu	11	8	10	11
Zn	65	257	51	79
Cr	<20	22	<20	<20
La	48	20	25	32
Ce	86	60	58	86

TABLE 2: Gold values for samples from Snow Camp Mine and pyrophyllite pit. Analyses by fire assay, Roosevelt Moore, Analyst; P.G. Aruscavage, Project Leader.

FIELD #	Au (ppm)	SAMPLE DESCRIPTION AND LOCATION
CRU 5029	<0.075	Black rhyolitic pyritic rock east of Snow Camp Mine Ridge
CRU 5047	0.180	Brecciated pyritic pyrophyllite rock on the south wall of the Snow Camp pit.
CRU 5048	0.430	Pyritic pyrophyllite rock in pod just east of 5047.
CRU 5049	<0.075	Pyritic pyrophyllite rock in pod in southeast corner of Snow Camp pit.
CRU 5050	<0.150	Pyritic pyrophyllite rock in pod on east wall of Snow Camp pit.