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VOLCANIC–HOSTED GOLD AND HIGH–ALUMINA ROCKS OF THE CAROLINA SLATE BELT

edited by
P.G. Feiss

Society of Economic Geologists
Field Trip

1985 Fall Meeting
October 16–20, 1985

Volcanic-Hosted Gold and High Alumina Rocks of the Carolina Slate Belt

Edited by P. Geoffrey Feiss

Guidebook for the Field Trip

held in conjunction with

the 1985 Fall Meeting
of the
Society of Economic Geologists

and

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of the
Geological Society of America

Orlando, Florida

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Cover Photograph: Siliceous sinter at the Brewer mine, South Carolina. Photograph by Christopher Cherrywell.

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INTRODUCTION

In the next three and a half days we will look at gold prospects and aluminosilicate-rich rocks in the Piedmont province of the southern Appalachians in North and South Carolina. The host rocks of these deposits are within rocks of the Carolina Slate belt and the Kings Mountain belt. Figure 1 shows the location of the stops.

Our goal is to investigate the environment of volcanism and mineralization-associated, argillic, silicic and advanced argillic (alumina-rich) alteration represented by pyrophyllite (kyanite)-sericite-quartz-pyrite assemblages. We will discuss the geometry and origin of the alteration and the gold mineralization related to these systems.

The guidebook is organized as follows:

- Trip itinerary.
- A discussion of general Carolina Slate belt and Kings Mountain belt geology to acquaint you with the regional setting, geologic history, mining history, and literature on the region.
- Field trip narrative. Discussion of the geology between stops is limited to brief paragraphs between stop descriptions.
- Appendix I includes a mileage log for those wishing to

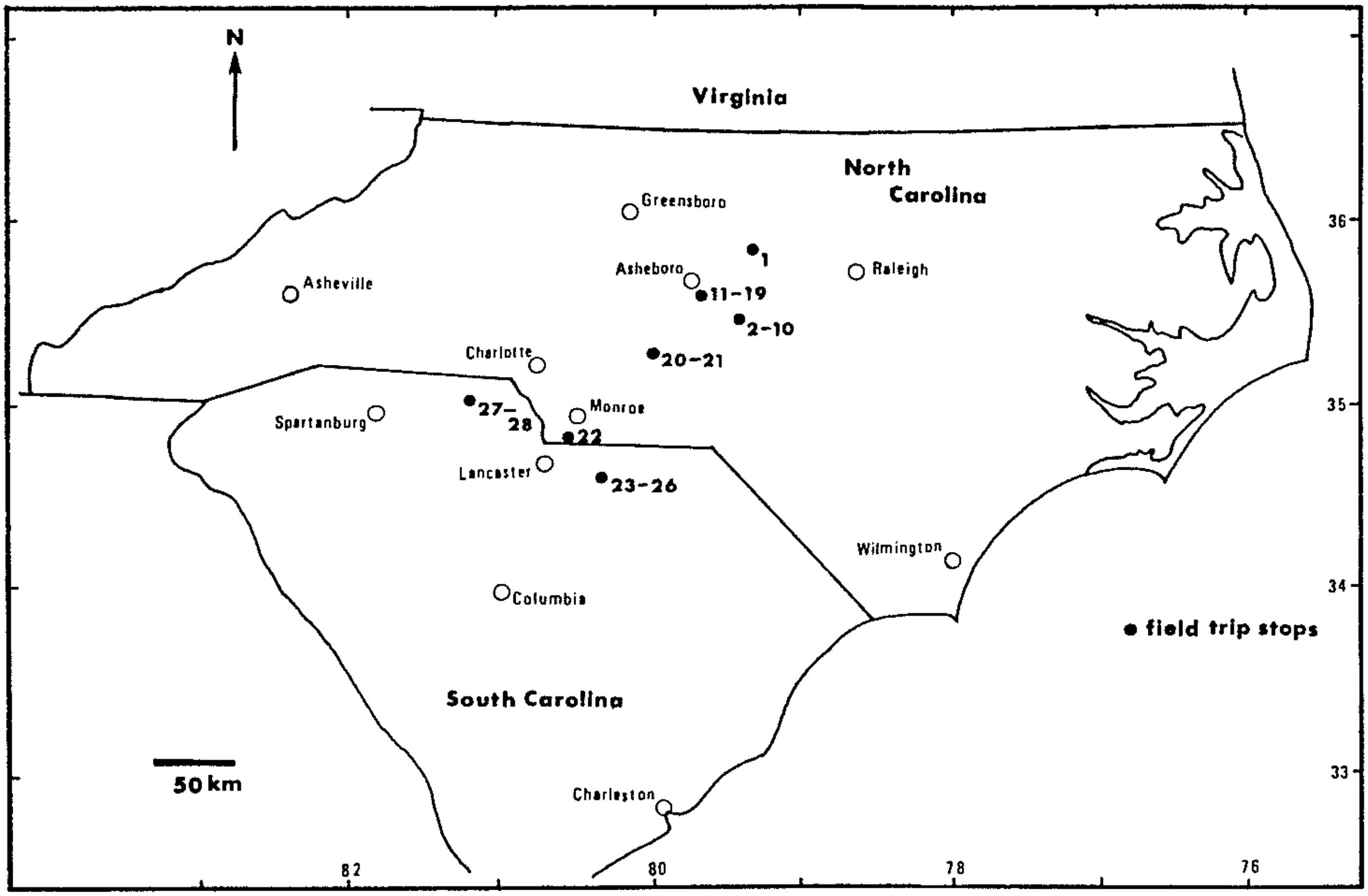

Figure 1: General location of the stops to be made on the field trip. Numbers refer to the numbers used in the text and Table of Contents.

retrace the trip on their own. In that regard, please note that many of the stops on this trip are on private property and that, in the southeastern US, it is wise to obtain prior permission from land-owners before visiting such areas.

- Appendix II summarizes the minerals to be seen, their chemical composition and physical properties. This appendix also includes a number of pertinent mineral stability diagrams.

ITINERARY

October 23, 1985
Assemble at Raleigh Inn, Raleigh, NC

October 24, 1985
Visit Snow Camp and pyrophyllite deposits near Glendon in Moore County, NC
Spend the night at Best Western Motel, Asheboro, NC

October 25, 1985
Visit Pilot Mountain Au-andalusite-pyrophyllite prospect and the Parks Crossroads Pluton, Randolph County, NC.
Stop to see typical slate belt metavolcanics and meta-sediments
Spend the night at Holiday Inn, Monroe, NC

October 26, 1985
Visit the Nesbit mine, Union County, NC and the Brewer mine, Chesterfield County, SC.
Spend the night at Carriage Inn, Lancaster, SC

October 27, 1985
Visit Henry Knob kyanite deposit, York County, and the Kings Creek barite mine, Cherokee County, SC
Arrive Charlotte, NC Airport at ca. 2:00 pm

GEOLOGY OF SOUTHERN APPALACHIAN PIEDMONT

by

P. Geoffrey Feiss
University of North Carolina at Chapel Hill

Regional Setting

The Piedmont province of the southern Appalachians is bounded on the east by Cretaceous and younger Coastal Plain marine and fluvial sediments and on the west by the Blue Ridge province (Figure 2). The Blue Ridge province is generally distinguished from the Piedmont by significantly higher metamorphic grades, a more complex deformational history, and by the presence of Grenville-age basement. Geographically, in the area of interest to us, the Piedmont province is defined by a gently rolling lowland and the Blue Ridge by the Blue Ridge Mountains, which include the highest elevations in eastern North America. To the south in Georgia and Alabama, the Blue Ridge geological province loses elevation and becomes topographically indistinguishable from the Piedmont.

The western margin of the Piedmont (Figure 2) is commonly marked by a major shear zone. In southern North Carolina and South Carolina this is the Brevard zone - a complex zone of cataclasis and mylonitization that has been variously described as a suture, a major strike slip fault, the root zone of Blue

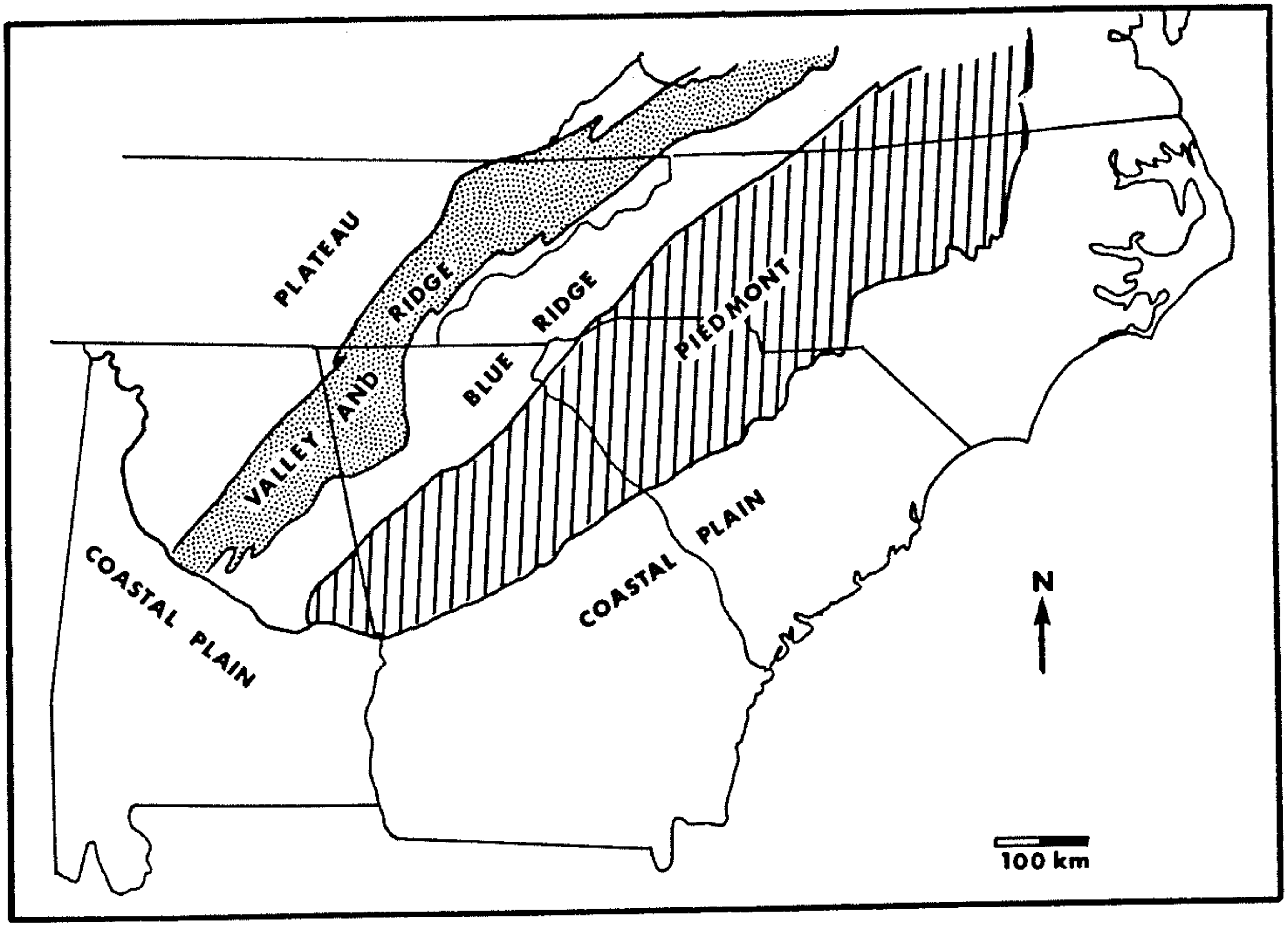

Figure 2: Geographic terranes of the southern Appalachians.

Ridge nappes, and the up-dip expression of major, low-angle thrust faults. Interpretation of the Brevard Zone remains a problem of major interest to Appalachian geologists.

Within the Piedmont, the only geological features of non-Appalachian affinities are the northeast-southwest trending, Triassic-Jurassic fault-bounded basins. These are classic rift basins filled with continentally-derived clastics, lacustrine sediments, and basalt flows, dikes, and sills. They were produced during the early Mesozoic opening of the Atlantic Ocean. In several areas, such as Moore and Union Counties, North Carolina, Triassic fault basins mark the eastern margin of the Piedmont itself. Such basins are known in the subsurface in North Carolina, South Carolina, and Georgia.

The Piedmont is divided into a number of northeast-trending belts (Figure 3). In general, there are three sets of paired (low and high grade) metamorphic belts, although in no single east-west traverse of the Piedmont can one see all six belts. It is quite likely that these belts are not regionally extensive along strike. However, one cannot exclude the possibility that either the marine onlap has covered one or more belts in some of the eastern portions of the Piedmont or that complex structures have eliminated or obscured belts by faulting or folding.

The host rocks for the deposits to be studied are units of the Carolina Slate belt and the Kings Mountain belt. Each is the low-grade member of a paired belt sequence - in the case of the Carolina slate belt, the Charlotte belt lies immediately to the

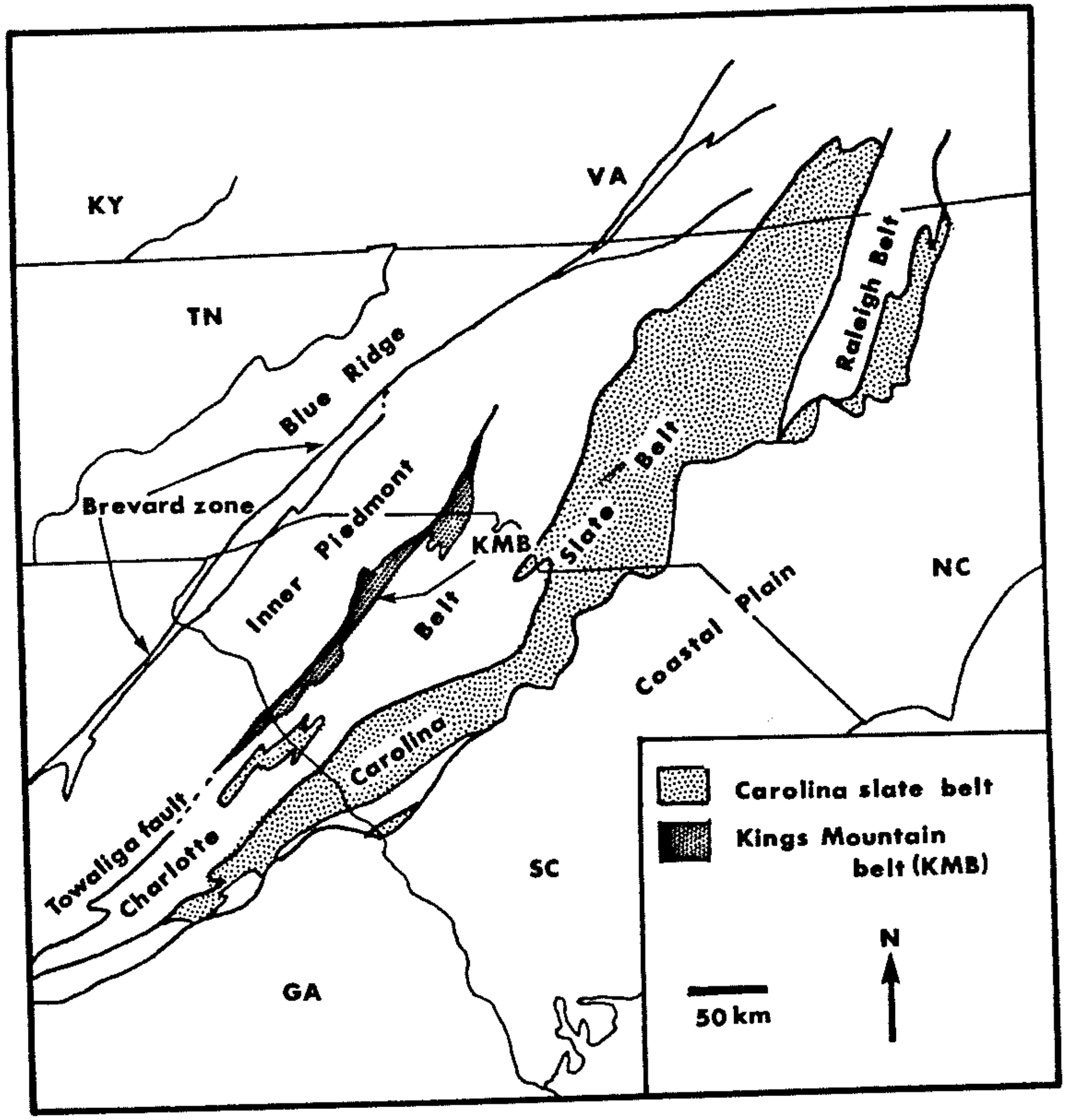

Figure 3: General geologic map of the southern Appalachian Piedmont.

west, and in the case of the Kings Mountain belt, the Inner Piedmont belt. East of the Carolina slate belt in central and northern North Carolina, the high-grade Raleigh belt, which is paired with the Eastern Slate belt, marks the Carolina slate belt margin. The contacts of these belts are of uncertain character. In most cases, large fault zones and zones of cataclasis appear to mark the border, e.g. the Gold Hill-Silver Hill fault zone between the Carolina slate belt and the Charlotte belt in central and southern North Carolina and the Boogertown and Kings Mountain shear zones on the east and west sides of the Kings Mountain belt, respectively. As with the Brevard zone, the nature of these regionally significant shear zones is controversial. None of the deposits that we will see appear to bear any direct, causal relationship to these shear zones.

With the possible exception of several allochthonous terranes in northwestern North Carolina, all the exposed rocks in the Piedmont of the Carolinas are Proterozoic Z to early Paleozoic in age. The Carolina slate belt is a Proterozoic Z to Middle Cambrian volcano-sedimentary sequence, intruded by granitic plutons with ages ranging from 265 to 650 m.y. (Fullagar and Butler, 1979; Kish and Black, 1982). The Kings Mountain belt is generally similar to the slate belt in lithology and age and includes a significantly larger proportion of granitic intrusive rocks than the portions of the Carolina slate belt to be observed in this trip. The Carolina slate belt has all been subjected to a Taconic to Acadian deformation resulting in relatively broad, open folds (Figure 4). North of a poorly defined line from just south of Asheboro to Chapel Hill in North Carolina, the slate belt rocks appear to have been subjected to an Early Cambrian (575 to 620 m.y.) deformation, the Virgilina event (Glover and Sinha, 1973). The metamorphic grade is greenschist facies or less; many primary depositional textures are preserved. The Kings Mountain belt has been subjected to multiple deformations ranging in style from isoclinal to open folds and is typically metamorphosed to upper amphibolite (first sillimanite) grade. The Kings Mountain belt is unique, relative to either of the adjacent terranes, the Charlotte belt or Inner Piedmont belt, in that there are inliers of greenschist and lower amphibolite facies rocks.

The Carolina slate belt is a regionally extensive terrane, running continuously from north of the North Carolina-Virginia line to northwestern Georgia. Some of it is time correlative with similar terranes in the Carolinas, the Little River belt in South Carolina and Georgia, and the Eastern Slate Belt in North Carolina (Secor and others, 1983). Significant areas of Cambrian (?) metavolcanic rocks in the central Virginia Piedmont, such as the Virgilina Synclinorium and the Arvonia and Chopawamsic formations, are also time correlative (Glover and Sinha, 1973; Pavlides, 1981). Carolina slate belt rocks have been observed in the subsurface of the Coastal Plain from North Carolina to Georgia. Many view the Carolina slate belt as an Avalonian terrane (Feiss, 1984).

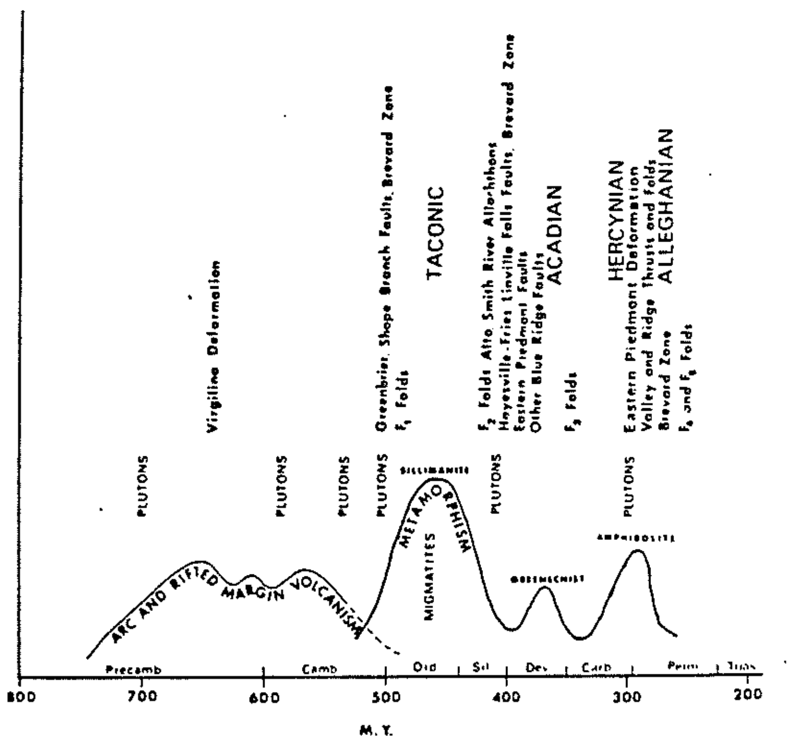

Figure 4: Summary of structural and metamorphic events affecting the southern Appalchian orogen. Folding events are not <u>all</u> recognizable at one site in the low grade terranes such as the Carolina slate belt. The metamorphic curves are most applicable in the Blue Ridge and the high grade terranes of the Piedmont, such as the Inner Piedmont and the Raleigh belts. From Hatcher and Butler, 1979, p.2.

The Kings Mountain belt is variously correlated with rocks of the Charlotte belt and the Carolina slate belt. Recent models based on seismic traverses across the Peidmont (Figure 5) suggest that the Piedmont is entirely allochthonous, consisting of numerous thrust slices which were thrust on-board the North American continent during the late Paleozoic closing of the Iapetus Ocean (Cook and others, 1979). This would make correlation of the Kings Mountain belt with adjacent terranes, as well as with the Carolina slate belt, highly problematic. All the Piedmont belts must be viewed as suspect terranes.

The Carolina slate belt

General Geology:

The stops on the first three days will be in the Carolina slate belt. The Carolina slate belt was first described in 1824 by Dennison Olmstead (North Carolina's and the nation's first state geologist) as the Great Slate Formation. The origins of the name are lost in the early nineteenth century literature - and this may be just as well since the Carolina slate belt, by analogy with the Holy Roman Empire, is neither confined to the Carolinas nor made up entirely of slate. In central North Carolina, where the stratigraphy is best known (Figure 6), the Carolina slate belt consists of a thick (perhaps >10,000 m) sequence of felsic volcanic rocks, the Uhwarrie Formation,

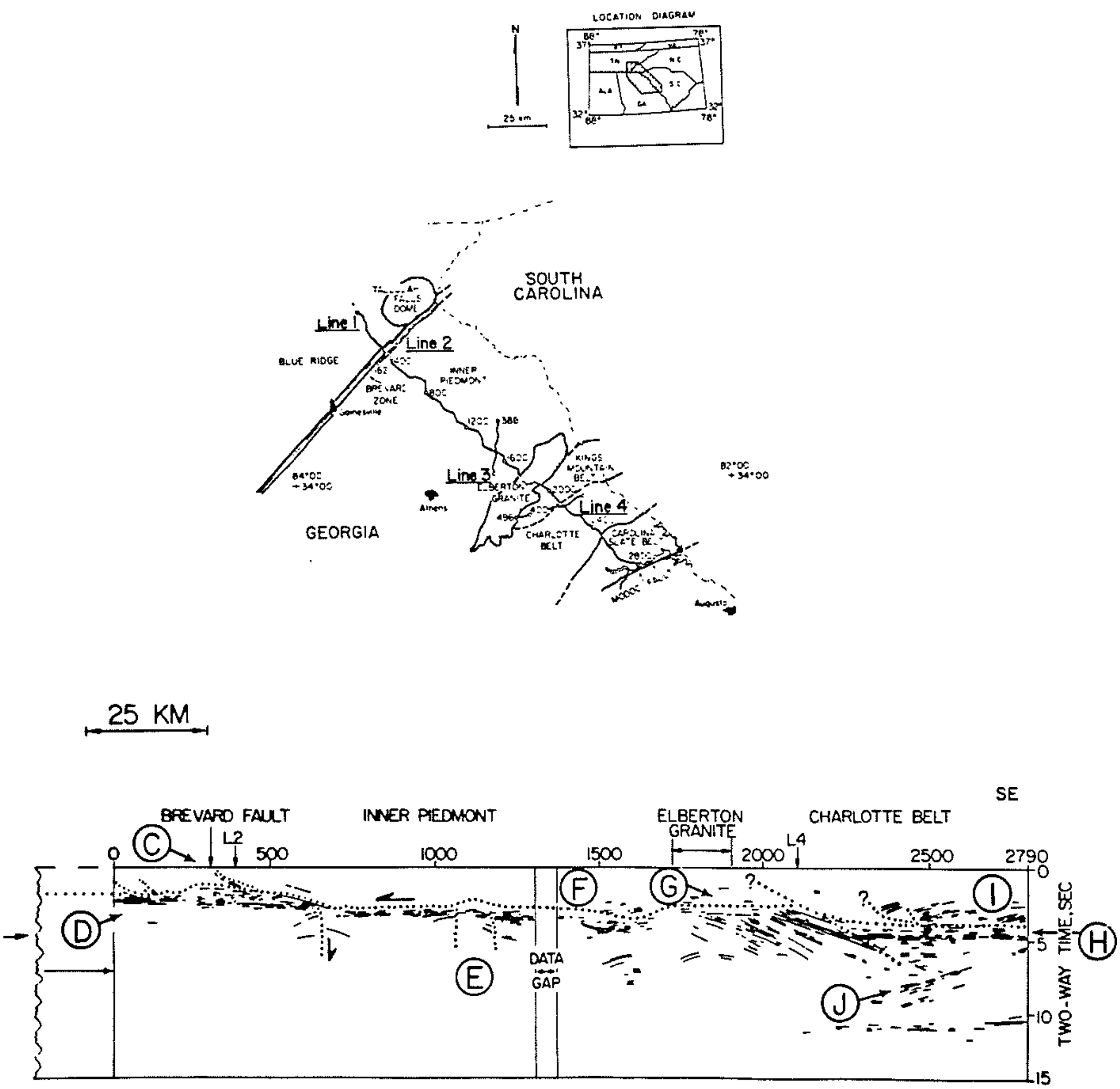

Figure 5: COCORP data from the southern Appalachian traverse. The map shows the line of traverse in areas of Georgia that can be correlated with the areas in the Carolinas of interest to us. The cross-section shows one interpretation of the seismic events along that line. Note particularly the horizontal reflectors beneath the Charlotte and Carolina slate belts. Letters refer to specific events discussed in Cook and others (1979). From Cook and others, 1979, p. 564.

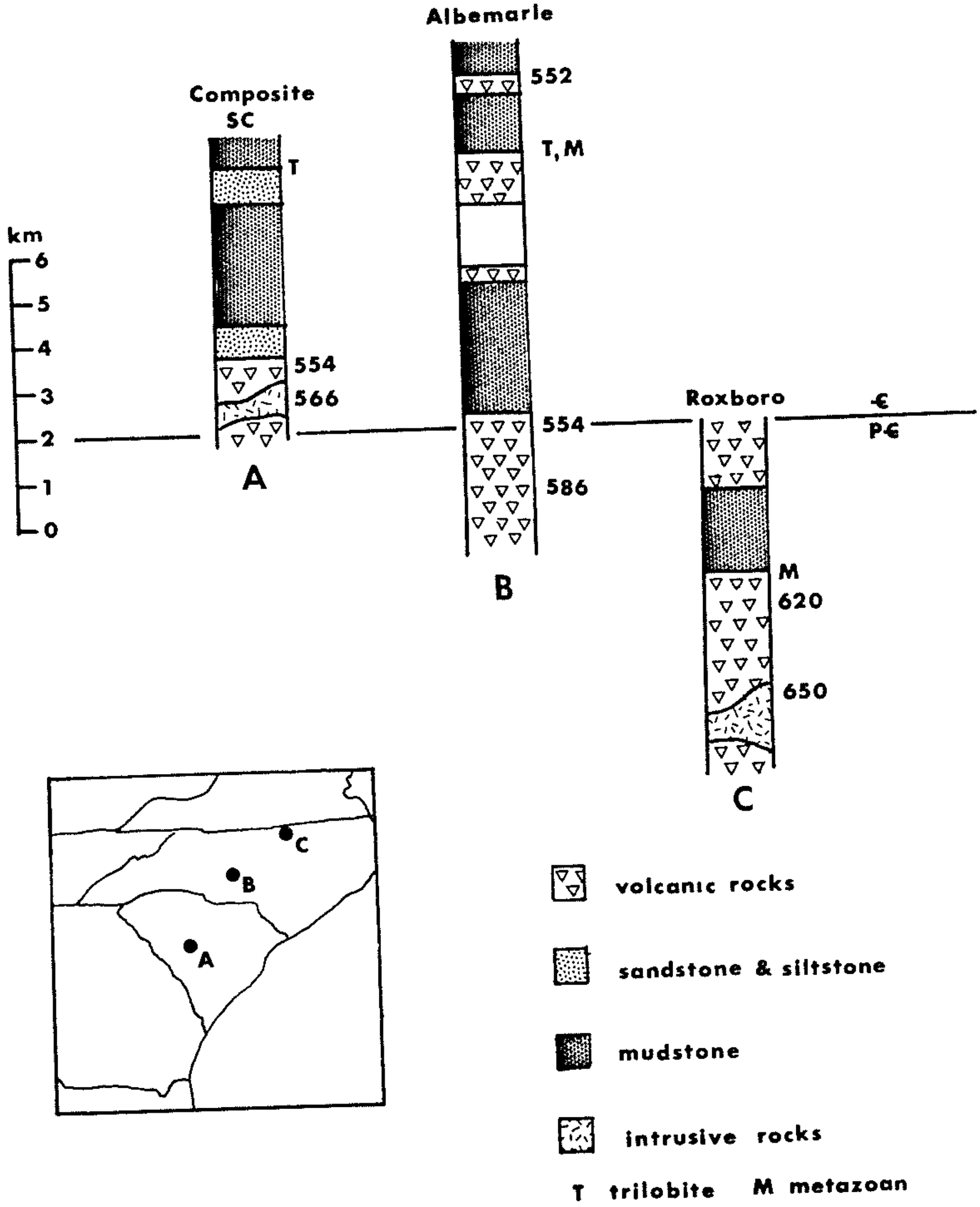

Figure 6: Generalized stratigraphy for three areas of the Carolina slate belt. Lithologic units only are shown, with important age dates and fossil horizons. The detailed stratigraphy of the Albemarle area is shown in Figure 25. Modified from Secor and others, 1983.

overlain by a mixed volcano-sedimentary sequence of unknown thickness, the Albemarle Group (Conley and Bain, 1965). Figure 7 shows the major contact between the Uhwarrie and the Albemarle Groups in the area of this trip. Beneath or time-correlative with the Uhwarrie Formation is a sequence of more mafic to intermediate volcanic and volcaniclastic rocks known as the Virgilina sequence (Laney, 1917, Glover and Sinha, 1973). These rocks are best known north of Durham, North Carolina (Figure 8) where they have been subjected to a late Precambrian-Early Cambrian deformation (between 575-620 m.y.) known as the Virgilina deformation (Glover and Sinha, 1973). Whether the Virgilina deformation affects Carolina slate belt rocks south of Durham or whether there is a regional unconformity between the Virgilina and Albemarle sequences is the subject of continuing discussion (see p. 107 of this text for a more complete review of this problem).

Detailed regional correlations are difficult to impossible given the poor exposure, low relief, deep weathering, and generally unfossiliferous nature of the Carolina slate belt rocks. Furthermore, the volcanic rocks were, in all likelihood, produced by local, relatively short-lived volcanic centers. Many of the rocks were subjected to extensive and pervasive hydrothermal alteration. Regional correlations are impossible without detailed mapping at a scale only recently attempted in the Piedmont.

In general, post-Virgilina, slate belt volcanism is bimodal

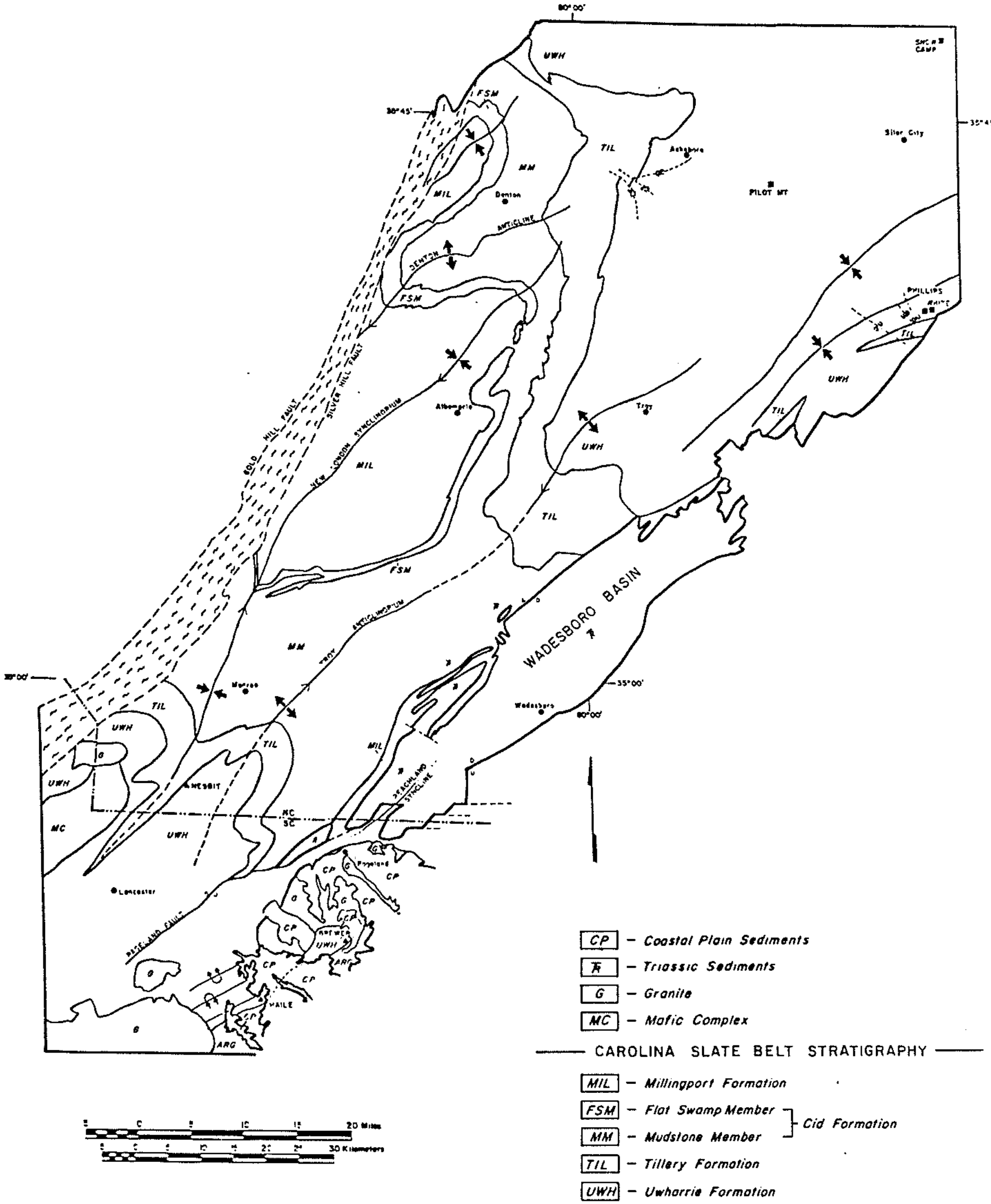

Figure 7: Generalized geologic map of the central Carolina slate belt in northern South Carolina and south-central North Carolina. The Virgilina stratigraphy in the Ramseur area (see Figure 8) is not shown on this map. From McKee, 1985.

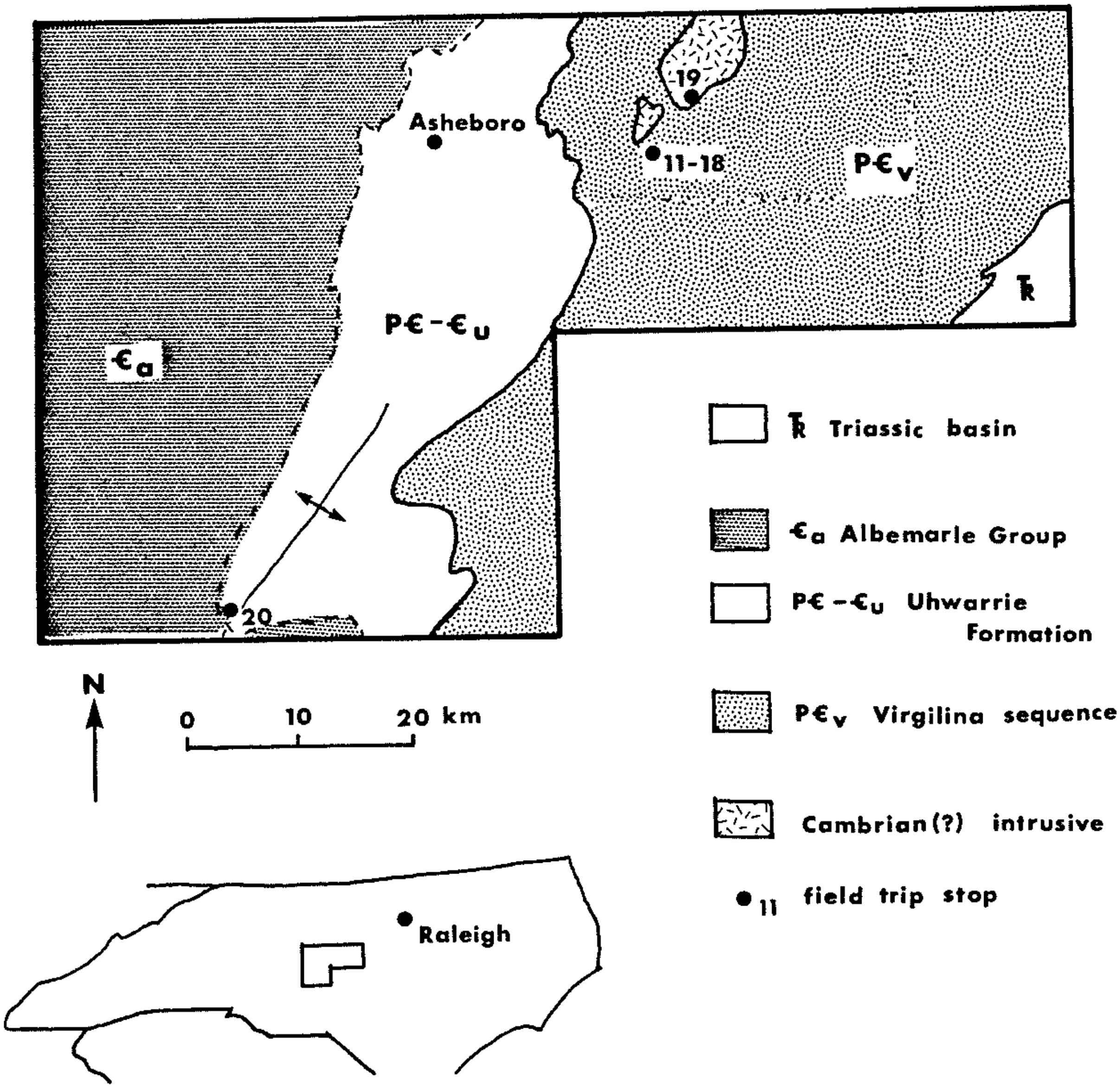

Figure 8: Generalized geologic map of the Asheboro-Ramseur area of the central North Carolina slate belt. Field trip stops are shown by number. The Glendon district, Stops 2-10, lies immediately south of the southern edge of the map on the eastern "panhandle" of the map. Modified from Harris, 1982.

and shallow submarine to subaerial. There is strong evidence for wholesale remobilization of alkalis and, possibly, silica (Feiss, 1982). Few good radiometric ages are available. Selected ages for Carolina slate belt metavolcanics are:

Date (m.y.)	Method/Location	Reference
620 +/- 20	U-Pb/Roxboro, NC	(Glover and Sinha, 1973)
586 +/- 10	U-Pb/Albemarle, NC	(Wright and Seiders, 1980)
540 +/- 7	Rb-Sr/Albemarle, NC	(Black, 1977)
554 +/- 20	Rb/Sr/Lincolnton, SC	(Carpenter and others, 1982)

Fossils from Carolina slate belt sedimentary rocks include Middle Cambrian trilobites from Batesburg, South Carolina (Maher and others, 1981), Middle Cambrian or younger sponge spicules from south of Jefferson, South Carolina (Bourland and Rigby, 1982), possible late Precambrian metazoans from Albemarle, North Carolina (Gibson and others, 1984), and Late Precambrian metazoan worm tubes from north of Durham, North Carolina (Cloud and others, 1976). In a regional sense, Carolina slate belt rocks appear to become younger from northeast to southwest. However, this may be an artifact of sampling different parts of the stratigraphic section. Based on available dating and fossils, one can only speculate as to whether the rocks seen on this trip are time correlative.

All the stops in the first three days of the trip are in the Carolina slate belt. Stops 1 through 19 are in the portion of the slate belt where correlations with the Albemarle sequence are questionable, and these areas are best correlated with the

Virgilina sequence (Figure 8). Stops 20 through 26 lie in the Albemarle sequence, east of the Troy anticlinorium - a major structure in the southern North Carolina portion of the Carolina slate belt (Figure 7). In general, these large scale folds are broad and open and control the regional distribution of major rock units. On a local scale, dips are often steep to vertical, where bedding can be discerned. The rocks vary from unfoliated to foliated with slaty to phyllitic cleavage. Unequivocal bedding features are rare in well-foliated rocks, but when seen suggest that the S_0 and S_1 are parallel. Minor, isoclinal folds are rare, as are microscopic folds, but may be more abundant than commonly believed. Thus, the structural significance of the foliation is uncertain. The metamorphic grade of all the rocks is lower-greenschist facies, chlorite to biotite grade.

Intrusive rocks in the Carolina slate belt are predominantly granitic, although small mafic bodies are common. The granite plutons range in age from 265 m.y. to 650 m.y. They are commonly grouped into pre- or syn-metamorphic, foliated granites and post-metamorphic, unfoliated granites. The latter have been referred to as 300 m.y. old or Hercynian granites by many workers. These younger, post-metamorphic plutons are slightly more radiogenic and often contain weak molybdenum mineralization in localized vein systems (Schmidt, 1978). North of an east-west line that runs roughly through Raleigh, North Carolina, rocks exposed in the Carolina slate belt are 1/3 to 1/2 granite. South of this line, there are no large plutons. The Parks Crossroads pluton, our Stop 19, is the southernmost of these large slate belt plutons in the Carolinas.

The tectonic setting of the Carolina slate belt is uncertain. Many current workers see the Carolina slate belt as an exotic, perhaps Avalonian, terrane -- in which case tectonic reconstructions are of little assistance in placing the Carolina slate belt paleogeographically. The tectonic setting of the Carolina slate belt volcanics has been likened to primitive island arc spreading (Whitney and others, 1978), to rifting (Long, 1979), or to a continental margin environment (Butler, 1979; Rogers, 1982; Green and others, 1982). The essentially calc-alkaline, bimodal character does not help place the Carolina slate belt tectonically. Neither do trace element classification schemes. The best we can do is note that the Carolina slate belt formed in a shallow volcanic basin probably isolated from North America both sedimentalogically and faunally (Secor and others, 1983). Volcanism appears to have been shallow marine to sub-aerial and, as volcanism waned, shallow water sedimentation became dominant but with a striking absence of mature clastics or carbonate rocks.

Hydrothermal Alteration and Mineralization:

As one would expect from a shallow submarine volcanic setting, there appears to have been minor but widespread, chemical modification of the volcanic rocks. Superimposed on this regional alteration is local, through-going alteration probably associated with fossil geothermal systems. It is these latter that will concern us. In general, these systems comprise several square kilometers of extensive argillic alteration (quartz-sericite-pyrite rock) with smaller areas of advanced argillic or high-alumina (pyrophyllite-andalusite-sericite-quartz-pyrite) to silicic (quartz-pyrite) alteration. The advanced argillic and silicic alteration zones are complexly admixed and typically result in erosion-resistant knobs (such as Pilot Mountain, Stop 11). In some areas an even broader halo of propylitic (chlorite-rich) alteration has been recognized, but this can be extremely difficult to distinguish from metamorphic chlorite in weakly altered felsic units or in intermediate rocks.

The alteration typically destroys primary features and textures in the rocks. The alteration phases are aligned in the metamorphic foliation. Pressure shadows are common around "phenocrysts" of pyrite and andalusite. In addition to the pyrophyllite, andalusite, quartz, sericite, and pyrite, accessory minerals include topaz, chloritoid, paragonite, kaolinite, and locally alunite and rare diaspore, tourmaline, and lazulite. As a general rule, the alteration zones are strongly silicified on either the hanging or footwall side, which is usually interpreted as the stratigraphic hanging wall. "Crackle" breccia and stockworks are common. The alteration zones tend to be clustered and are aligned along roughly linear, strike-parallel zones. Old gold mines and prospects are found around the margins of many of these advanced argillic, high-alumina zones. Rock assays from many of the alteration systems contain detectable gold and, at times, show other base metal anomalies.

Most of the gold mines in the Carolina slate belt are associated with either massive sulfide deposits or argillic alteration systems. Formerly, most of the gold mines were described as vein-type, epithermal bonanza gold deposits. The early lode-mining was limited to metamorphic quartz veins where the gold is remobilized and concentrated during metamorphism and, possibly, as saprolite gold during supergene processes. There is no question that abundant disseminated gold is present in the high-alumina, altered rocks, though these deposits were not economic in the past. Generally the gold is free and intimately associated with pyrite.

Many of the advanced argillic, high-alumina systems also contain small isolated gossans of unknown origin. There is no direct association of these alteration systems with the volcanogenic massive sulfides mined elsewhere in the Carolina slate belt.

Gold and Aluminosilicate Mining in the Carolina slate belt:

Gold mining in the Carolina slate belt began in the early 1800's. The first discovery was a 17-pound nugget found on the Reed farm in Cabarrus County, North Carolina in 1799. Small placer operations began soon after this discovery and continue to the present day. During the latter part of the nineteenth and early twentieth centuries, large scale hydraulic mining of saprolite was common, the so-called "Dahlonega" method. Lode mining began in 1824, at the Barringer Mine in Stanly County, North Carolina.

Mining in the Carolinas has produced approximately 1.5 million ounces of gold - 1.17 million ounces in North Carolina and 0.32 million in South Carolina. The history of mining has been episodic, with mining ceasing with war (1861, 1916, and 1942) or national financial panics (1892 and 1906). In North Carolina, peak production occurred in the pre-Civil War era. During this period there were four years with annual production estimates in excess of 20,000 oz. of gold. During the post-Civil War era, gold production exceeded 10,000 oz only once, in 1887. In South Carolina, annual production did not exceed 10,000 oz. until the installation of a cyanide operation at the Haile Mine in 1937. For a four year period (1938 to 1941), production at the Haile averaged 13,500 oz. of gold per year. Production at the Haile recommenced this year (1985); the first 20.7 oz. of gold were poured on April 21, 1985 (Van Hecke, 1985). This makes renewed mining at the Haile the only significant gold production in the eastern U.S. since World War II.

Major gold producers (Figure 9) in the Carolinas include (Pardee and Park, 1948):

Haile mine, SC	250,000 oz
Gold Hill district, NC	160,000 oz
Rudisil, NC	50,000 oz
Howie, NC	50,000 oz
Reed, NC	48,000 oz
Nugget, NC	48,000 oz
Dorn, SC	44,000 oz
Iola, NC	44,000 oz

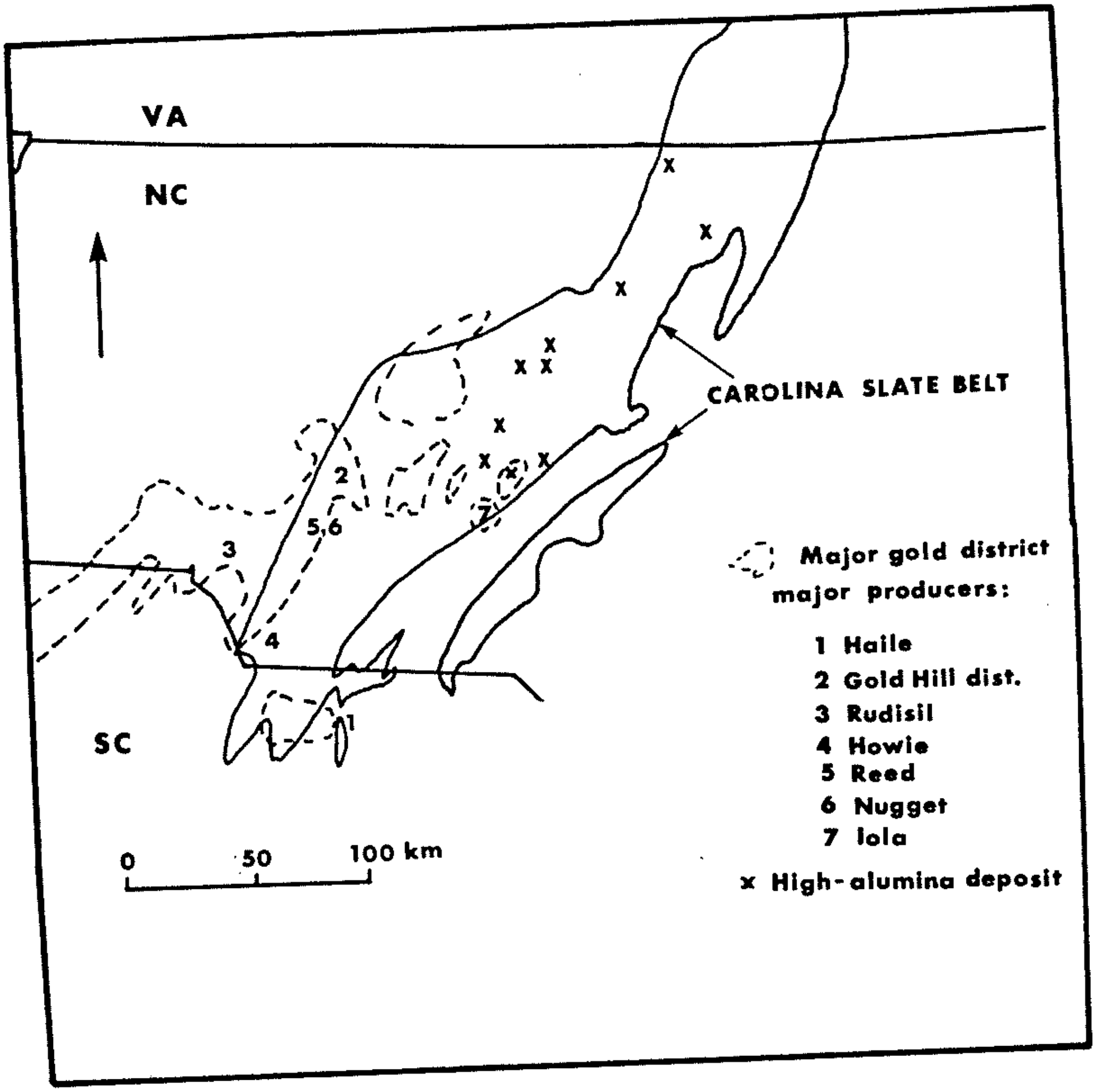

Figure 9: Major gold districts and mines and high-alumina deposits of the North and South Carolina portions of the Carolina slate belt. The only major gold producer not shown on the map is the Dorn mine, which is on the South Carolina-Georgia state line. From Pardee and Park, 1948, and Broadhurst and Councill, 1953.

The two gold mines to be visited on this trip were not major producers. The Nesbit had unknown production and the Brewer produced an estimated 22,000 oz. In addition, small scale production and prospecting for gold occurred near Pilot Mountain and a number of small gold mines, with unknown production, were active in Moore County.

Aluminosilicates, particularly andalusite and pyrophyllite, have been mined in the Carolina slate belt for at least 125 years (Stuckey, 1967), although in the early days these rocks were primarily quarried as dimension stone and fireplace liner. Beginning after World War II, significant mining of andalusite-pyrophyllite-sericite rock in North Carolina began at Hillsborough (Orange County), near Glendon and Robbins (Moore County), at Staley (Randolph County), and at Snow Camp (Alamance County). Production of mixed pyrophyllite-sericite-andalusite-quartz continues in the first two areas, the majority of production going into various grades of refractory and ceramics. Because of the limited number of mines, production statistics are not readily available. Annual pyrophyllite production in the U.S. is about 90,000 to 100,000 short tons with significant production only from North Carolina and California. Some sericite is also produced in a few areas, where previous mining has made quarrying relatively inexpensive, e.g. the Haile Mine, South Carolina.

Previous studies in the Carolina slate belt:

Because of the problems in regional correlation in the Carolina slate belt, there are few systematic studies of Slate Belt geology as a whole. Sundelius (1970) reviewed most of the literature prior to 1970. Since that review, a number of studies in specific areas are useful. These include Butler and Ragland (1969), Glover and Sinha (1973), Seiders (1978), Whitney and others (1978), Feiss (1982), Secor and others (1983), and a number of papers published in Bearce and others (1982). The gold deposits have been reasonably well described by Nitze and Hanna (1896), Nitze and Wilkens (1897), Pardee and Park (1948), McCauley and Butler (1966), and Carpenter (1976). Various models for Carolina slate belt gold deposition are described in Pardee and Park (1948) and more recently by Worthington and Kiff (1970), Spence and others (1980), and Worthington and others (1980).

The aluminosilicate deposits were originally described by Stuckey (1928) and by Broadhurst and Councill (1953). Espenshade and Potter (1960) reviewed the andalusite-bearing deposits of the Carolina slate belt. Conley (1962b) reviewed the pyrophyllite deposits of Moore County. A lively discussion on the origin of these aluminous rocks has been conducted for over twenty years and includes a variety of models (Zen, 1961; Sykes and Moody, 1978; Schmidt, 1982, 1985; Feiss and others, 1985).

THE KINGS MOUNTAIN BELT

General Geology:

On Sunday, our two stops will be to see deposits in the Kings Mountain belt (Figure 10). The Kings Mountain belt is about 150 km long and fifteen to twenty kilometers wide and runs northeast-southwest from near Statesville, North Carolina, to near Laurens, South Carolina. The belt is widest in northern South Carolina. The belt is bounded on the east by the Boogertown shear zone and on the west by the Kings Mountain shear zone (Horton and others, 1981). Southwest of Laurens, South Carolina, the Kings Mountain and Boogertown shear zones merge to form the Lowndesville shear zone. Kings Mountain belt lithologies only reappear to the south in the narrow Lowndesville belt, just north of the Georgia-South Carolina line. The Lowndesville shear zone can be traced more or less continuously into Georgia and, by some authors, into Alabama as the Towaliga fault.

The Kings Mountain belt, as defined by King (1955), consists of quartzite, conglomerate, marble, and associated mica schists at metamorphic grades that are considerably lower than the rocks of the adjacent Charlotte belt on the east and Inner Piedmont belt on the west. As can be seen in Figure 10 (Horton, 1981), the volcano-sedimentary lithologies of the Kings Mountain Belt are divided into an "eastern" and "western facies," separated by

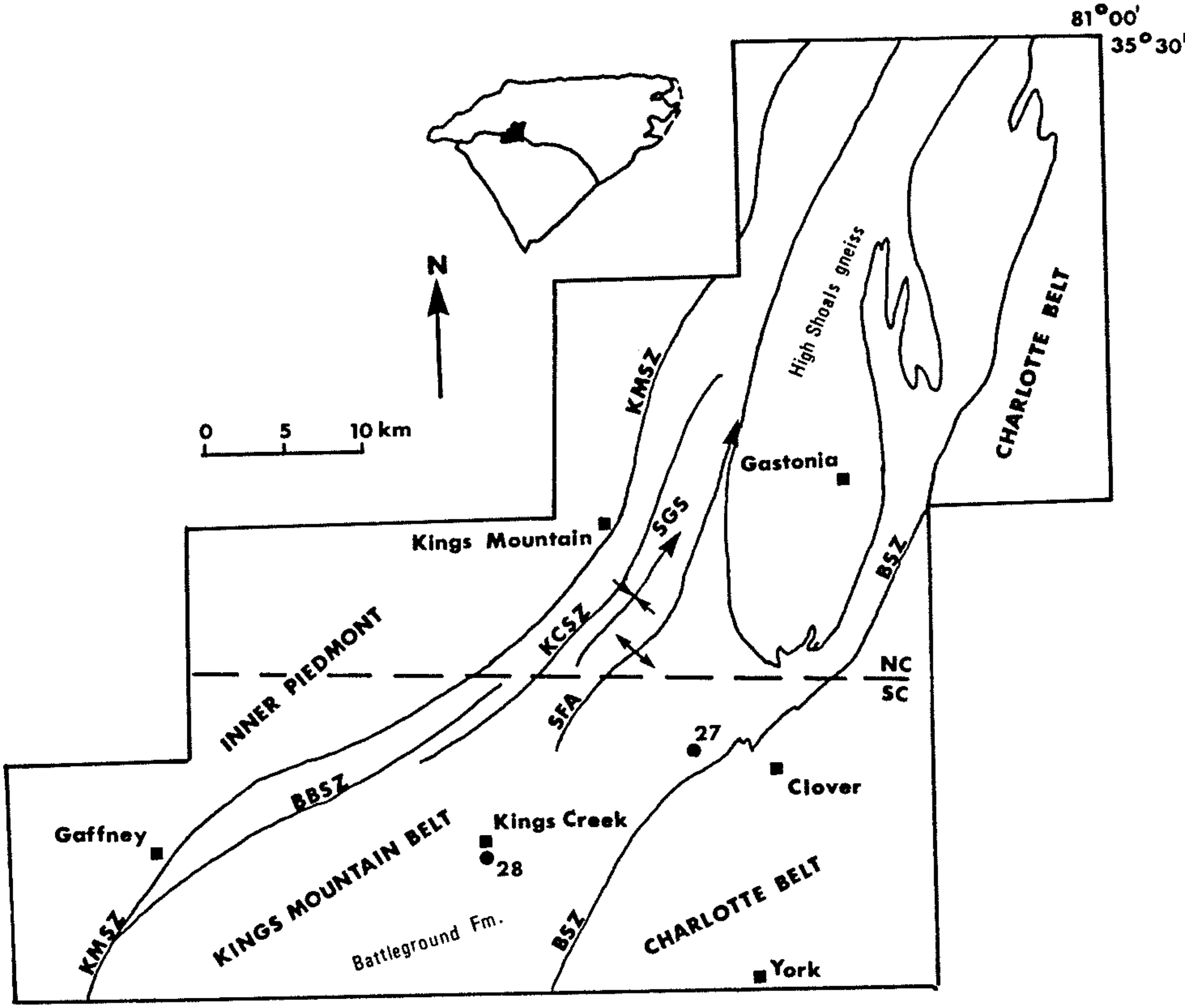

Figure 10: Generalized geologic map of the Kings Mountain belt with field trip stops shown by number. The map shows only the major structures. KEY: KMSZ, Kings Mountain shear zone; BBSZ, Blacksburg shear zone; KCSZ, Kings Creek shear zone; SGS, Sherrars Gap synform; SFA, South Fork antiform; BSZ, Boogertown shear zone. The Blacksburg Formation of Horton (1984) is not shown, but generally lies west of the Blacksburg and Kings Creek shear zones and the High Shoals granite. Modified from Horton, 1981.

the High Shoals Granite and the Kings Creek and Blacksburg shear zones. The "eastern facies" or Battleground Formation (Horton, 1984) consists of a lowermost metavolcanic series, predominantly dacitic to andesitic in composition. Murphy and Butler (1981) interpret these rocks as moderately reworked, volcaniclastic debris. These rocks include hornblende gneiss, feldspathic biotite gneiss, and a range of quartz-sericite phyllites and schists. The lower volcaniclastic rocks grade upward into metasedimentary rocks, dominantly quartz-sericite schist, high-alumina quartzite, and quartz-pebble conglomerate. The "western facies," formally the Blacksburg Formation (Horton, 1984), consists of sericite schist and phyllite, marble, micaceous quartzite, and lenses of amphibolite and calc-silicate rock. The sericite schists of the Blacksburg Formation, in many places, are graphitic. Whether the rocks of the western facies are the youngest units in the Kings Mountain belt or a lateral equivalent of the "eastern facies" is unknown. The problem is similar to that of correlating the rocks of the Virgilina sequence with those of the Albemarle Group in the slate belt.

The lowermost, volcanic-dominated sequence of the "eastern facies" contains abundant biotite metatonalite intrusions. Murphy and Butler (1981) interpret this lower sequence as a volcanic-plutonic complex in which metatonalite dikes, sills, and plugs intrude their own ejecta. Horton (1984) reports a Late Proterozoic age for these metatonalites. Metatrondjhemite, metagabbro, and metadiorite bodies are also common. The batholith-sized High Shoals granite gneiss (Yorkville Granite of Keith and Sterrett, 1931) is probably younger than Taconic (Brown and Barton, 1981). Post-metamorphic granites (e.g. the Gastonia pluton) and Triassic diabase dikes are also present. The famous lithium-bearing pegmatites of the Kings Mountain belt are 340 to 350 million years old and probably related to the Cherryville Quartz Monzonite in the Inner Piedmont.

As many as five periods of deformation are reported, ranging in style from isoclinal to open folding (Horton and Butler, 1981). As a rule, dips of both foliation and bedding are quite steep. A number of ductile shear zones are recognized, with two, as previously stated, marking the eastern and western margins of the Kings Mountain belt. Horton (1981) emphasizes that while the Kings Mountain belt is correctly characterized as a terrane with lower grades of metamorphism than either adjacent terrane, high grade rocks, upper amphibolite (first sillimanite), are also present in the Kings Mountain belt in adjacent terranes. The first sillimanite isograd is parallel to the contact of the High Shoals granite gneiss which Horton (1981) interprets as evidence of syn- or post-metamorphic emplacement of the High Shoals. The timing of metamorphism is poorly constrained in the Kings Mountain belt.

Regional tectonic models of the Appalachian Piedmont find the Kings Mountain belt particularly problematic, due to its distinctive lithologies and low metamorphic grades, as compared with rocks in either of the adjacent belts. Hatcher and Zeitz

(1980) propose a major structure, the "central Piedmont suture," which runs northeastward along the Lowndesville Fault and the southeastern margin of the Kings Mountain belt (the Boogertown shear zone of Horton). This suture implies that the Kings Mountain belt is part of a North American terrane that includes the Inner Piedmont west to the Brevard zone. Horton and Butler (1981) prefer to see the Kings Mountain shear zone on the northwest side of the Kings Mountain belt as the major crustal boundary. They base much of their reasoning on stratigraphic affinities between Kings Mountain belt lithologies, particularly the lower sequence of the "eastern facies," and the Charlotte and Carolina slate belt rocks. This model makes the Kings Mountain belt an exotic (Avalonian?) terrane, perhaps a more basinward facies of the Carolina slate belt.

Hydrothermal Alteration and Mineralization:

The Kings Mountain belt is noted for pegmatites which supply most of the domestic lithium production from spodumene-bearing pegmatites along its western margin. At present, two mines, operated by the Foote Mineral Company and the Lithium Corporation of America, produce spodumene. These pegmatites are also noted for their sub-economic cassiterite. This cassiterite enrichment, which led to the early characterization of this zone as the Kings Mountain tin-spodumene belt, is more extensive than the Kings Mountain belt proper as shown by recent stream sediment analysis by the USGS (Gair, 1983).

Other significant mineralization includes abundant banded iron formation (both oxide and sulfide facies), massive barite as at Stop 29, gold, and kyanite-rich rocks as at Stop 28 (Figure 11). In general, all these occurrences are stratabound, but detailed description is limited by the high metamorphic grade and poor exposure.

Except for the aluminosilicate-rich rocks, no evidence for any significant hydrothermal alteration, such as that seen in the Carolina slate belt, has been identified. As we shall see at Stop 27, the kyanite-rich rocks consist of kyanite-quartz-pyrite with accessory rutile, sericite, lazulite, barite, and topaz. The rock is foliated and generally stratabound. Such rocks are common in the Kings Mountain belt and form prominent monadnocks, such as Kings Mountain itself. [Kings Mountain is historically noteworthy. The Battle of Kings Mountain, in 1780, was a decisive blow to the British army in South Carolina. Tennessee, North Carolina, and Virginia volunteers administered the first major defeat to Cornwallis' army here. This reversal of fortunes for Cornwallis at Kings Mountain is held by many to have set the stage for the Battle of Cowpens and Cornwallis' fruitless pursuit of Nathaniel Greene's troops which ended at Yorktown.]

The origin of kyanite-rich rocks has been generally held to be sedimentary since the pioneering work of Espenshade and Potter (1960) who suggested that the kyanite quartzites are meta-sediments whose protolith was a "clay-rich sandstone." Horton and Butler (pers. comm., 1985) suggest that these kyanite-

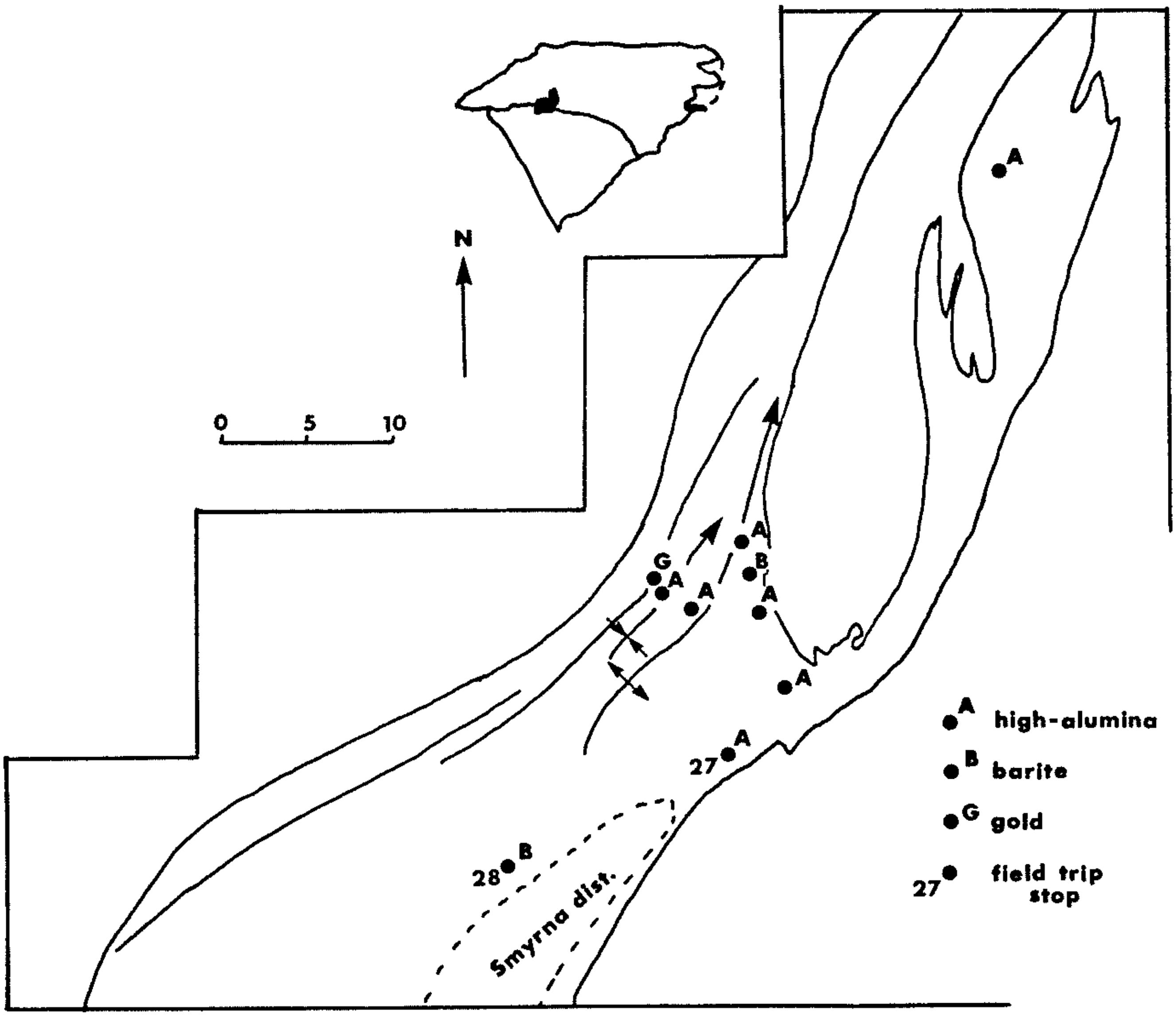

Figure 11: Major gold and high-alumina deposits and several barite localities in the Kings Mountain belt. High-alumina rocks include both kyanite- and sillimanite-rich deposits. In general, the sillimanite deposits are those closest to the High Shoals granite. The base map is the geologic map of Figure 10. From Espenshade and Potter, 1960; McCauley and Butler, 1966; Posey, 1981.

rich rocks "...formed by metamorphism of fine-grained silica and clay produced by hydrothermal alteration of volcanic or epiclastic material in hot springs or solfataras." Certainly, the mineral assemblage favors such a hypothesis.

Most of the gold deposits appear similar to the Carolina slate belt gold deposits. Gold mining never achieved the levels of the slate belt, but the Smyrna district in South Carolina included over fifty prospects and small mines (Butler, 1981). The Kings Mountain mine, near Kings Mountain, North Carolina, is singular in being carbonate-hosted and containing a number of precious and base-metal sulfosalts, not previously observed in the Piedmont (Supplee and others, 1985). This deposit is the only carbonate-hosted gold deposit reported in the Appalachians.

Gold and Aluminosilicate Mining in the Kings Mountain Belt:

The Kings Mountain mine is variously reported to have begun production from 1820 to 1834 (Pardee and Park, 1948). Total production was in the neighborhood of $750,000 to $1,000,000 during sixty or so years of production. Other than this single deposit, no other deposit is likely to have produced in excess of a thousand ounces of gold, although data is lacking for nearly all prospects and mines in the Kings Mountain belt (McCauley and Butler, 1966).

Kyanite production commenced in the Kings Mountain belt at Henry's Knob, South Carolina (Stop 27) in 1935. Production continued there until 1969. All U.S. kyanite production is currently from similar deposits in Virginia and Georgia. Extensive kyanite reserves are still present in the Kings Mountain belt, near Henry Knob at The Pinnacle and Crowders Mountain and in the Reese Mountain-Clubb Mountain area northeast of Henry Knob. Most of this area is, however, within state and federal parklands.

Previous studies in the Kings Mountain belt:

The classic work in the Kings Mountain belt includes the early mapping of Arthur Keith which culminated with Keith and Sterrett (1931) and the work of King (1955), who first formally recognized the Kings Mountain belt as a distinct terrane in the Piedmont. Kesler (1942, 1955) presented the first detailed work on the spodumene-bearing pegmatites. The work of Espenshade and Potter (1960) stands as the best review of the aluminosilicate-rich rocks. No single review of the gold deposits exists. As with the Carolina slate belt, the best single source is Pardee and Park (1948). Butler (1981) reviews the gold prospects in the Smyrna district, South Carolina. Supplee and others (1985) provides the first study of the Kings Mountain, carbonate-hosted gold deposit in nearly forty years.

In the last ten years, renewed interest in the Kings Mountain belt has resulted in a number of useful studies (Horton and others, 1981). The CUSMAP Program for the Charlotte 2 Degree Sheet has resulted in a new stratigraphic nomenclature (Horton, 1984) as well as a 1:250,000 scale geologic map of the northern portion of the Kings Mountain Belt (Goldsmith and others, in press).

FIELD TRIP NARRATIVE

DAY 1

The field trip on the first day will visit two districts where there has been active pyrophyllite mining. The first area is the Snow Camp pyrophyllite deposit, about 5.5 km southeast of the village of Snow Camp in southern Alamance County, North Carolina. The second set of stops will be in the large pyrophyllite district in Moore County, North Carolina, where we will visit two operating mines near the town of Glendon.

STOP 1

SNOW CAMP PYROPHYLLITE MINE

by

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This pyrophyllite deposit is typical of many intermediate size deposits in the Carolina slate belt in central North Carolina. The deposit occurs within an alteration system that is similar to many others in the belt. This property was mined from the mid-thirties to the mid-sixties by the North State Pyrophyllite Company; it is no longer in operation. About 600,000 tons of pyrophyllite ore has been removed from this deposit. The location of the mine is shown in Figure 12.

General Geology of the Area:

The Snow Camp deposit and probably several other nearby alteration systems are found in a sequence of weakly metamorphosed felsic to intermediate volcanic rocks that have not been subdivided in mapping. Detailed mapping is being carried out at the present time by Elizabeth H. Hughes, USGS.

West of the pond near the mine (Figure 13), the volcaniclastic rocks are dacitic to andesitic and generally crystal-rich. Locally they superficially resemble plutonic rocks (Figure 13). Breccia fragments are locally abundant and are as large as 10 cm. Some outcrops exhibit well-formed bedding or flow-

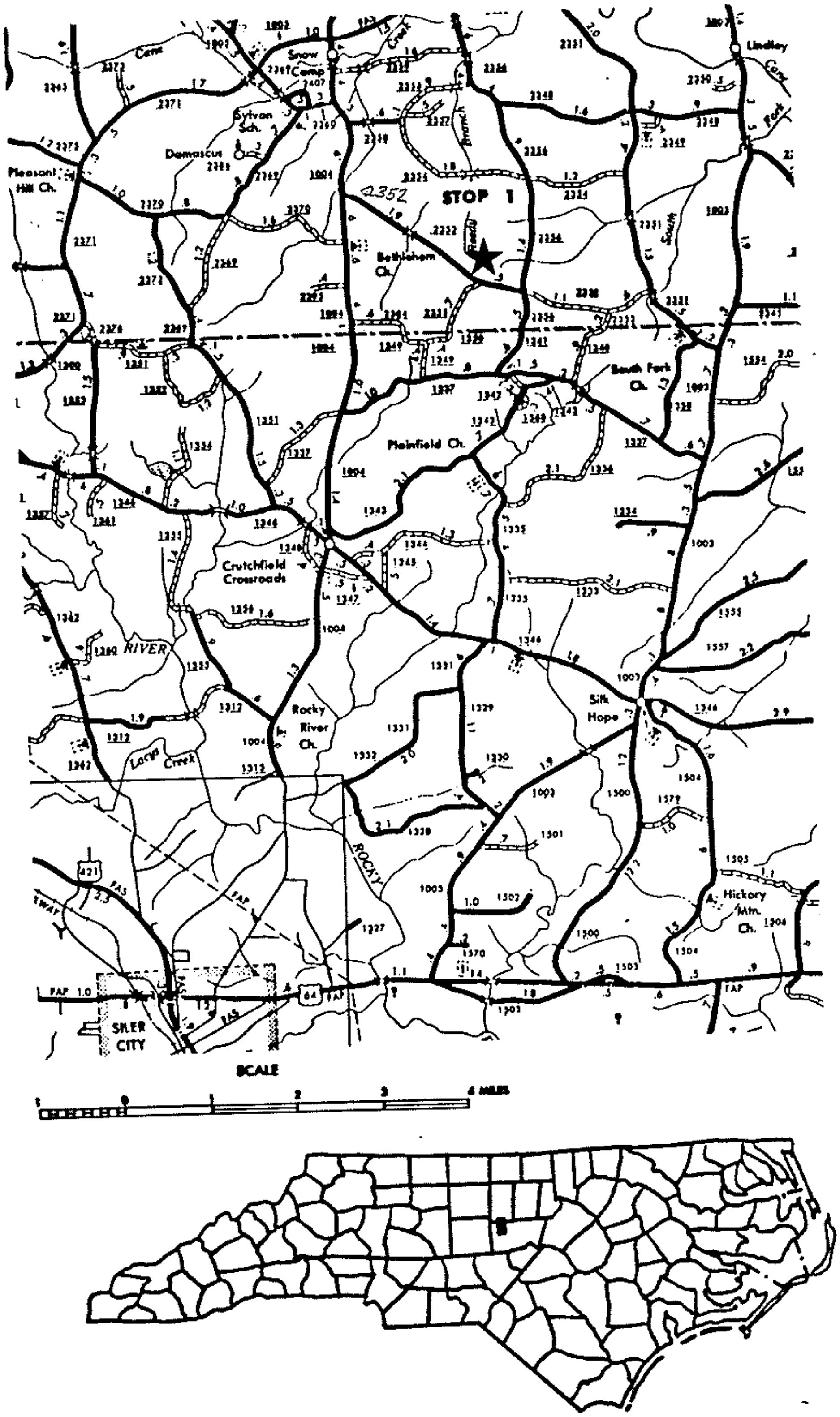

Figure 12: Location map for STOP 1 -- the Snow Camp pyrophyllite deposit, Alamance County, North Carolina.

layering. Rock similar to this volcaniclastic rock is the most probable protolith for the pyrophyllite deposit. Similar crystal-rich volcanic rock is probably the predominant country rock east of the mine as well. Outcrops on the banks of Cane Creek, four kilometers north of the mine (Figure 13), are coarse, fragmental volcanic rocks with clasts of felsic material at least 10 cm long, including pieces of flow-banded rhyolite.

Little is known of the structural or metamorphic geology at this location. Rocks in this area are generally deformed along N 25-40o E axes; closely spaced, tight folds and crudely to well-developed axial plane foliation both tend to follow this trend in other parts of the slate belt.

Geology at the Snow Camp Mine:

The pyrophyllite mine is located in a northeast-trending zone of intensely altered rock that forms a ridge with large areas of outcrop. Few outcrops are present on the lower slopes of the ridge east of the pond or on the steep slopes north, east, and south of the highly altered zone (Figure 14). Thus the relation of the hydrothermally altered rock to unaltered rocks must be inferred. The closest, extensive unaltered outcrops to the alteration system are the fragmental volcanic rocks west of the pond and in a small area on the main ridge south of the mine. Within the open pit, partially altered rocks of unknown original composition are fragment-rich volcaniclastic rocks.

The northeast-trending altered zone and corresponding

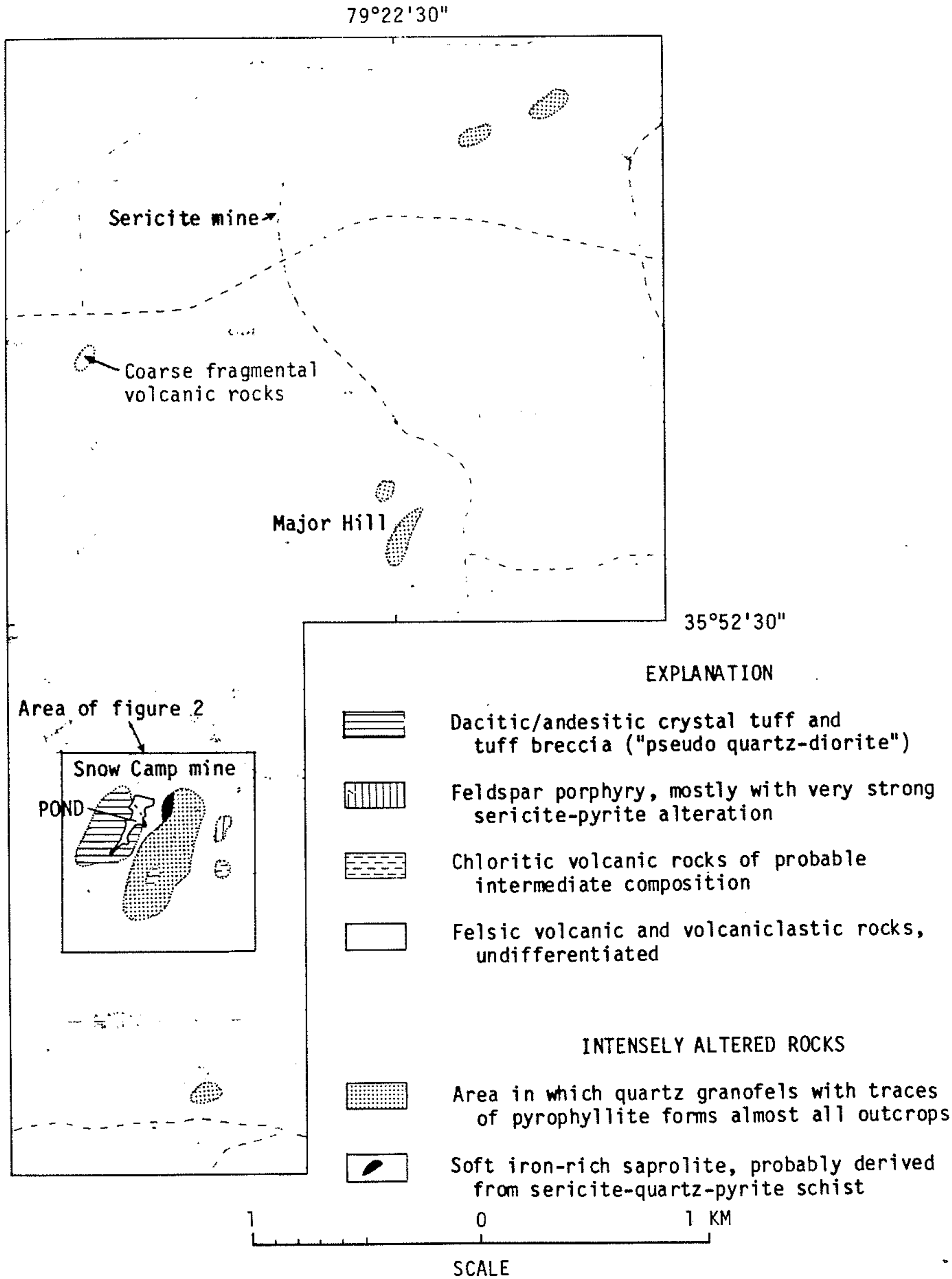

Figure 13.--Snow Camp mine and nearby hydrothermal alteration systems

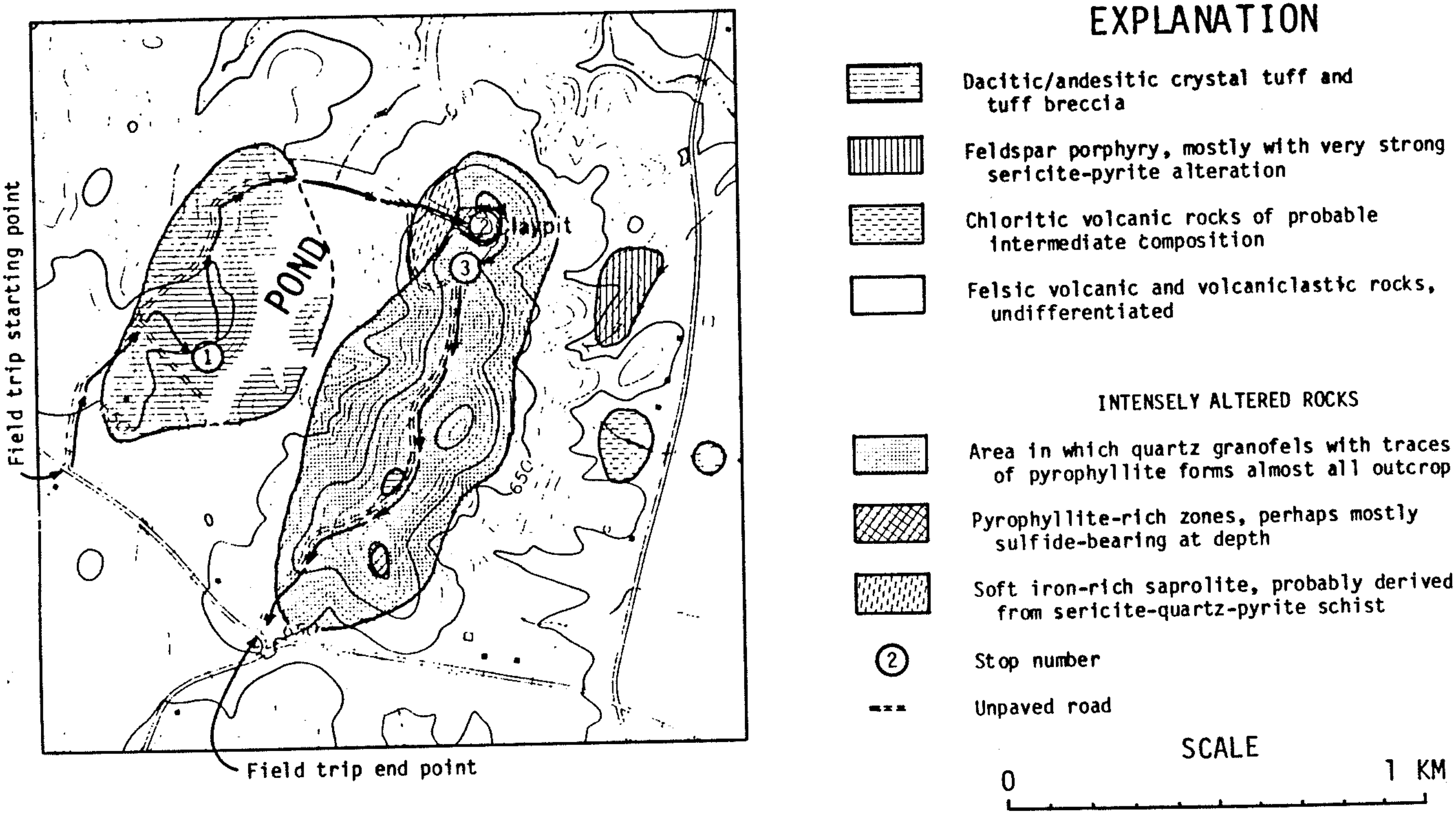

Figure 14.--Field trip route, Snow Camp mine

ridge are 1.5 km long and about 0.5 km wide. Outcrops, common near the crest of the ridge, are almost entirely of quartz-rich rock that locally resembles fine-grained, sugary quartzite but which probably formed by hydrothermal replacement of pre-existing volcanic rocks. We call this rock quartz granofels, following a suggestion by Gilles Allard. The rock commonly contains minor amounts of pyrophyllite or sericite, but pyrophyllite is a major constituent locally. One specimen examined consists entirely of paragonite (Werner Schreyer, written commun., 1985). Small voids and iron oxide stains found in most of the quartz granofels are believed to indicate the former presence of pyrite or chloritoid. The amount of inferred sulfide ranges widely from a trace to as much as 15%, and tiny disseminated crystals of chloritoid are a common and widespread constituent of some areas in the alteration zone. A common variety of pyritized quartz granofels is an intensely fragmented rock, in which the individual pieces are mostly smaller than 1 cm and tend to have a lenticular shape and a planar orientation. The surfaces of the fragments are coated with iron oxide and small voids in the rock are filled with iron oxide to give the rock a distinctly red color.

The long, deeply-cut haulage road into the mine transects a thick section of dark, red-brown saprolite, which is interpreted as derived from quartz-sericite-pyrite rock. Such rock is a common alteration product at several of the other pyrophyllite deposits, but does not form many outcrops. The extent of this material within the Snow Camp alteration system is not known; it could be widespread.

The pyrophyllite orebody formed a blocky mass within the northeast trend of the alteration zone. Before mining, the ore at this location formed a knob or small hill that extended perhaps 15 m above the present ridge level. Although the mined portion of the orebody is roughly equidimensional, narrow zones of ore probably extend northeastward and southwestward from the pit. Float boulders east of the mine suggest that pyrophyllitic rocks may extend many tens of meters eastward as well.

On the southeast side of the ridge, crystal-rich, porphyritic rocks that are similar to the volcaniclastic rocks west of the pond form sparse, low outcrops on the lower slopes, mostly in streambeds. Fresh quartz-feldspar, rhyolite porphyry (?), was observed in one place. This porphyry (?) contains abundant plagioclase crystals as much as 7 mm long and sparse quartz grains no larger than 2 mm; the groundmass is fine-grained, dull gray, and commonly contains biotite. In most exposures, the crystal-rich rock is very weathered and probably has been strongly altered, with the addition of silica and pyrite. The porphyry (?) outcrops are several hundred meters from the nearest rocks with high-alumina alteration. A genetic relationship cannot be shown with certainty, but the porphyry, if a subvolcanic intrusive, may have the caused the alteration.

Features within the Mine:

The long, east-west dimension of the mine is at nearly right angles to the trend of the altered zone. To some extent, the shape of the opening has been controlled by the deep cut made for drainage and a haulage road, but the configuration of the orebody is nevertheless generally transverse to the elongation of the alteration zone. The orebody consisted of quartz-pyrophyllite-andalusite rock stained by minor iron-oxide. Some remaining ore contains too much pyrite to be usable without elaborate mineral-dressing procedures; this pyrite-rich material is abundant in the pit floor and in large masses in the lower south wall. Small amounts of diaspore are reported from the ores, and rutile in minute, amber grainlets (<0.15 mm) is relatively abundant, perhaps exceeding 1% in some samples. Lazulite is present as a rare but showy curiosity.

The breccia-textures in pyrite-rich rock along the south side of the mine are noteworthy. Highly altered or weathered dikes, probably with an original mafic composition, cut the orebody in a generally northeast direction. The dikes apparently postdate mineralization. A dull, gray-green to light tan rock layer at the east end of the pit may also be a dike. This rock contains iron-oxide casts after pyrite up to several cm across. A narrow layer of fragmental volcanic rock is present in the north wall of the mine near the field trip exit route.

Two channel samples of the saprolite in the haulage cut, taken close to the ore, contained maximum concentrations (in ppm) of 260 As, 1700 Ba, 140 Cu, 5 Mo, 19 Sn, and 160 Zr.

Quartz-pyrophyllite rock with chloritoid forms the ridge crest 800 m southwest of the mine. Silicified breccia, probably a pyroclastic rock and composed of abundant small fragments, is associated with the quartz-pyrophyllite rock. The matrix of this rock contains chloritoid.

Remote Sensing Experiments:

The slate belt in central North Carolina has been the site of several promising remote sensing experiments that use both airborne and Landsat data. The experiments were designed to discriminate forest vegetation growing on hydrothermally altered rocks and on certain characteristic lithic rock types, such as felsic volcanic rocks. Additionally, studies are now underway to evaluate spectral reflectances of cultivated fields as a method of locating zones of hydrothermal alteration. Aerial photographs, radar images, and Landsat images are being studied to determine what structural geologic data these images can provide. A cooperative study between the U.S. Geological Survey and the Instituto de Geologia y Minero de Espana (Madrid) was begun in 1984, to evaluate remote-sensing techniques for augmenting conventional mineral exploration methods. Areas in west-central Spain and central North Carolina are being used for these studies. Some of the studies described below are being conducted by this cooperative project and involve scientists from both countries.

Airborne surveys using a high-resolution spectroradiometer were made of the Pilot Mountain zone of hydrothermal alteration (Milton and others, 1983). Spectral changes in the chlorophyll absorption region were found to correlate well with areas of strongest alteration; these areas are generally the same as those in which soils contained anomalous Cu, Mo, and Sn and the leaves of canopy trees contained relatively large amounts of Cu when compared to trees in a control area.

Distinctive vegetation suites, especially those with abundant chestnut-oak (Quercus prinus L.,), are associated with certain lithologic units. Some of these units can be discriminated on Landsat multispectral scanner (MSS) images if principal-component processing is used (Krohn and others, 1981). Recent maps made from principal-component images of the central North Carolina slate belt show that areas of distinctive spectral reflectances correlate well with areas underlain by three types of highly siliceous rocks (Schmidt and Koslow, in press). Most of the delineated areas lie within belts of felsic volcanic and volcaniclastic rocks and are topographically high. Fewer such areas are associated with certain parts of intrusive granite bodies, although most granitic rocks in the region cannot be distinguished by remote sensing. The least abundant type of siliceous rock are zones of hydrothermal alteration that contain high-alumina deposits, especially pyrophyllite. Where a distinctive spectral reflectance occurs in areas of andesitic volcanic and volcaniclastic rocks, it generally correlates with zones of intense hydrothermal alteration. Three hydrothermal zones have been identified in this fashion.

Digital classification maps using data from MSS scenes obtained in the fall (September and October) delineate essentially the same areas of highly siliceous rocks as does principal-component processing. In many instances, however, the maps separately identify areas related to hydrothermal alteration, such as Pilot and Fox Mountains (Randolph County).

Studies of enhanced thematic mapper-data images are now underway, one special objective being to identify areas of hydrothermally altered plutonic rocks by the unique spectral reflectances of cultivated fields.

STOPS 2-10

GLENDON PYROPHYLLITE DEPOSITS

by

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The Glendon pyrophyllite deposits are located in central North Carolina along the Glendon Fault, which extends more than 30 km from southern Chatham County into southern Moore County. A group of similar deposits occurs near Robbins, also in southern Moore County (Figure 15). The Glendon deposits consist of a group of four mines, three of which are active, the Womble (Standard Pyrophyllite) and the Phillips and White (Glendon Pyrophyllite) (Figure 15). The fourth, the Bates mine, located east of the Phillips, has been inactive since about 1930. The location of stops 2-10 are shown in Figure 16.

Pyrophyllite in the Glendon area has been known since 1822, when Olmstead (1822) published a list of mineral commodities that included soapstone and talc, both probably misidentified pyrophyllite. The "soapstone" deposits at Hancock's Mill (Glendon) were first described by Emmons (1856), who noted the first commercial mining had begun at the Womble deposit before 1855. Stuckey (1928, 1967) and Conley (1962b) made the first comprehensive investigations into the characteristics and origins of the Moore County deposits. Stuckey (1928) first recognized

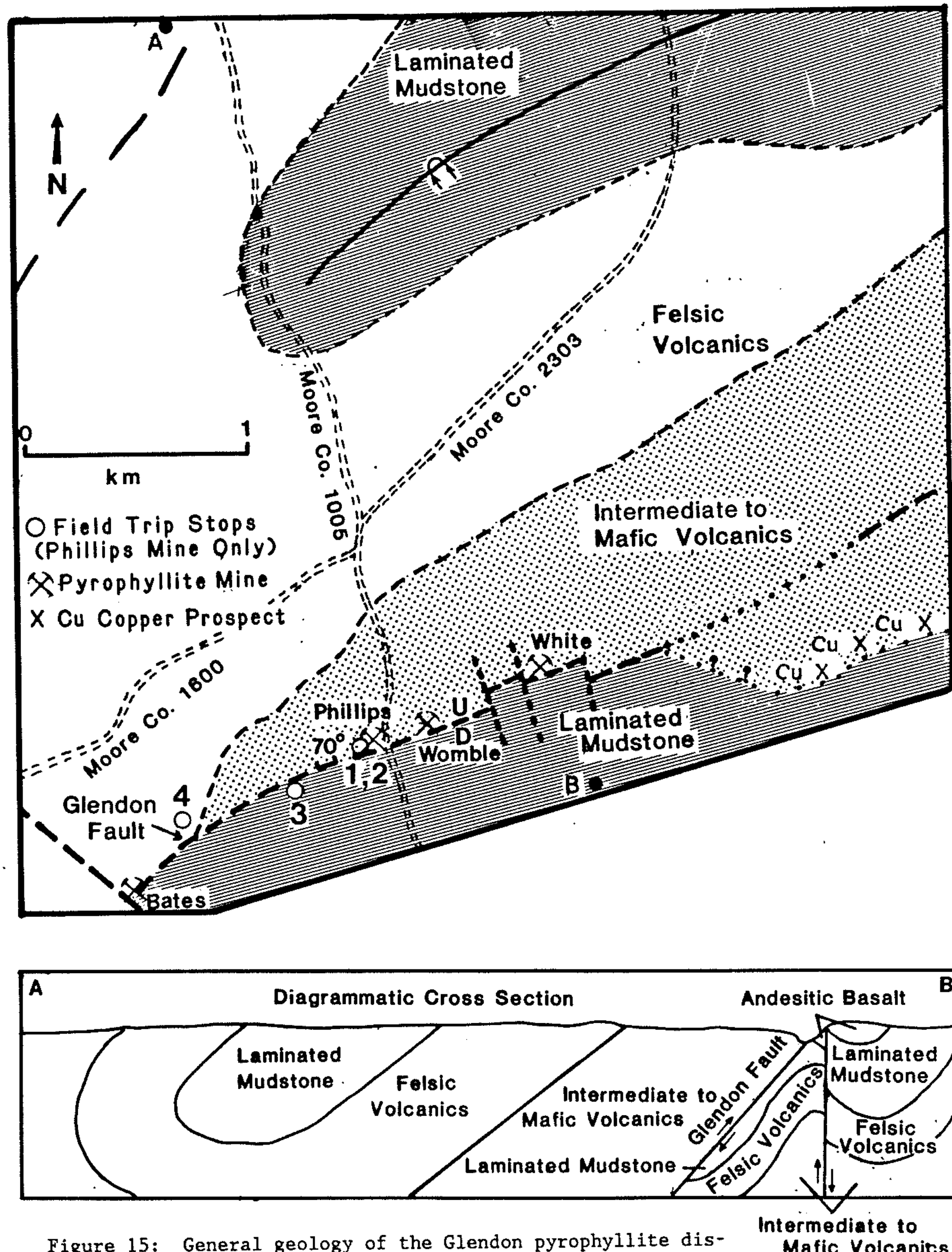

Figure 15: General geology of the Glendon pyrophyllite district. The four stops at the Phillips mine, 1-3, are equivalent to Stops 7-10 in the guidebook.

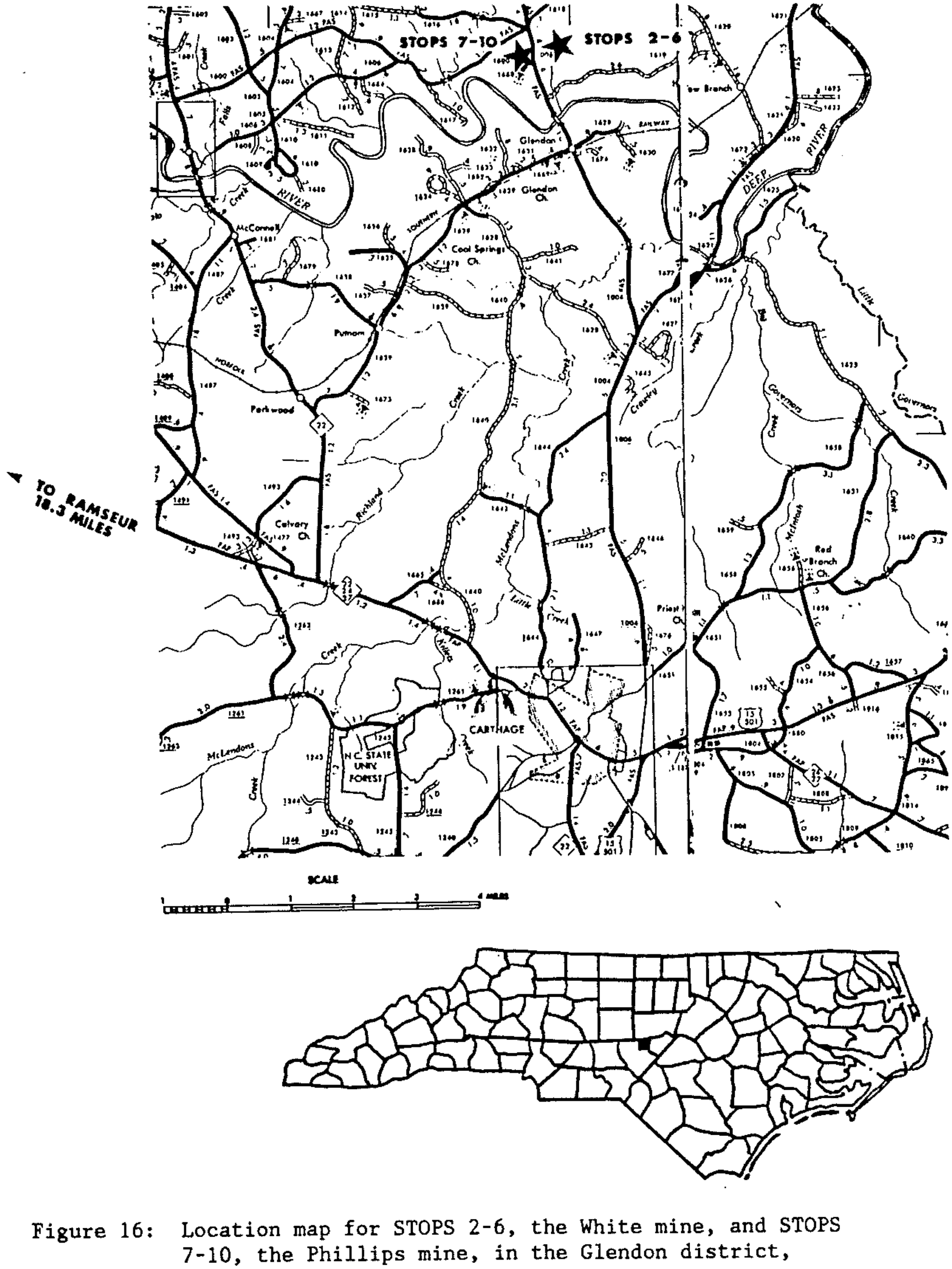

Figure 16: Location map for STOPS 2-6, the White mine, and STOPS 7-10, the Phillips mine, in the Glendon district, Moore County, North Carolina.

the lenticular nature of these deposits, their coincidence with major, regional- scale reverse faults, their strong tendency to pinch and swell along strike, and the ubiquity of the association of andesitic volcanics in the hanging wall and laminated sediments in the footwall. Broadhurst and Councill (1953) recognized a consistent mineralogical zoning in many of the Slate Belt pyrophyllite deposits as follows: a siliceous footwall zone, alumina-rich central pyrophyllite zone, and sericitic hanging wall zone. Conley (1962b) further defined zoning surrounding the deposits as consisting of an inner high-alumina zone succeeded outward by a potassic (or alkali-rich) zone and then by a siliceous or a magnesium- and iron-enriched zone. Recent investigations by McDaniel (1976) and Spence (1975) indicate that the alumina-rich alteration is similar to that in some modern hot spring systems.

Traces of gold are found in many of the pyrophyllite deposits in Moore County, particularly those near Robbins. Lesure (1981) collected 244 samples of pyrophyllite- and sericite-altered rocks from Moore County, 48 of which contained gold from 0.04 to 2.4 ppm. These samples also commonly contain anomalous Mo (20-30 ppm). Most of the gold deposits do not occur in pyrophyllite bodies but in thin, gold-bearing quartz veins and pyritic zones in adjacent sericitized felsic or intermediate volcanic rocks. However, the Standard Minerals mine at Robbins was developed on a gold mine site. At Glendon, Lesure (1981) reported gold to range from 0.02 to 0.04 ppm.

Regional Geology of the Glendon District:

The volcanic sequence in Moore County contains equal amounts of felsic and intermediate volcaniclastic rocks and laminated mudstones with minor felsic flows and mafic volcanics. Using regional correlation, Conley (1962b) placed the volcanic rocks of Moore County in the Uwharrie Formation. The large proportion of intermediate and mafic volcanic rocks in this area is uncharacteristic of the Uwharrie Formation and caused Harris (1982) to suggest that the volcanics in the Glendon area may belong to dominantly intermediate- to mafic-composition volcanics that unconformably underlie the Uwharrie volcanics. Lack of detailed geologic mapping in the areas adjacent to Moore County make these regional correlations tenuous.

The regional structure is dominated by doubly-plunging parasitic folds, with wavelengths of 1 to 5 km and axial planes dipping 50-70o NW. The folds impart a ubiquitous northwest dipping axial-planar cleavage to most lithologies (Conley, 1962b, Green and others, 1982). The folding may be of Taconic age (ca. 480 m.y. ago) or may be the result of the Virgilina deformation (600 m.y.) (Harris, 1982). Many faults in the area, such as the Glendon and Robbins faults, show reverse movement (Conley, 1962b), are parallel to the regional northeast-trending axial-planar cleavage and commonly displace fold limbs. Intense silicification and quartz veining are common along these faults. Quartz veins may be folded and sheared by deformation subsequent to that causing the dominant regional structures. Northwest-trending faults that crosscut the regional faults controlled the emplacement of Mesozoic diabase dikes.

Metamorphism in this region appears not to have exceeded the chlorite zone of the greenschist facies of Miyashiro (1973) (Sundelius, 1970; Hauck, 1977). The age of the latest regional metamorphic event is 483+/-15 m.y. (Kish and others, 1979).

The stratigraphic sequence exposed in the Glendon area, described by Green and others (1982), is shown in Figure 17. The sequence consists of felsic and intermediate to mafic volcanic rocks and volcaniclastic rocks, which were primarily shallow-water, subaqueous deposits but contain a subaerial component. The intermediate to mafic volcanic rocks have silica contents from 50 to 60 wt. percent and the felsic rocks from 65 to 74 wt. percent. Many of the volcanic units grade laterally into distal sedimentary facies and, in general, the interlayering of the felsic and mafic rocks suggests that the entire sequence is the result of volcanic input from contemporaneous, adjacent volcanic centers of differing compositions. The early felsic graywacke (Unit B) and the mafic volcanic rocks (Unit C) had source areas to the northeast and northwest respectively, whereas the source of the late felsic volcanic rocks (Unit D) was to the south (Figure 17).

At the White mine (Figure 18), the rocks on the north side of the pit are sericite-altered, fine to very coarse andesitic lithic tuffs and tuff-breccias, probably correlative to mafic volcanic rocks of unit C of Green and others (1982) (Figure 17).

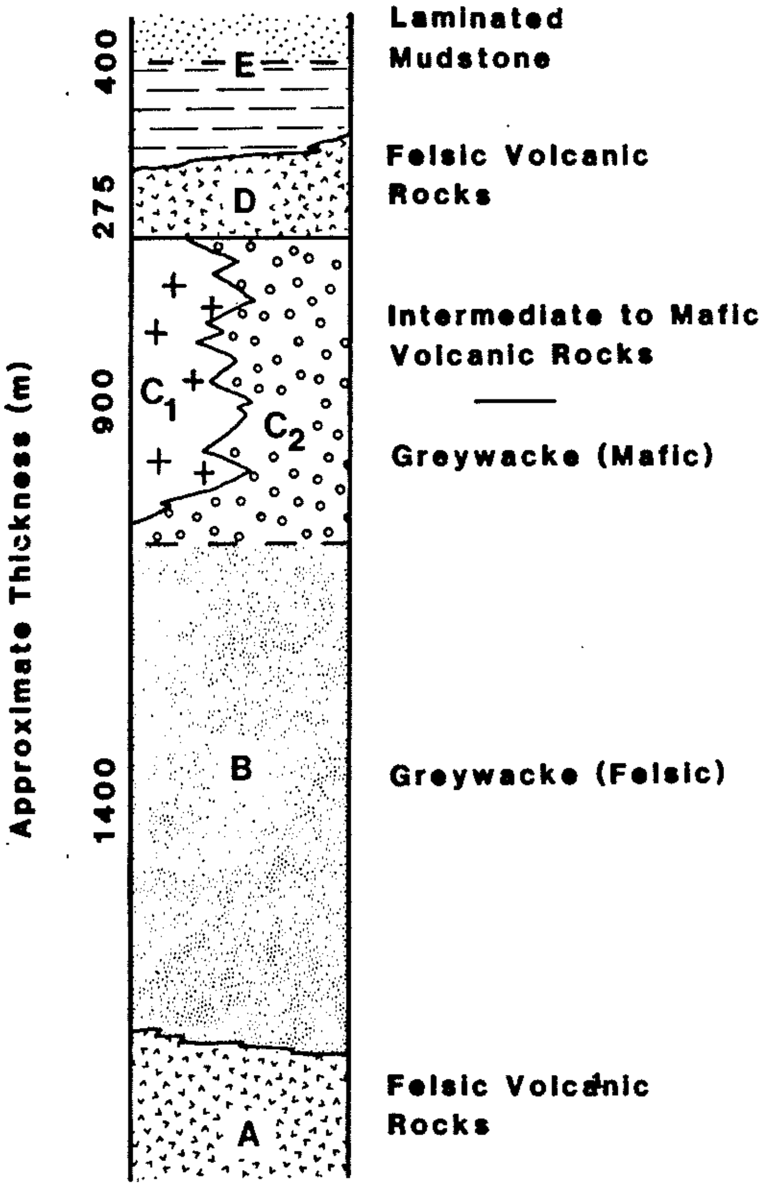

Figure 17: Stratigraphic section for the rock units in the Glendon district, Moore County, North Carolina.

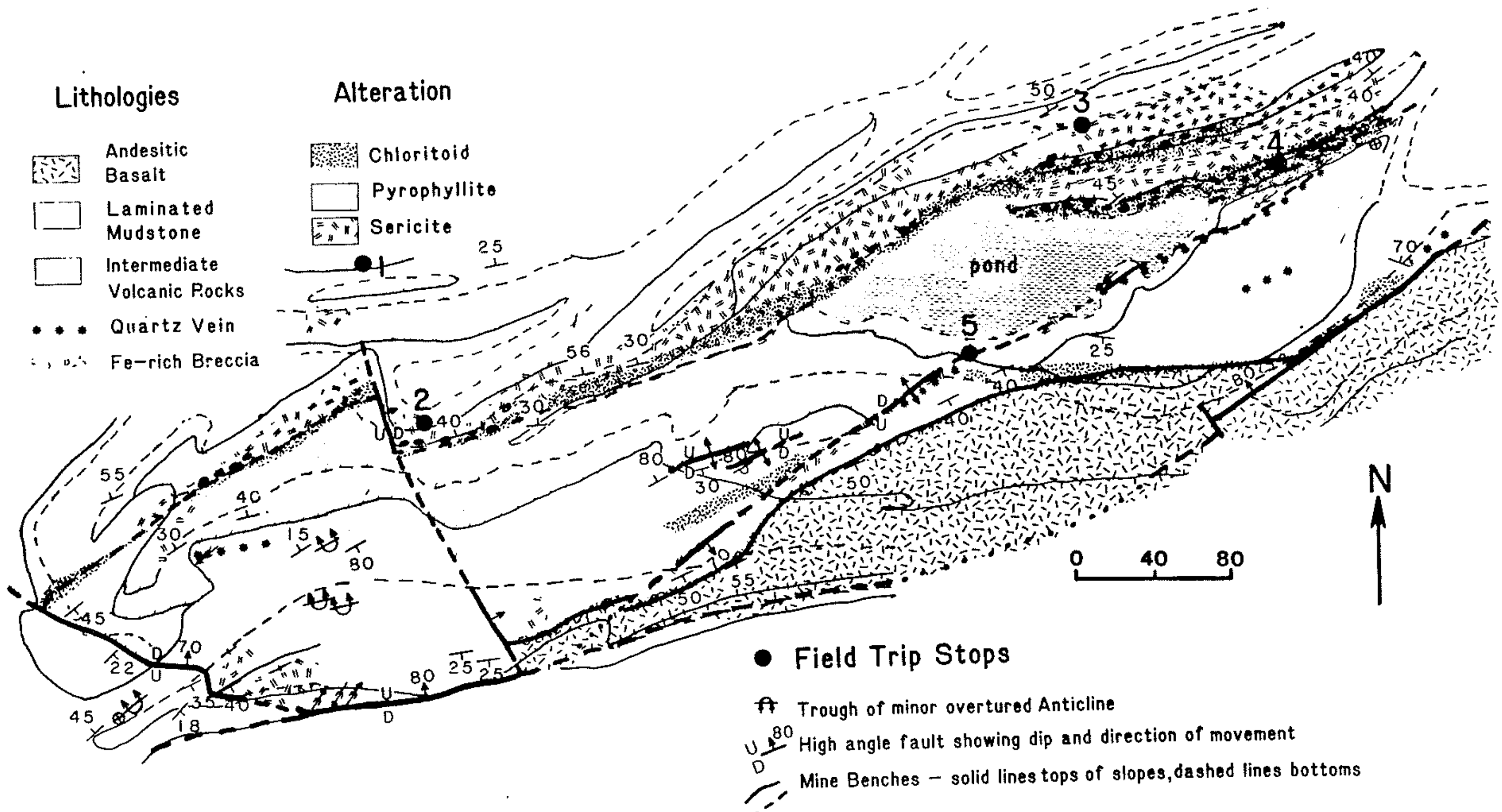

Figure **18** Geologic map of the White Mine, near Glendon, North Carolina.

This unit contains angular to subangular fragments of intermediate to mafic volcaniclastic rocks and flows as well as what may be collapsed pumice lapilli. The intermediate volcanic rocks grade laterally, in the direction of the alteration zone, into highly schistose, sericitized volcanic rocks which locally contain flat, rounded pebbles. Chemical analyses of both altered and unaltered intermediate volcanics are shown in Table 1 for comparison.

The hosts for pyrophyllite bodies at the White, Womble, and Phillips mines are laminated mudstones. The mudstones commonly show graded bedding and, at the Phillips mine, contain thin interbeds of felsic volcaniclastic material throughout. The mudstone in the mine areas is thought to be correlative with Unit E of Green and others (1982). Chemical analyses of the least altered mudstone and pyrophyllite-altered mudstone are shown in Table 1.

A distinctive volcanic breccia between the mudstone and an andesitic basalt is well exposed along the south wall of the White Mine (Figure 18) and is similar to breccias described by Stuckey (1928, 1967), McDaniel (1976), and Green and others (1982). It consists of 5 to 25 cm in diameter, rounded to angular, vesicular and non-vesicular basalt and sparse mudstone clasts in a red, very fine-grained, siliceous matrix. Sub-millimeter, color-banded laminations suggest that the matrix is a chemical precipitate, probably of exhalative origin. This breccia was deposited on an undulating mudstone surface. It

TABLE 1
Chemical analyses of selected rocks from the vicinity of the pyrophyllite deposits near Glendon, North Carolina

	LAMINATED MUDSTONE		INTERMEDIATE VOLCANIC ROCKS	
	unalt.	alt. (pyr.)	unalt.	alt. (ser.)
SiO_2	68.3	68.7	54.9	62.9
Al_2O_3	17.6	23.9	14.8	17.8
TiO_2	0.56	0.55	0.70	0.81
FeO [tot Fe]	5.68	0.65	8.46	9.57
MgO	1.88	<0.05	9.9	1.14
CaO	0.23	0.11	2.43	0.39
Na_2O	1.21	0.46	4.00	0.57
K_2O	2.36	0.32	0.01	3.08
MnO	0.05	<0.01	n.d.	n.d.
LOI	3.25	4.85	4.10[H_2O]	3.25
Total	100.97	99.47	99.49	100.33
(ppm)				
Rb	62	6	n.d.	86
Sr	152	75	n.d.	73
Ba	748	28	n.d.	960
Zr	159	320	n.d.	143

	FELSIC VOLCANIC ROCKS	"SINTER"
	unalt.	
SiO_2	73.8	84.5
Al_2O_3	n.d.	8.33
TiO_2	0.21	0.20
FeO [tot Fe]	<0.05	1.73
MgO	<1.5	<1.58
CaO	0.87	<0.16
N_2O	3.10	n.d.
K_2O	2.26	2.25
MnO	<0.04	<0.04
LOI	0.60[H_2O]	1.98
Total		96.26
(ppm)		
Rb	49	66
Sr	120	51
Ba	679	692
Zr	147	140

locally truncates bedding and extends laterally approximately one kilometer into the footwall rocks of the Glendon Fault.

McDaniel (1976) suggests that the breccia matrix was formed by surficial hot spring activity, and correlated it with a "banded siliceous sinter" outcrop located immediately southwest of the Phillips Mine. McDaniel (1976) and Spence (1975) relate the alteration in the Glendon pyrophyllite deposits to the same hot spring activity that formed the Fe-rich breccia and the "sinter." The Fe-rich breccia is affected by pyrophyllite alteration and thus formed earlier than the pyrophyllite. Thin, laminar color-banding and the high silica content of the "sinter" was cited by McDaniel (1976) as evidence for an exhalative origin. However, the banding is similar to that of adjacent rhyolitic flow rocks and Ti/Zr ratios of the two rocks are identical (Table 1). This suggests that the "sinter" is silicified felsic volcanic rock rather than a chemical precipitate.

A 20 m thick andesitic basalt layer overlies the basaltic breccia in the vicinity of the White Mine. It is massive with a few breccia horizons observed near the base. A relict, fine-grained, subophitic texture suggests that this is a flow or shallow sill.

Felsic volcanics, found primarily to the north of the pyrophyllite bodies (Figure 15), consist of volcanic flows and lapilli-rich tuffs. The flows are aphanitic to sparsely porphyritic, some having well-developed flow-banding and zones of spherulites and lithophysae. Tuffs in this area have fine-grained matrices with numerous pebble and small cobble-sized lithic fragments. These volcanic rocks appear to be the result of local subaerial dome building in this area and are transitional upward into laminated mudstones, suggesting gradual subsidence after initial subaerial volcanism. An analysis of a rock from this unit is given in Table 1.

The Glendon Fault, as mapped by Stuckey (1928) and Conley (1962b), is the locus of the high-alumina alteration and pyrite mineralization for a distance of over 30 km. The fault is a zone of extreme disruption, from 10 to 50 m wide, in which many small scale folds and fractures occur, apparently related to repeated movement within the zone. The Glendon Fault (Figure 15) is axial-planar to the regional overturned folds and exhibits a high-angle reverse sense of movement. The fault occurs near the crest of a regional, overturned anticline and cuts out the upper limb of the adjacent overturned syncline. The Glendon Fault brings laminated mudstones into contact with intermediate-composition fragmental rocks at the White mine (Figure 18). West of the Phillips mine, the intermediate-composition volcanic rocks pinch out along the fault plane. Laminated mudstone, southeast of the fault, is brought into contact with felsic flows on the northwest side of the fault plane by the southward plunge of the faulted anticline. A nearly vertical fault immediately east of the Glendon Fault is younger than the alteration. The Glendon Fault is interrupted by northwest-trending cross-faults of possible Mesozoic age and related to the development of the

Mesozoic Deep River Basin, which lies immediately to the east of the map area (Figure 15).

Geology of the Pyrophyllite Deposits:

The three active mines at Glendon are located along a 1 km segment of the Glendon Fault (Figure 15). High grade pyrophyllite bodies ranging from 20 to 50 m wide are continuous between mine sites. Pyrophyllite bodies are offset by northwest trending crossfaults having displacements of several meters to tens of meters.

At the White mine (Figure 18), the pyrophyllite body is in a zone containing several subparallel reverse faults which have dips ranging from 30o to 80o NW. The pyrophyllite is highly deformed and relict mudstone bedding defines complex isoclinal folds which transpose bedding along axial planes. Multiple folds confined to the width of the pyrophyllite body suggest that it was the locus of ductile shearing between the less ductile wall rocks. Fold axes within the pyrophyllite and associated folded quartz veins show moderate southeast plunges, implying a component of strike-slip movement. Folding and fracturing of late quartz veins in all the pyrophyllite bodies and cobble-sized fragments of silicified fault breccia and strained pyrite cubes in the footwall of the Glendon Fault, at the Phillips mine, suggest that deformation continued after early, fracture-controlled high-alumina alteration and sulfide deposition.

The pyrophyllite bodies are confined generally to laminated mudstones and fine felsic tuffs. At the White mine, however, minor pyrophyllite occurs within the intermediate-composition volcanic rocks along narrow fractures parallel to the Glendon Fault. The high-grade pyrophyllite is white, light gray or light tan, highly foliated, and commonly contains relict mudstone laminae. The layering is accentuated locally by light red iron oxides along bedding planes. Pyrophyllite is present in parallel flakes, ranging in size from 0.01 to 0.05 mm in diameter. Locally, pyrophyllite grains occur in randomly oriented or semi-radiating aggregates that have been deformed by extensively developed kinkbands. This suggests that early pyrophyllite was not distinctly foliated and that at least part of the foliation is due to movement along the Glendon Fault after the pyrophyllite was formed. Ubiquitous, fine-grained quartz (0.05-0.2 mm) always accompanies pyrophyllite, exhibiting seriate and smooth boundaries.

Well-formed chloritoid prisms and rosettes, everywhere present in small amounts, are interpreted as pre- or syn-tectonic. The chloritoid consists of partially rotated grains or of grains parallel to the foliation planes in the pyrophyllite. Chloritoid also forms an envelope around folded quartz veins within the pyrophyllite body at the White mine.

Small amounts of sericite and moderate amounts of kaolinite accompany pyrophyllite. Veins and disseminated grains of pyrite are widespread. Other minerals reported or observed in the Glendon deposits are diaspore, apatite, zircon, ilmenite, rutile, epidote, and fluorite.

The rocks enclosing the pyrophyllite bodies are weakly to intensely sericitized. Pyrophyllite alteration grades upward into intense sericitic alteration in hangingwall laminated mudstones and intermediate-composition volcanic rocks at the Phillips and White mines, respectively. Laminated mudstone in the footwall at the White Mine shows weakly developed sericite alteration and the transition to pyrophyllite occurs very abruptly. Chloritoid and chlorite are present in distinctive zones within sericitic alteration and may locally be associated with thin zones of disseminated pyrite.

A thin, stratiform, pyrite-rich replacement body is present in the sericite-altered hangingwall rocks of the White mine. Fine-grained pyrite replaces both rock fragments and matrix in an andesitic volcaniclastic rock. The body contains abundant chlorite and chloritoid and is probably a zone of sulfide replacement along bedding-parallel fractures developed during pyrophyllite alteration.

Silicification is intense in several quartz-rich pods near the middle of the pyrophyllitic alteration zone, along the fault plane exposed in the south wall of the Phillips Mine and locally within hangingwall sericitic alteration. Silicification is accompanied by abundant disseminated pyrite in the sericitic hangingwalls of the Womble and Phillips mines. Widespread silicification, such as that found in other areas of high-alumina alteration which affects up to several square kilometers of volcanic rocks (e.g. Staley, Pilot Mountain, and Hillsborough, North Carolina) is not present in the Glendon area.

Quartz veins were deposited during several stages. Most veins contain no associated sulfide minerals. However, abundant pyrite was deposited with some late quartz veins. Large chalcocite masses were found in one early, folded quartz vein at the White Mine.

The greenschist facies metamorphism and the severe deformation affecting the Glendon pyrophyllite deposits make their origin difficult to interpret. Most investigators agree that the alteration was caused by hydrothermal fluids (Conley, 1962b; Stuckey, 1967; Spence, 1975; McDaniel, 1976). However, the origin of the present mineral assemblage is open to speculation. Spence (1975) and McDaniel (1975) suggest that the original alteration was quartz-kaolinite and that pyrophyllite was produced during regional metamorphism. Sykes and Moody (1978) also favor a metamorphic origin for similar assemblages in the Hillsborough, North Carolina high-alumina deposit, but offer a primary hydrothermal origin as an alternative. Schmidt (1982) and Carpenter and Allard (1982) favor a primary hydrothermal origin for many of the slate belt, high-alumina mineral assemblages.

Many examples of pyrophyllite alteration are found in unmetamorphosed or slightly metamorphosed volcanic terrains - including the Foxtrap deposit, Newfoundland (Papezik and others, 1978), various "Roseki clay" deposits and active geothermal systems in Japan (Sumi, 1969; Iwao and Udagawa, 1969; Hayashi and Yamasaki, 1974), and an active geothermal field on Taiwan (Chen, 1981). Schmidt (1985) presents additional examples of such deposits. The dominant hydrothermal alteration assemblage, quartz-pyrophyllite, observed in many of these occurrences, is present in the Glendon deposits and would have persisted through greenschist facies regional metamorphism. Other minerals, such as andalusite, fluorite, topaz, lazulite, and diaspore (Papezik and others, 1978), which are products of acid hydrothermal alteration and are present in unmetamorphosed occurrences, are common in the slate belt occurrences. By analogy, the simplest explanation for pyrophyllite and its associated minerals in the Glendon deposits and elsewhere in the slate belt is through a primary process, perhaps with recrystallization during regional metamorphism.

The chemical analyses shown in Table 1 illustrate some of the profound compositional changes resulting from alteration by acidic fluids along the Glendon Fault. Pyrophyllitization of the laminated mudstone has resulted in the depletion of all constituents except SiO_2 and TiO_2, which appear to remain nearly constant, and Al_2O_3, which increases. Sericitization of intermediate-composition volcanic rocks resulted in the removal of Na_2O, CaO, and MgO and an apparent increase in SiO_2, K_2O, and Al_2O_3. Iron, mobile in the sericite alteration zone, may show local enrichment or depletion. Base metals, as well as Ba, Sr and Rb, are depleted within the pyrophyllite body and locally enriched in the adjacent sericitic alteration zone.

The depletion of alkalis, Ca, Mg, Fe, and base metals in the pyrophyllite zone and the enrichment of K in the sericitic alteration halo, indicates an outward increase in the K+/H+ ratio of the altering fluid, probably through an increase in the effective pH resulting from a decrease in the water/rock ratio outward. The K+ liberated by pyrophyllite formation in the laminated mudstones may have contributed to the outward increase in K+/H+ ratio in the fluid and sericitization of the adjacent intermediate-composition volcanic rocks. The ubiquitous kaolinite associated with pyrophyllite is either the result of the temperature reaching, but not exceeding, the kaolinite-pyrophyllite transition temperature (about 270oC) (see Appendix 2) or is a product of a retrograde reaction producing kaolinite + quartz from pyrophyllite in the presence of water during cooling of the system or regional metamorphism.

The formation of chloritoid and chlorite in the sericitic halo results from the addition of Fe, Mn, and Mg derived from the highly leached pyrophyllite alteration zone. Late chloritoid formation within the pyrophyllite probably was the result of the reaction of kaolinite + iron oxides by retrograde alteration during regional metamorphism.

The lower temperature for formation of pyrophyllite at pressures less that 1 kb is defined by the kaolinite-pyrophyllite transition at 275oC in acid solutions (Althaus, 1966). The upper temperature limit is the pyrophyllite-andalusite transition at approximately 350oC (Haas and Holdoway, 1973). The absence of kyanite in the Glendon pyrophyllite deposits implies total pressure less than 1.5-2.0 kb for the temperatures at which pyrophyllite is stable (see Appendix 2). The Glendon deposits contain mineral assemblages that require formation from fluid with a relatively low pH, at temperatures of between 275oC and 350oC with some fluorine. Similar temperatures, low pH, and characteristic acid alteration assemblages are present at deep levels in several modern geothermal systems, such as Matsao, Taiwan (Chen, 1970) and Matsukawa, Japan (Sumi, 1969; Nakamura and others, 1970). Such acid fluids are not typically generated during regional metamorphism. Therefore, a synvolcanic origin is likely. A hydrothermal system developed around an unexposed pluton, as proposed for the Foxtrap pyrophyllite deposit by Papezick and others (1978), is a plausible source for acid fluids. The fluids from relatively deep within a hydrothermal system may have been channeled along a pre-folding fracture system. Repeated movement along this fracture system allowed continual influx of fluid and prolonged the period of alteration. Later, intense deformation along the Glendon Fault during regional folding was facilitated by the extreme ductility of pyrophyllite. The pyrophyllite cross-cuts the Fe-rich breccia, a hot-spring-related deposit (McDaniel, 1976), and, therefore, cannot be clearly related to the surficial hot springs environment.

The age of the Glendon pyrophyllite deposits is not known but, if we assume it to be synvolcanic, it must be either pre-Virgilina deformation (>600 m.y.) or the age of the Uwharrie Formation, approximately 575 m.y.

Field Trip Stops:

The field trip will visit two of the three operating pyrophyllite mines at Glendon, the Phillips and the White mines. The planned stops are shown in Figures 15, 16 and 18 and are keyed to the following field guide.

Pyrophyllite is currently being mined at Glendon by the Glendon Pyrophyllite Company and Standard Minerals Company. Pyrophyllite, sericite, and other micaceous and clay minerals are selectively mined and blended to provide a variety of products with applications in the refractory, ceramics, and filler industries. Much of the early mining at both the Glendon and Robbins deposits was underground; however, all current production is from open pits.

Stops at the White mine will illustrate key lithologic units and the structural complexity found within the Glendon Fault zone as well as allowing an examination of the alteration. Stops at the Phillips mine will allow examination of the intensely pyritized, laminated mudstones, the Glendon Fault zone, the outcrop of the "siliceous sinter" of Spence (1975) and McDaniel (1976), and flow-banded felsic volcanics.

White mine stops (Figure 18) -

Stop 2: This stop permits an overview of the largest active mine in the Glendon district. Intermediate-composition volcanics overlie the pyrophyllite body and dip 30o to 45o N. The pyrophyllite body, consisting of altered, laminated mudstone, is exposed in the bottom of the pit. Sericite-altered mudstones are seen on the opposite wall of the pit, where they are cut off by a late fault which is parallel to the trend of the Glendon Fault. At the east end of the pit, the south-dipping, laminated mudstones are overlain by andesitic basalt.

Stop 3: A stratiform pyrite replacement body, present at the front of the bench, is generally concordant with bedding in sericitized intermediate-composition volcanic rocks and is continuous along strike for 225 m. At this locality, both the pyrophyllite and the sulfide bodies are offset by a northwest-trending, vertical cross-fault (Figure 18). The sericitized volcanic rocks here contain abundant chloritoid. The volcanics are heterolithic breccias and tuffs containing fragments of flattened pumice, altered devitrified intermediate and mafic flows, and tuffs.

Stop 4: The sericite-altered intermediate volcanic rocks at this stop consist chiefly of poorly sorted, angular to subangular, purple volcanic clasts as much as 6 cm in diameter in a fine-grained tuffaceous matrix. Chloritoid is abundant immediately to the southeast and the clast size decreases to the south. The matrix becomes highly foliated and the amount of sericitization increases adjacent to the pyrophyllite body.

Stop 5: Lenses of tuffs containing ovoid clasts of fine-grained volcanic rocks, that are now completely replaced by sericite, are found near the bottom of the exposed section of intermediate volcanic rocks. The highly ductile pyrophyllite has provided a locus for intense shearing, the result of movement along the Glendon Fault. Small scale, rootless, tight folds, with amplitudes of 1 to 3 m, are found in the mudstone in areas where bedding has not been obliterated by shearing.

Stop 6: A large, east-dipping, fissure-filling quartz vein follows a segment of a minor fault that cuts pyrophyllite-altered mudstone. The vein was folded during post-alteration fault movement. It contains small masses of chalcocite and chlorite with molybdenite coating some fractures. A chloritoid halo surrounds this vein. Laminated mudstone dips southward and is overlain by an iron-rich breccia. The contact between the mudstone and breccia is exposed along the mine road where it dips 30o to 45o S. Locally, the breccia has been pyrophyllitized, giving the normally red matrix a tan or light gray color. The breccia matrix is probably a hot spring precipitate that predates the pyrophyllite alteration. An andesitic basalt body overlying the breccia is exposed along the steep slopes above the mine road. The basalt at the east end of the pit is highly fractured by movement along an east-west trending fault that is subparallel to the trend of the alteration. The fault is younger than the alteration but older than the northwest-trending, Mesozoic (?)

cross-faults.

Sericite, rather than pyrophyllite, is the dominant alteration mineral in mudstones on this side of the pit. Abrupt color changes from dark gray to purple and tan and then to light gray commonly occur within the laminated mudstones as the intensity of alteration increases.

Phillips mine stops (Figure 15) -

Stop 7: Laminated mudstone and subordinent interbeds of fine-grained, felsic volcanic rocks are the dominant rock types at the Phillips mine. Pyritization and silicification are more widespread here than at the White mine. The entire north pit wall contains from 3% to 10% disseminated pyrite in the sericitized mudstone. The pyrophyllite body dips 50o to 60o N and is overlain by the sericite-altered mudstone and tuffs which show an upward increase in pyrite content and degree of silicification. The south pit wall is a fault plane that locally contains cobble-sized, silicified mudstone breccia fragments and abundant, large pyrite crystals.

Stop 8: Along the Glendon fault plane, the pyrophyllite body is cut by veins containing quartz, pyrite and green clay. Green clay seams locally follow foliation planes but more commonly follow cross-cutting gash fractures. The clay is a 20 A mixed layer type, provisionally identified as illite-montmorillonite. Pyrite and chloritoid are disseminated along the fault plane. Severely deformed pyrite crystals show the effects of post-alteration strain, the result of late deformation along the Glendon Fault.

Stop 9: The siliceous rock exposed here probably is that which Spence (1975) and McDaniel (1976) described as "siliceous sinter," and suggest is time-equivalent to the iron-cemented breccia exposed in the south wall of the White mine (Stop 6). The banding in this outcrop was considered by these authors to be laminations in opaline, hot spring sinter. As an alternative, I suggest that this rock represents a silicified and sericite-altered, flow-banded rhyolite because: 1) the immediately underlying rocks have volcaniclastic texture, 2) the banding in the sinter is similar to that in lithophysae-bearing dacite flows at the next stop (Stop 10), and 3) the Zr/Ti ratio of the rhyolite and the "sinter" are identical (Table 1).

Stop 10: Felsic volcanic rocks consisting of flow-banded and porphyritic rhyolite crop out along the high ground north and northeast of this stop (Figure 15). The flow-banded rhyolite commonly contains lithophysae. The depositional environment of the felsic volcanic rocks (Unit D) is dominantly subaerial here, changing to subaqueous northward (Green and others, 1982). Sericitic alteration is common in the rhyolite near the Glendon fault. A purple, sericiticized volcanic breccia containing greater than 20 % total Fe (expressed as Fe_2O_3) is present on the south side of the creek. The volcaniclastic texture is well preserved despite the intense alteration. The origin of this rock is not clear, but the high Fe content may be due to leaching and reprecipitation of Fe from pyrophyllite-altered rocks into adjacent porous volcanic rocks or, as suggested by McDaniel (1976), the breccia may be a time-equivalent to the Fe-rich breccia found on the south side of the White mine and formed by an exhalative process.

DAY 2

The field trip on the second day will stop in the vicinity of Pilot Mountain, a large silicified monadnock in south-central Randolph County, about 12.5 km southeast of Asheboro, North Carolina. Pilot Mountain itself has been explored for high-alumina minerals and for gold. It is owned by Piedmont Minerals Company. In addition, we may have an opportunity to visit a major granitic to granodioritic pluton, typical of the foliated plutons of the slate belt, unaltered intermediate volcaniclastic rocks which host most of the high-alumina alteration, an outcrop of unaltered Uwharrie felsic volcaniclastic rocks, and an exposure of the Tillery Formation.

STOPS 11-19

Geology of the Pilot Mountain-Fox Mountain Alteration System

by

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The Pilot Mountain-Fox Mountain alteration system is located in a thick, structurally complex sequence of andesitic and dacitic lapilli tuffs and volcaniclastics, interpreted to be among the oldest and most deformed units in the Carolina slate belt. Within these deformed stratified volcanic rocks are a variety of plutonic bodies, some forming distinct stocks and plutons and others of unknown size and shape. The intense hydrothermal alteration at Pilot Mountain is related to one of these, a subvolcanic dacite porphyry stock.

Younger felsic volcaniclastic rocks and porphyritic rhyolites probably unconformably overlie the dominantly andesitic and plutonic rocks described above. The unconformity separating the felsic volcanic rocks from the older andesitic volcanic rocks developed after the Virgilina deformation event (ca. 600 m.y.) (Harris, 1982). All the volcanic rocks have undergone low to middle greenschist facies metamorphism, probably during the Early to Middle Ordovician (460-480 m.y.) (Black, 1977; Kish and others, 1979). The location of the stops in the Pilot Mountain area is shown in Figure 19.

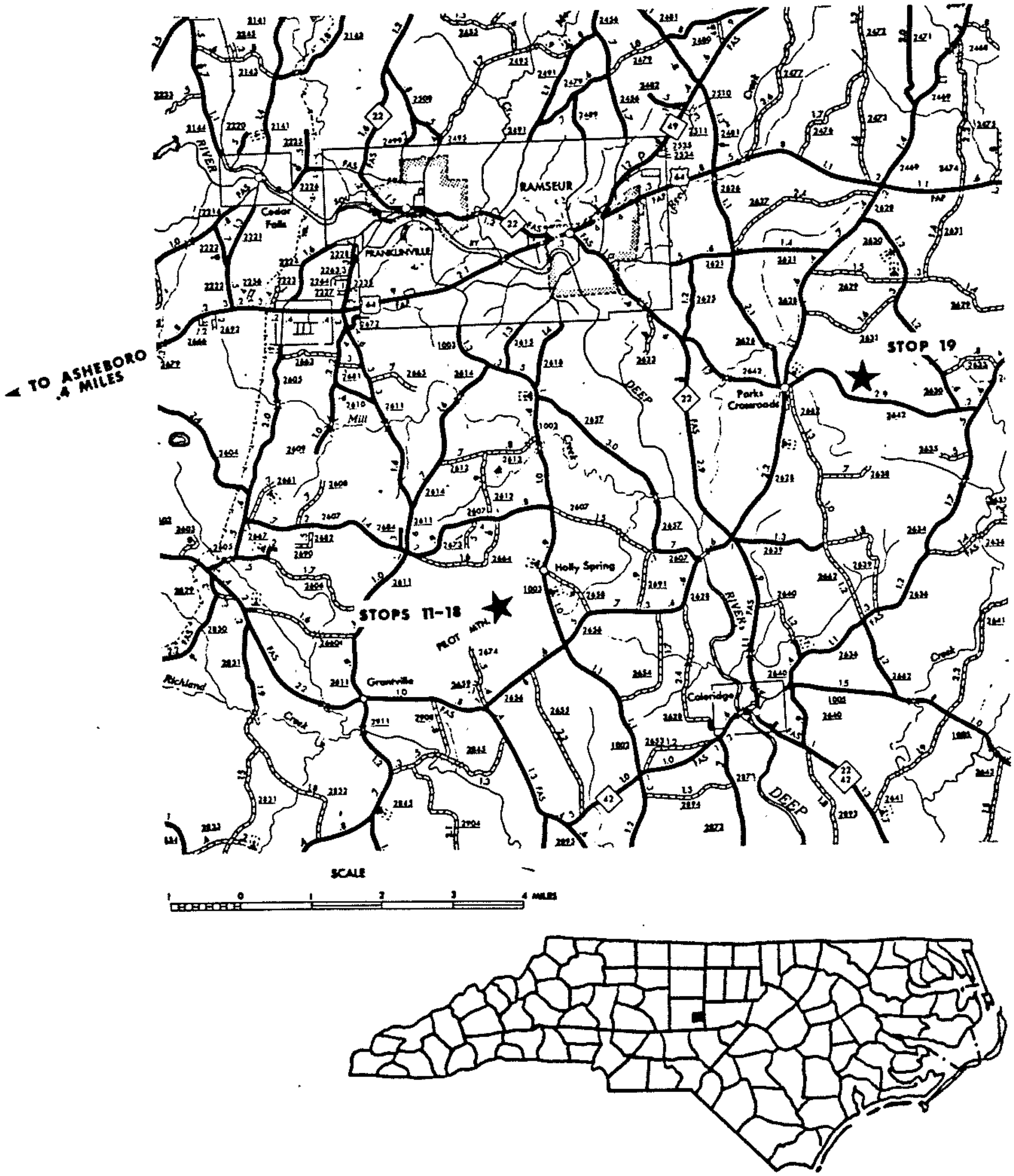

Figure 19: Location map for STOPS 11-18, Pilot Mountain-Fox Mountain alteration system, and STOP 19, the Parks Crossroads granodiorite, Randolph County, North Carolina.

Regional Geology of the Pilot Mountain-Fox Mountain Area:

Stratified rocks

Stratified volcanic rocks of the Pilot Mountain area are predominantly andesitic crystal and lithic tuffs with lesser amounts of rhyolitic lapilli tuffs, crystal tuffs, and volcanic-derived sandstones and mudstones (Figure 20). These rocks have been mapped in detail only in the northern part of the Ramseur quadrangle by Harris (1982), who correlates the rocks with two units in the Virgilina district near the Virginia-North Carolina border, the Hyco and Aaron Formations (Laney, 1917, Kreisa, 1980). We consider this correlation of volcanic strata over a distance of 100 km tentative without detailed mapping in the intervening area. However, if Harris' correlation is correct, then these andesitic volcanic rocks must be older than 620 m.y. (Glover and Sinha, 1973).

The andesitic volcanic rocks in the Ramseur quadrangle are mostly tuffs and tuff breccias with interbeds of volcaniclastic conglomerates and breccias, and relatively minor, mafic amygdaloidal flows and porphyritic flows. Andesitic tuff breccia is well exposed at Franklinville, in the northern part of the Ramseur quadrangle, and west of Pilot Mountain. Harris (1982) considers this unit equivalent to the Hyco Formation and to reflect a transitional, subaqueous-subaerial environment.

Arenite, siltstone, and argillite derived from volcanic source rocks with lesser amounts of conglomerate and vitric tuff

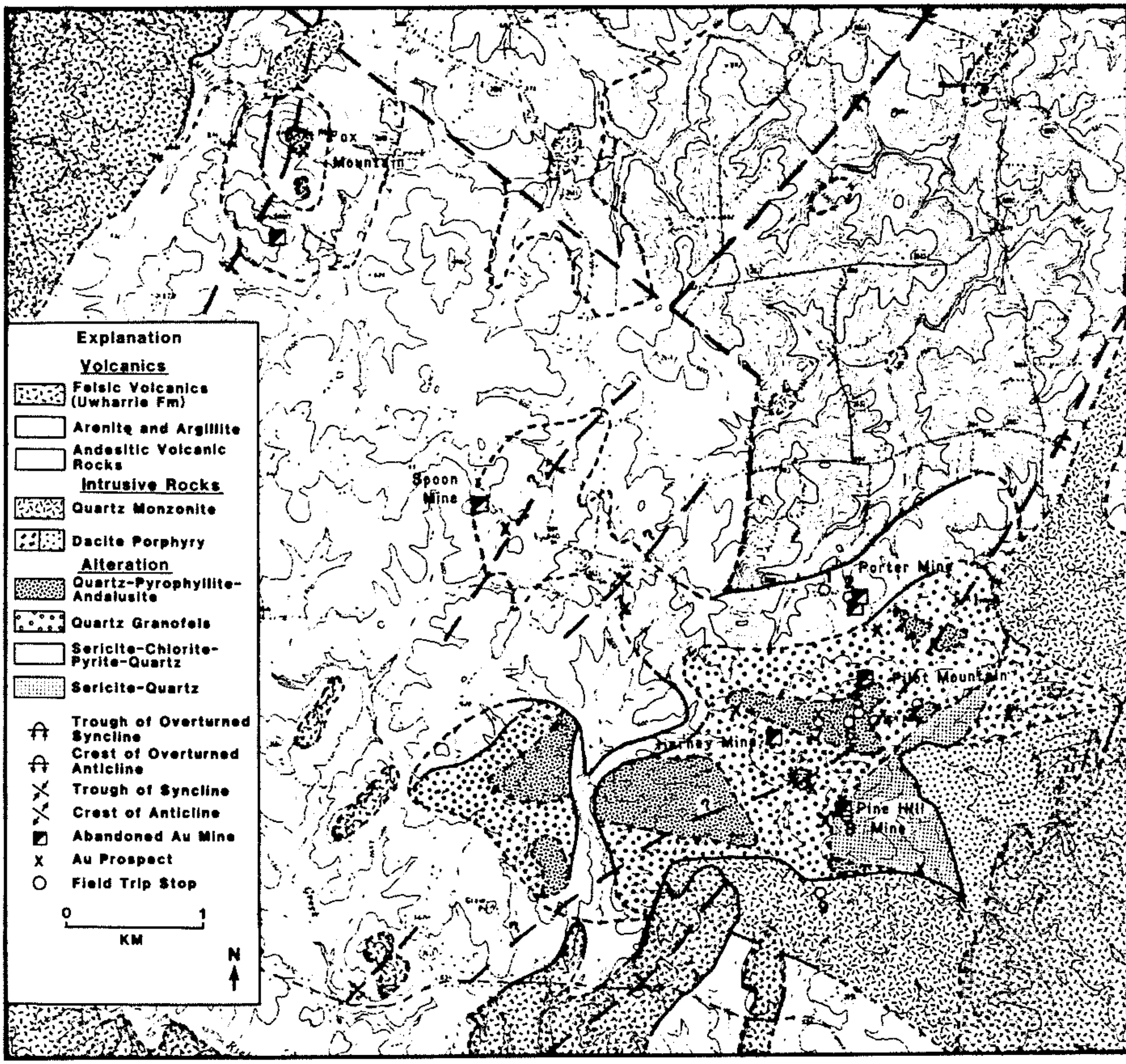

Figure 2? Geologic map of the Pilot Mountain area, Randolph County, North Carolina. Geology based on the mapping of Harris (1982) and unpublished mapping by R. G. Schmidt and T. L. Klein. Topographic base is a portion of the Ramsuer 7 1/2' topographic quadrangled map (USGS). Field trip stops are numbered.

are abundant near Ramseur, northeast of Pilot Mountain. The volcanic-derived sediments extend southwestward toward Pilot Mountain from Ramseur, but are not known to extend beyond Mill Creek (Figure 20). Harris (1982) correlates these dominantly sedimentary rocks with the Aaron Formation of Laney (1917) from the northern slate belt and interprets them to disconformably overlie the andesitic volcanic rocks in this area and be largely derived from them.

Felsic extrusive and volcaniclastic strata, widespread and abundant in the Asheboro area to the west, are present along the western edge and southwest corner of the Figure 20. Abundant rhyolite flows are locally flow-banded, spherulitic, or auto-brecciated. These strata are part of the Uwharrie Formation (Seiders, 1981) and considered by Harris (1982) to unconformably overlie the older, dominantly andesitic and plutonic units. Rocks of the Uwharrie Formation were dated by Wright and Seiders (1980) at 586 +/- 10 m.y., based on a U-Pb age on zircon.

Light gray, arenaceous, felsic volcaniclastics, interpreted to be part of the Uwharrie Formation, are present immediately southwest of Pilot Mountain (Figure 20). These volcaniclastics are fine-grained and tuffaceous, containing sparse, 1-2 mm, equant quartz and feldspar crystals in a fine-grained quartz and feldspar matrix and may grade into fine crystal-rich tuffs.

Plutonic rocks

Southeast of Ramseur, the Parks Crossroads pluton (Tingle, 1982) covers an elliptical area of 6 x 13 km. The pluton consists of two rock types. The most abundant is a foliated, equigranular, intermediate-composition rock that ranges from granodiorite to quartz diorite. The second, a fine-grained, non-foliated, locally porphyritic potassic granite, is found in several areas east of Ramseur. The rock is light gray with a salt-and-pepper appearance, grains up to 0.5-1.0 mm in greatest dimension and, where the rock is porphyritic, sparse plagioclase phenocrysts about 5 mm long. The rock contains about 50% quartz, 33% potassic feldspar, and 15% plagioclase. The fine-grained potassic granite cuts the foliated quartz diorite.

The quartz diorite has been dated by the Rb/Sr method at 566 +/- 46 m.y. (Tingle, 1982). This corresponds roughly to the age of the Roxboro metagranite of Briggs and others (1978) (ca. 575 m.y.) located in the northern slate belt (Glover and Sinha, 1973; Briggs and others, 1978).

Granodioritic to quartz dioritic plutonic rocks, resembling those of the Parks Crossroads pluton, are found north and south of Pilot Mountain (Figure 20). They include a variety of foliated, dark rocks with both equigranular and porphyritic textures and diverse compositions. Relationships in drill core on the southern edge of the Pilot Mountain alteration system suggest the quartz diorite is younger than the hydrothermal alteration.

The subvolcanic, dacite porphyry related to the hydrothermal alteration at Pilot Mountain is present in a 2 km2 area east and southeast of the mountain. It has abundant, often partly resorbed, relict, bipyramidal phenocrysts of quartz and plagioclase porphyroclasts up to 5 mm across and is usually strongly altered. In weathered exposures and float blocks, the abundant quartz phenocrysts are the only identifying feature. Highly altered rock (quartz granofels), containing 3 to 5 mm relict quartz phenocrysts, near the top and on the north slope of Pilot Mountain, may be apophyses of coarse-grained, porphyritic dacite within the host volcanics. A locally altered felsic porphyry with phenocrysts less than 2 mm is present in adjacent areas to the north and may be a finer phase of the dacite porphyry.

Fine- to coarse-grained, porphyritic rhyolites and dacites are present in several patches north and northeast of Pilot Mountain where they have been mapped as dikes by Harris (1982). Field relationships indicate that some outcrops are dikes, but others may be layers of felsic volcaniclastic or flow rocks interbedded with or downfolded into the sequence.

Structural geology

Folding is complex and difficult to characterize from the normally sparse outcrops. Based on the apparent stratigraphic succession and mapping in nearby areas, at least three periods of folding produced the major deformation in the oldest rocks, the andesitic volcanics. Axial trends of all the fold stages are nearly coaxial and trend 30o-60o NE.

Harris (1982) interprets the volcanic-derived, fine-grained strata near Ramseur (Aaron Formation of Laney, 1917) to be younger than the coarse-grained andesitic tuffs and tuff breccias (Hyco Formation), and to be infolded with them into a large, complex syncline. The folding style and fold frequency that he has mapped are similar to our own observations immediately west of the map area (Figure 20), in the Asheboro area, where northeast- and southwest-plunging folds are common. Outlines of southwest-plunging, synclinal folds are shown by the distribution of felsic arenites of the Uwharrie Formation southwest of Pilot Mountain (Figure 20), indicating a succession of parallel, tight folds with fairly uniform wavelengths of 1-3 km.

Penetrative axial-planar foliation is present in most of the rock units. Strong, near-vertical foliation, striking 30o-60o NE, has formed in the oldest unit, the andesitic volcanics and, to a somewhat lesser extent, in the younger volcanic-derived sediments near Ramseur. The felsic volcanic rocks of the Uwharrie Formation have a similar foliation, but it is the least well-developed of the three volcanic units. The dacite porphyry and the granodioritic rocks near Pilot Mountain are also usually foliated.

Geology of the Pilot Mountain-Fox Mountain alteration system:

The area of hydrothermal alteration surrounding Pilot Mountain is over 4.5 km long and up to 2 km wide. Most rocks within this zone shows significant changes in the original textures and bulk composition, caused by intense, feldspar-destructive, acid, hydrothermal alteration. Highly altered intermediate and mafic volcanic rocks, now consisting of 80% to 100% quartz, resemble quartzite in appearance and are termed "quartz granofels." Alteration at Pilot Mountain is zoned around the "apex" of the dacite porphyry present southeast of the summit (Figure 20). The inner-most alteration is sericite, quartz, and pyrite replacement, followed outward by a zone of intense silicification and abundant high-alumina minerals. This, in turn, is enclosed by a sericite-chlorite-pyrite-quartz schist which is gradational outward to chlorite-epidote alteration.

In the innermost alteration zone, the dacite porphyry stock and immediately adjacent volcanics show replacement by fine-grained sericite, quartz, and disseminated pyrite. Scattered quartz granofels and pyrophyllite pods are found within this alteration zone. Sericite is commonly foliated in thin-section, but patches of randomly oriented sericite suggest a relict hydrothermal replacement texture. Chalcopyrite and molybdenite have been identified in surface samples and drill core and a large area of gold enrichment is found in this zone.

The sericite zone is followed outward from the porphyry by the silicification and aluminous alteration of the high-alumina zone. The alteration is dominantly silicification with pods of andalusite, andalusite-pyrophyllite, and massive pyrophyllite. These alteration products are extremely resistant to erosion and result in the positive topographic expression of Pilot Mountain. Quartz-sericite and kaolinite-altered mudstones, andesitic tuffs, and mafic volcanics are present between quartz-rich pods in drill core, but generally are not exposed at the surface. Anastomosing fractures and zones of intense brecciation, possibly caused by hydrofracturing, are common within the quartz granofels and high-alumina rocks. Gold mineralization and exploitable high-alumina minerals occur in this alteration zone. Westward from Pilot Mountain, quartz granofels becomes less abundant and sericite-chlorite-pyrite schists enclose the lenses of high-alumina minerals.

Common alteration assemblages within the zone of high-alumina alteration are:

1. massive, monomineralic pyrophyllite consisting of radiating clusters and random masses, commonly less than 1 mm in diameter, but also forming rosettes up to 1 cm in diameter.

2. pyrophyllite-andalusite-quartz (+/- sericite) rock, in which equant clusters of andalusite crystals (0.3-1 cm in diameter), in a quartz-pyrophyllite matrix, are often intergrown with pyrite and commonly mantled by pyrophyllite.

3. topaz-quartz rock where the topaz and quartz are

found in nearly pure masses, a few millimeters to a few centimeters across. The quartz consists of mosaics less than 0.1 mm in diameter and the topaz is found in mats of nearly sub-microscopic grains.

4. quartz-pyrophyllite-sulfide granofels consisting of 80%-90% quartz with hematite or goethite after pyrite making up 2%-5% of the rock, along with sparse, foliated or non-foliated pyrophyllite.

5. quartz-pyrophyllite veins with radiating pyrophyllite rosettes up to 3 cm in diameter and accompanied by up to 30% hematite after pyrite.

Diaspore and lazulite are found in other slate belt high-alumina alteration zones, but have not been recognized at Pilot Mountain.

Sericite-chlorite-pyrite-quartz schist, the result of alteration of andesitic volcanic rocks, is present northwest of Pilot Mountain, adjacent to the high-alumina alteration. Finely disseminated pyrite locally comprises ~ 30% of the rock. Small, isolated pods of quartz granofels and/or pyrophyllite are also present within this unit. Contacts with the surrounding andesitic volcanic rocks are generally gradational and "islands" of unaltered andesite lie within the schist. This sericite-chlorite-pyrite-quartz alteration is also found near the Spoon Mine and surrounds the high-alumina alteration at Fox Mountain (Figure 20).

Origin of the Pilot Mountain alteration system

The pyrophyllite-andalusite deposits of the slate belt have resulted from a complex interaction of hydrothermal alteration, regional metamorphism, and intense weathering. The quartz-andalusite and pyrophyllite deposits of the Slate Belt have been considered by Spence (1975), McDaniel (1976), and Sykes and Moody (1978) to be the result of regional metamorphism of clay-rich, hydrothermal alteration. However, andalusite at Pilot Mountain and at Bowlings Mountain (Sexauer, 1983) is probably pre-metamorphic because the foliation developed in the surrounding micaceous minerals is deformed around many andalusite grains. Topaz occurs at Pilot Mountain and has been reported at the Brewer mine, South Carolina (Stop 26), Bowlings Mountain, North Carolina (Sexauer, 1983), and the Hillsborough pyrophyllite-andalusite deposit in North Carolina (Sykes and Moody, 1978). Crystallization temperatures of topaz from Hillsborough and the Brewer mine, assuming 1 kb total pressure, are approximately 425oC to 525oC respectively, using the variation of hydroxyl content with respect to temperature and pressure of formation (Barton, 1982). This temperature is probably greater that the temperature of the slate belt regional metamorphism and suggests that topaz was derived from high-temperature hydrothermal fluids.

Evidence to support a metamorphic or hydrothermal origin for the lower temperature minerals, such as pyrophyllite, diaspore, and kaolinite, is not clear because of the overprint of greenschist facies metamorphism and related deformation. Andalusite and topaz are probably hydrothermal minerals, based on textural evidence and high formation temperatures that exceed middle greenschist facies temperatures respectively. Pyrophyllite is a stable mineral under greenschist facies conditions and may be a relict hydrothermal product recrystallized during regional metamorphism or, as suggested by Spence (1975) and McDaniel (1976), a product of regional metamorphism of quartz and kaolinite developed during early hydrothermal alteration. The alteration zoning around the dacite porphyry stock at Pilot Mountain closely resembles that found in unmetamorphosed or slightly metamorphosed porphyry systems containing aluminous alteration assemblages, such as El Salvador, Chile (Gustafson and Hunt, 1975), the Ivaal deposit, New Guinea (Asami and Britten, 1980), and several deposits in northern Sulawesi (Lowder and Dow, 1978). Pyrophyllite, a common hydrothermal alteration product in these unmetamorphosed systems, was probably present in the Pilot Mountain system as a hydrothermal product before metamorphism. Kaolinite is present in drill core from Pilot Mountain below the weathering zone, suggesting that it is a retrogressive alteration product formed at temperatures less than the pyrophyllite-kaolinite transition temperature (270oC) and not a weathering product.

The alteration surrounding these porphyry systems, sericite succeeded outward by andalusite-pyrophyllite, can be explained in terms of decreasing fluid temperatures outward from an intrusive. Figure 21, adapted from Hemley and Jones (1964) and Shade (1974), illustrates a hypothetical path of acidic hydrotheraml fluids generated from a shallow level felsic intrusive with respect to temperature and K+/H+ at 1 kb pressure with quartz present, both reasonable conditions considering the high degree of silicification and the subvolcanic nature of these systems. A relatively high water/rock ratio in the interior of these systems is suggested by the complete destruction of feldspar and high degree of base-leaching resulting in a nearly linear reaction path.

Sericite-chlorite-quartz alteration cannot be totally explained using Figure 21, but is represented by the low temperature deflection of the reaction path to the right into the muscovite field. The deflection may result from a rapidly increasing fluid pH near the system's margin. The pH increase may have resulted from a reduction of the water/rock ratio which allows the rock to begin buffering the fluid composition through hydrolysis reactions and/or neutralization and dilution of the hydrothermal fluids by near-neutral meteoric waters near the system's margin.

Sericite-chlorite-quartz alteration grades outward into chlorite-epidote alteration typical of the propylitic alteration of a porphyry system. At Pilot Mountain, any propylitic alteration formed by the hydrothermal system is now indistinguishable from later greenschist facies metamorphic alteration.

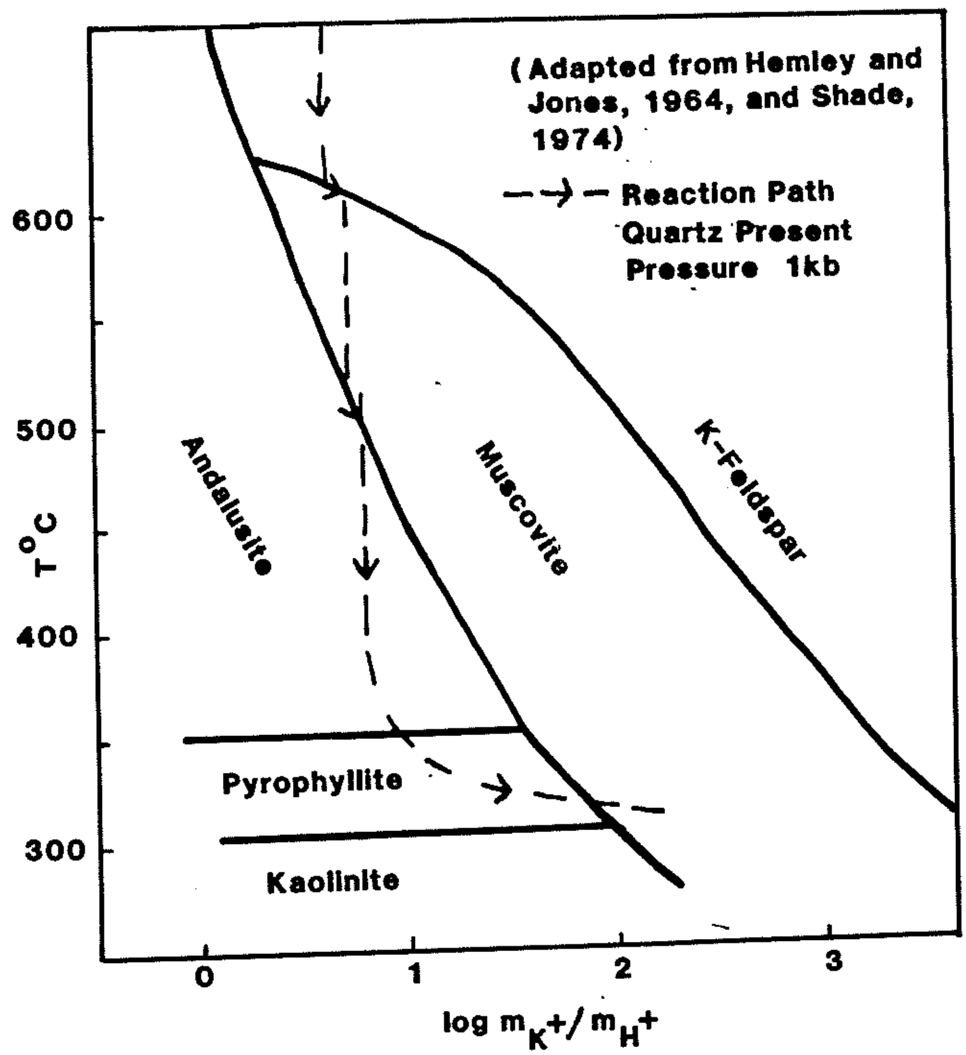

Figure 21: Mineral stability curves for potassium-aluminum silicates associated with argillic to advanced argillic alteration, as a function of temperature, pH, and K+-activity. From Hemley and Jones, 1964; Shade, 1974).

Chemistry

Drastic changes in bulk composition resulting from extensive alkali-leaching by acid solutions are illustrated in Table 2. Immobile trace element ratios such as Ti/Zr are probably not affected by the acid alteration except in the most severely altered rocks. Examination of the Ti/Zr ratio from many rocks in the Pilot Mountain alteration system suggest that andesitic and mafic volcanic rocks were the dominant protoliths. A chemical analysis of an andesitic crystal tuff from outside the hydrothermal alteration area is shown in Table 2. An analysis from a least-altered dacite porphyry is shown for comparison to the andesitic volcanic rocks.

Two examples of high alumina-altered rocks are shown in Table 2, with a wide range of Si/Al ratios requiring that one or both of these elements was mobile. Extensive depletion of the relatively mobile elements (Na, K, Ca, Mg, and Fe) is found with respect to either possible protolith - andesitic tuff or dacite porphyry. The high Si and/or Al content of the altered rocks is the result of residual enrichment caused by depletion of the mobile elements during alteration.

The contrasting compositions of the two types of "sericitic" alteration is apparent in Table 2. The quartz-sericite alteration is higher in Si and K and lower in Fe, Mg, and Ca than the sericite-chlorite-quartz alteration. The quartz-sericite assemblage reflects the more felsic composition of the dacite porphyry and alteration by high temperature, acidic fluids

TABLE 2

Representative partial chemical analyses
from the Pilot Mountain area, Randolph County, North Carolina

	ANDESITE	DACITE PORPHYRY	ALTERED VOLCANICS Qtz-ser	ALTERED VOLCANICS Ser-Chlor-Qtz
SiO_2	60.7	69.8	87.8	71.8
Al_2O_3	18.0	16.4	9.51	21.2
TiO_2	0.64	0.38	0.54	0.84
FeO [tot Fe]	5.95	1.93	<1.7	<1.7
MgO	1.91	<1.5	<0.20	<0.20
CaO	4.13	2.86	0.26	<0.16
Na_2O	2.63	2.50	<0.10	<0.10
K_2O	2.06	2.92	0.49	0.29
LOI	4.06	2.14	n.d.	2.94
Total	100.08	98.7	98.6	97.1
(ppm)				
Cu	44	16	6	94
Mo	<5	<10	2	11
Sn	<5	7	36	32

	SERICITE-ALTERED VOLCANICS Qtz-Ser	SERICITE-ALTERED VOLCANICS Ser-Chlor-Qtz
SiO_2	72.1	66.7
Al_2O_3	18.7	16.8
TiO_2	0.34	0.56
FeO [tot Fe]	2.37	4.13
MgO	<0.20	3.74
CaO	0.35	1.78
Na_2O	0.84	1.52
K_2O	3.48	1.58
LOI	3.32	4.09
Total	101.50	100.90
(ppm)		
Cu	10	<10
Mo	<10	<10
Sn	4	<5

All analyses by XRF in the laboratories of Eastern Minerals Resources, Reston, VA.

present near the pluton. The sericite-chlorite assemblage results from the alteration of the dominantly andesitic volcanic rocks by lower temperature, more alkaline fluids near the periphery of the system.

The important association of Cu, Sn, and Mo with the high alumina alteration was first recognized by Schmidt (1982) at Pilot Mountain. The high metal values in soil and rock samples generally correspond to the area of silicification and high-alumina alteration around Pilot Mountain. Enrichment of Sn, Mo, Cu, B, Au and locally Pb and Zn in the alteration zone suggests they were deposited from the same fluids that caused the intense alteration. Copper concentrations up to 1200 ppm (commonly <1-200), Mo up to 400 ppm (commonly 20-50) and Sn up to 360 ppm (commonly 20-50) are present. Gold occurs throughout the system in the sub-ppm to ppm range. Silver contents are low, usually less than half that of Au. Other anomalous elements include Li, Bi, Ge, Ga, As, Sb and some rare-earth elements.

Soil Geochemistry

An A_1-horizon soil survey defines the metal distribution within the system at Pilot Mountain. Mo, Sn, Cu, B, and Pb form coherent anomalies near the "apex" of the dacite porphyry stock. The distribution of Sn (Figure 22) illustrates a typical metal pattern at Pilot Mountain similar to that of B, Cu, and Pb. Mo distribution is more restricted in extent and closer to the stock than Sn. Distribution patterns for all the metals are elongate

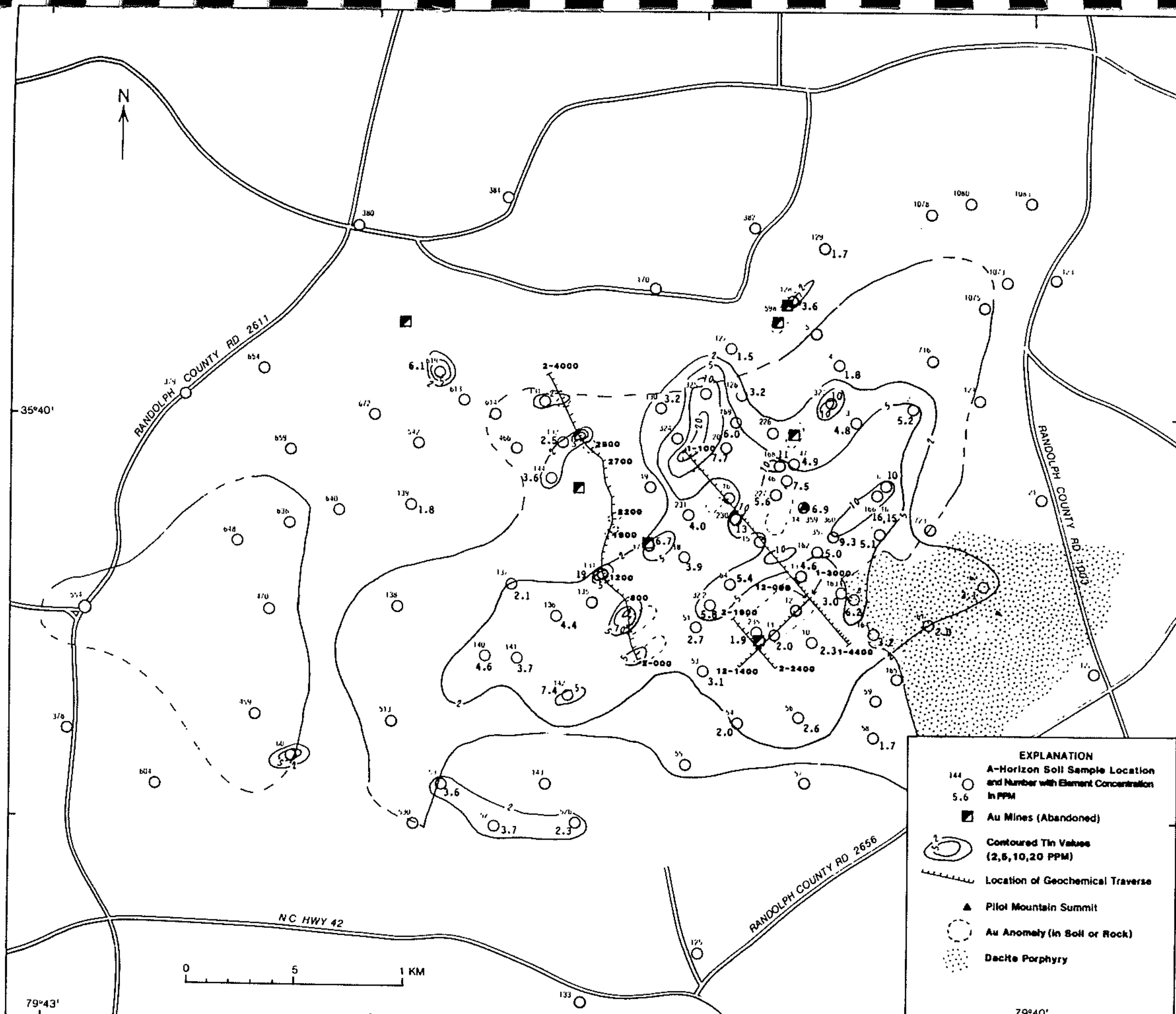

Figure **22** Map showing contoured Sn values, Au anomalies and soil sample locations at Pilot Mountain, North Carolina. The dacite porphyry and the area affected to the west-northwest and imply that the porphyry stock may plunge in that direction. Intense weathering forms thick saprolite in much of the Piedmont, oxidizes the abundant pyrite associated with this alteration system, and leaches the more mobile metals such as Zn and Cu. Drill core samples from below the top of Pilot Mountain contain high Cu concentrations (50-1200 ppm). However, the Cu distribution in soil (Figure 23) shows a bullseye pattern with low values on the mountain top caused by leaching during intense weathering. High Cu concentr-ations in soil are found only on the flanks of the mountain where weathering effects are less intense. The low Cu concentrations in the soils between the monadnock and the surrounding andesites may be the result of hydrothermal leaching of Cu from the andesitic volcanic rocks in the outer part of the alteration system. High copper concentrations in the soils over unaltered andesites outside the alteration zone reflect regional background values typical of intermediate rocks.

Gold deposits:

The distribution of abandoned gold mines and prospects in Figure 20 forms a crude halo around the porphyry stock. The Pilot Mountain and Porter mines are developed along shear zones parallel to regional axial-planar cleavage. The Harney mine and several unnamed prospects are located along late-stage pyrophyl-lite-bearing quartz veins southwest of the summit of Pilot Mountain. Many small gold anomalies in soils are scattered

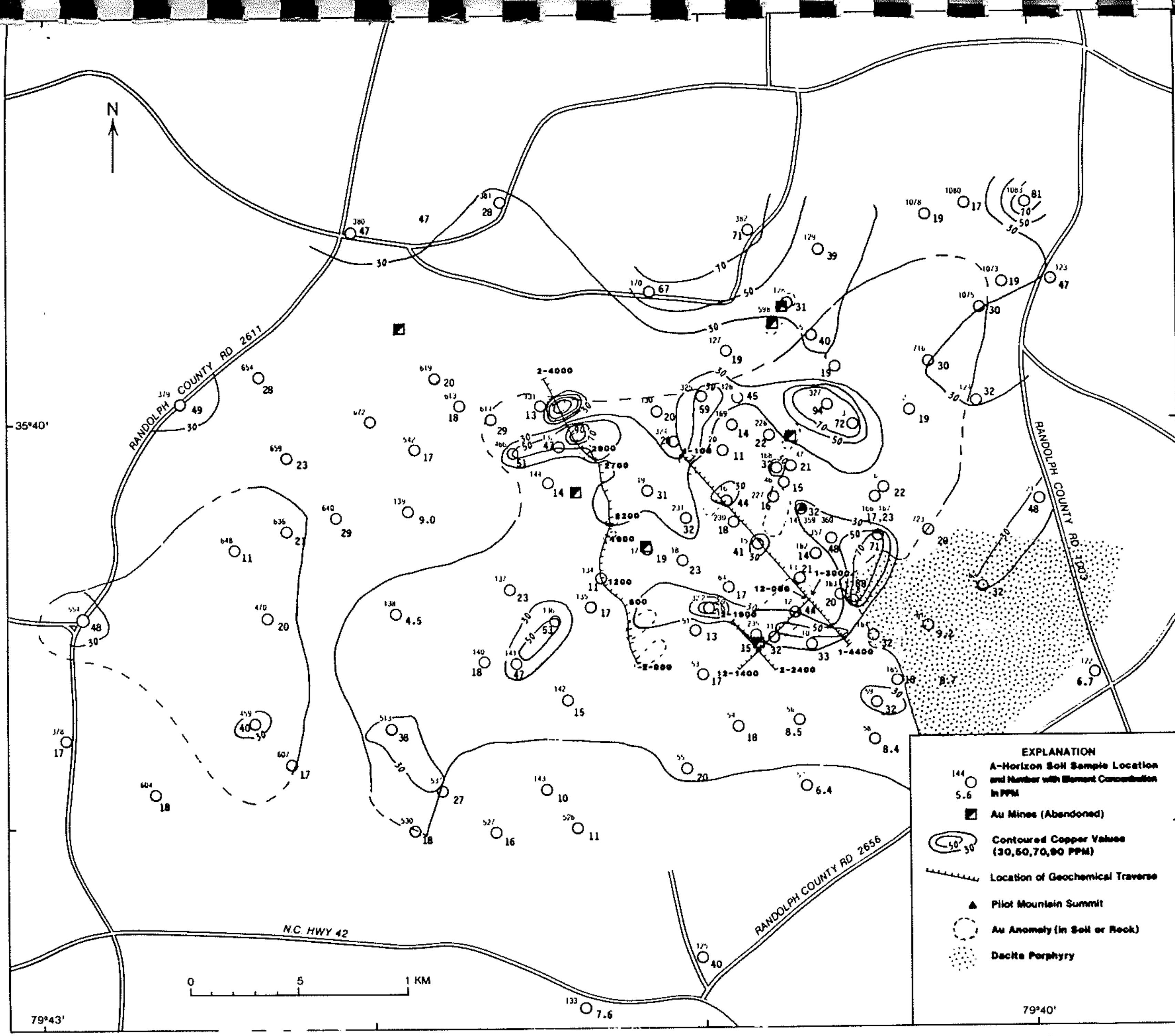

Figure **23** Map showing contoured Cu values, Au anomalies and soil sample location at Pilot Mountain, North Carolina. The dacite porphyry and the area affected by hydrothermal alteration are outlined.

throughout the high-alumina alteration zone but the largest, most coherent anomaly occurs near the boundary between the quartz-sericite and adjacent high-alumina zones near the Pine Hill mine (Figure 20). The Spoon mine is located within sericite-chlorite altered, intermediate volcanic rocks probably in an area of disseminated pyrite along the northwest trend of prospects and mines (Figure 20) between Pilot Mountain and Fox Mountain. The northwest trend, perpendicular to the regional structural trend, could be related a large porphyry system at depth, which may extend between Pilot and Fox Mountains and could be repeated by folding.

Age of Alteration:

A minimum alteration age of 586 +/- 10 m.y. is inferred from the age of the Uwharrie Formation (Seiders and Wright, 1980) that is unaltered and overlies the alteration system south of Pilot Mountain (Figure 20). An age of 620 m.y. was suggested by Harris (1982) for the andèsitic volcanic rocks affected by alteration. High-alumina alteration affects intermediate volcanic host rocks at Bowlings Mountain (Sexauer, 1983), Hillsborough (Sykes and Moody, 1978), Snow Camp, and Glendon suggesting that the alteration may be restricted to the areas of the older, dominently intermediate-composition volcanic rocks in this part of the Carolina slate belt.

Gold-Bearing Porphyry Systems:

The striking similarity of Pilot Mountain to certain porphyry-related metal deposits and to deep-levels of volcanic-related hot spring systems with respect to alteration style, metal association, and probable origin was recognized by Schmidt (1982, 1985). The El Salvador deposit in Chile (Gustafson and Hunt, 1975), the Ivaal deposit in the Frieda River area, New Guinea (Asami and Britten, 1980), several deposits in northern Sulawesi (Lowder and Dow, 1978) and the Equity Silver deposit, British Columbia (Cyr and others, 1984; Wojdak and Sinclair, 1984) all have many features in common with the Pilot Mountain deposit.

The deposits have these common characteristics:

1. They are found in unmetamorphosed or little metamorphosed, intermediate-composition volcanic sequences with some subaerial depositional component.

2. Mineralization is associated with intermediate to felsic, shallow level (1-2 km depth) porphyry systems.

3. High-alumina alteration (andalusite-pyrophyllite +/- topaz) is present.

4. Alteration zoning is quartz-sericite, andalusite+/-pyrophyllite and sericite-chlorite (+/-kaolinite and mixed-layer clays) outward from the pluton.

5. The metal association is Mo-Cu-Au. Tin, reported from

a number of slate belt high-alumina systems, is reported from analogs.

The relationship of gold mineralization to alteration in the Au-bearing porphyry deposits is summarized in Figure 24. The deposits range from 200 m.t. to well over 500 m.t., contain economic to subeconomic gold (0.1 to 1.5 ppm), and have significant copper concentrations (0.3 to 1.0%). Gold mineralization at El Salvador is located in the inner portion of the sericite alteration zone. Frieda River (Ivaal deposit) and the N. Sulawesi deposits contain Au concentrations within the upper quartz-sericite zone and in the immediately overlying high-alumina zone, the same position as the broad Au anomaly at Pilot Mountain. The Equity Silver deposit offers an additional variation of the high-alumina alteration system, that of mineralization in permeable beds adjacent to the main system.

The Nena deposit (Frieda River area) illustrates a possible link between the shallow level porphyry system and surficial hot-spring related deposits. It is a massive sulfide deposit underlain by alunitic and clay-rich alteration and is probably related to the subvolcanic porphyry systems in the Frieda River area. The pyrite-rich massive sulfide deposit at the Haile Mine in South Carolina may be a slate belt analog to the Nena deposit. Any deeply penetrating fracture system which taps the acidic hydrothermal fluids may form a tabular high-alumina alteration zone by focussing them upward along the fracture systems as illustrated in Figure 24. The tabular

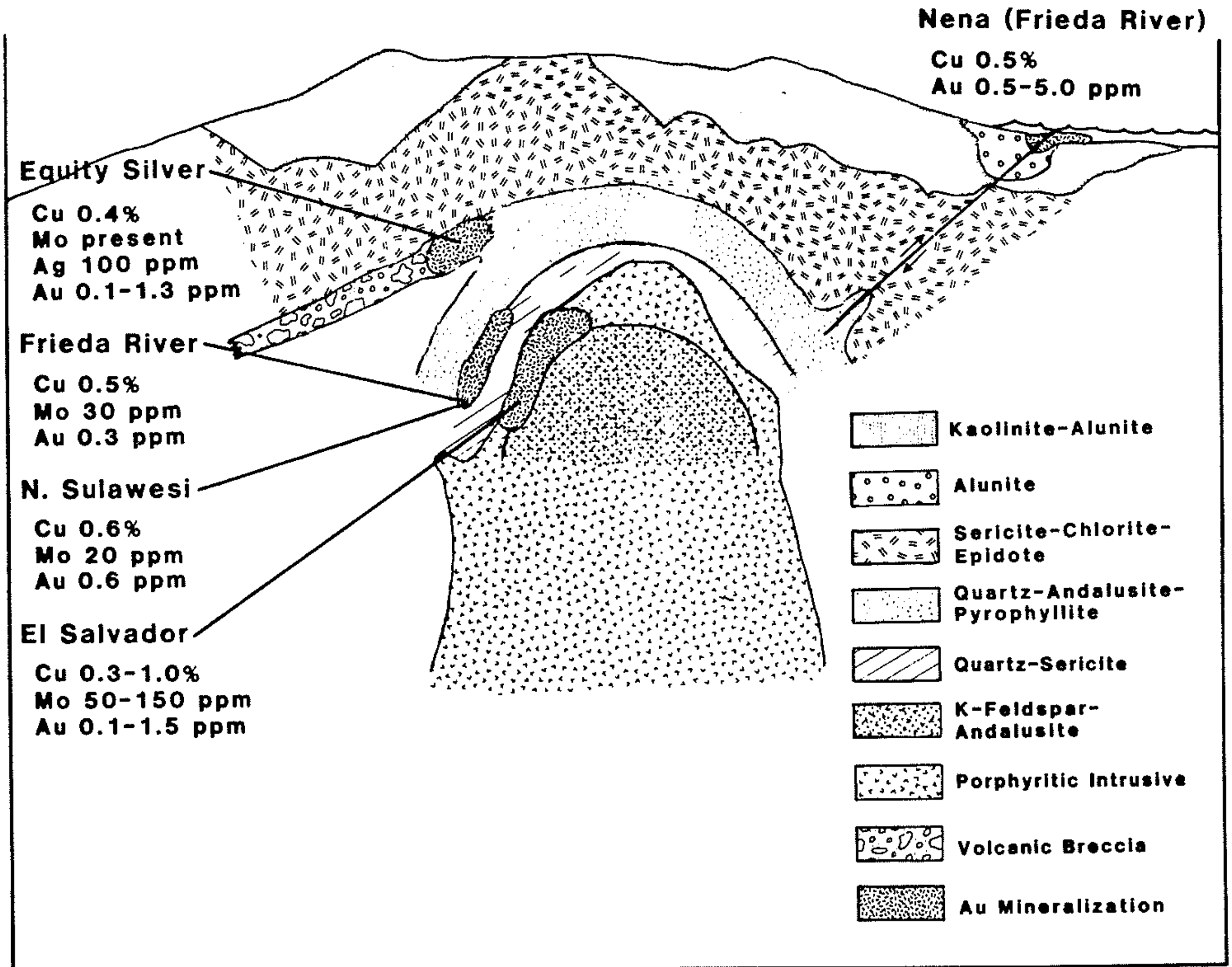

Figure **24** Generalized cross-section of Au-bearing porphyry-systems accompanied by high-alumina alterations. The relationship of alteration mineralogy to Au mineralization and the characteristic metal concentrations of selected deposits are shown (see text for references).

pyrophyllite deposits at Glendon and Robbins, North Carolina, and the Au deposits at Robbins may have formed along a persistent fracture system, tapping fluids from a remote plutonic source.

Exploration Considerations:

The Carolina slate belt hosts many types of Au deposits probably including massive sulfide (pyritic and base metal-rich), structurally controlled deposits (both syngenetic and metamorphogenic), shallow level epithermal deposits, and subvolcanic porphyry-related deposits. The porphyry-related deposits, such as Pilot Mountain, present large exploration targets relative to most of the other deposit types.

In North Carolina, the alteration centers are restricted to the dominantly intermediate volcanic terrains and are unconformably overlain by younger felsic volcanic rocks. The highly folded nature of the intermediate volcanic terrane and the possible unconformable relationship of the overlying Uwharrie Formation implies that there is a high potential for the discovery of blind deposits below the unconformity or in alteration systems which, without topographic expression, have only their outer sericitechlorite alteration exposed. Some of the large areas of "sericitic" alteration in the slate belt may be related to subvolcanic porphyry systems.

Many exploration techniques can successfully locate areas of high-alumina alteration and related metallization. At the regional scale, stream sediment sampling and remote sensing using LANDSAT-derived data (Schmidt and Koslow, in press) may be useful in locating the hydrothermal alteration. Regional scale soil sampling may also be effective because of the large size of these hydrothermal systems (2-10 sq. km).

Approximately 50 stream sediment, silt samples were collected from the area surrounding Pilot Mountain. Copper, molybdenum, and boron were effective in defining the Pilot Mountain hydrothermal system. Tin and molybdenum were limited in their effectiveness by low abundance and high detection limits. Boron was very effective in outlining the alteration because it has a low detection limit and background/anomaly ratio. The presence of alumino-silicates in panned concentrates was also effective in locating the high-alumina alteration for at least 1 km downstream from known alteration.

Soil sampling from the A_1 horizon is a very effective technique in defining the metal dispersion and the configuration of the alteration system at Pilot Mountain as discussed earlier.

Geophysical surveys using total-field ground magnetics and gamma-ray spectroscopy have not been useful in locating alteration or mineralization at Pilot Mountain.

Field Trip Stops:

The approximate route of the field trip can be followed in Figure 19 and 20. The traverse begins on the northern side of the Pilot Mountain alteration system. The route will take us from the sericite-chlorite alteration zone through the high-alumina alteration and finally to an inner quartz-sericite alteration zone, essentially working our way from the outside to the inside of the alteration system.

Stop 11: Overview of Pilot Mountain

Stop 12: Porter Mine

Prospect pits and shafts here are collectively known as the Porter Mine and trend N 40o E parallel to the regional axial-planar foliation. The mineralization is concentrated on a highly foliated shear zone approximately 3 m wide. The host rock has a volcaniclastic texture with lithic fragments commonly up to 1 cm in diameter. Gold is associated with disseminated pyrite present in this relatively narrow zone that dips 75o W. Thin discordant and concordant quartz veins are present and contain occasional limonite after pyrite boxwork.

Gold concentrations in soils and from the mineralized zone range from 0.1 to 0.5 ppm and Ag to 0.1 ppm. Composite grab samples of dump material contain the following anomalous concentrations (in ppm) by semi-quantitative E-spec: As 190, Bi 1800, Cu 210, Li 140, Mo 210, Sn 340, Zn 180.

Stop 13: Dacite Porphyry

The ridge spur on the northeast side of Pilot Mountain consists of an altered apophysis of dacite porphyry. This is one of the few exposures of dacite porphyry. The porphyry is extremely foliated and the groundmass altered so that the 2 to 5 mm gray quartz "eyes" are its only recognizable feature here. Alteration products include pyrophyllite and muscovite in a siliceous granofels groundmass. Locally the porphyry contains abundant anastamosing limonite- and hematite-filled fractures generally parallel to regional foliation. Older fractures are oblique to regional foliation. The early fractures may have contained pyrite deposited during hydrothermal alteration whereas the younger fractures contained sulfides remobilized during regional folding and metamorphism.

Rock samples of the altered dacite porphyry from the area contain as much as 0.5 ppm Ag, 200 ppm As, 180 ppm Cu, 46 ppm Mo, and 18 ppm Sn. Gold has not been analysed. Soil samples from this area show 5-16 ppm Sn, 40-140 ppm B, and 20 ppm Mo. Copper, although anomalous in the rock samples, is not anomalous in soils (<20 ppm) probably because of leaching during weathering.

Stop 14: The Crest of Pilot Mountain

Here, Pilot Mountain is underlain by intensely silicified and high-alumina altered, predominantly intermediate volcanic rocks with minor interlayered mafic tuffs, and some laminated sediments. The chestnut-oak park on the top of the mountain is like many others developed on high-alumina alteration in the slate belt and they may be useful in locating poorly exposed deposits (Milton and others, 1983). The parks are characterized by a very limited floral suite, chestnut oak (Q. prinus L.), the most abundant species, a generally open canopy, and a very open understory. Although now subject to much human use, observations were made here when the area was little used and the nature of the forest and understory had not been modified significantly.

LUNCH STOP

Stop 15: Quartz-Topaz Rock

Massive topaz-bearing rock described by Schmidt (1982) from Pilot Mountain is similar to topaz-rich rock at the Brewer Mine in South Carolina (Pardee and others, 1937; Stop 26). The rock in hand specimen resembles a dark gray, fine-grained quartzite; however, its relatively high specific gravity is a clue to the high topaz content. In thin section, the rock is an extremely fine-grained intergrowth of quartz and topaz. The topaz-rich zones may be several meters wide and often contain amoeboid-shaped "breccia" fragments with bleached rims now completely replaced by the quartz and topaz. These may represent late fluorine-rich breccia pipes.

Stop 16: Quartz-andalusite and quartz-pyrophyllite alteration

A large prospect pit was excavated here for bulk testing of the high-alumina industrial minerals. The rubble in the pit contains gray or blue, equant andalusite in a pyrophyllite and/or quartz-rich groundmass. Andalusite is often intergrown with and mantled by pyrophyllite. Massive non-foliated and radiating pyrophyllite is also abundant and intermixed with andalusite-bearing rocks. Pyrite, intergrown with andalusite and in thin fractures disseminated in the groundmass, has been converted to iron oxides by weathering. Chemical analyses of selected samples of diamond drill core from this area show a number of anomalous metals. High values of Cu (1200 ppm), Mo (400 ppm), and Sn (360 ppm) occur together with low level Au anomalies (0.1 to 0.5 ppm) in selected small intervals of core. Nearly all high-alumina altered samples in this area are anomalous in Mo (10-30 ppm) and Sn (10-60 ppm).

Stop 17: Pyrophyllite-bearing quartz veins

Prospect pits contain thick quartz veins with abundant large pyrophyllite rosettes, massive pyrophyllite, and locally abundant pyrite gossan. The veins are usually well-fractured with widespread filling by late, clear quartz apparent in thin sections. Several generations of pyrophyllite are present with radiating pyrophyllite the youngest and less abundant than massive, non-radiating, pyrite-bearing pyrophyllite. Several composite rock samples from the pit waste piles were analysed by fire assay (Au) and semiquantitative emission spectrography and contained the following anomalous elements, with values in ppm: Au (0.25), As (190), Bi (27), Cu (140), Pb (110), Sn (44), and Zn (43).

Stop 18: Pine Hill Mine

The Pine Hill mine was probably the largest gold producer on Pilot Mountain, judging from the amount of dump material above ground and that used to backfill the two shafts at the site. Highly altered, fine-grained quartz porphyry and, less commonly, coarse-grained, quartz porphyry (phenocrysts to 1 cm) are present. Traces of copper carbonate and molybdenite are found in the dump samples. The prospect trench to the northeast contains foliated quartz-sericite schist with the prominent regional foliation of N 60o E, dipping 60o NW. Hairline fractures filled with hematite are abundant and locally crosscut the regional foliation at low angles. A composite sample of dump material contained 10 ppm Au. Another composite sample contained 2200 ppm Cu and 0.64 ppm Ag with less than 0.05 ppm Au.

A coherent zone of Au mineralization, detected with A_1 horizon soil samples, begins immediately southwest of the mine area and extends to the northeast for at least 0.5 km and is approximately 150 m wide (Figure 22). Gold concentrations in the soil range from 0.1 ppm to greater than 1 ppm. Boron concentrations are high, 50-200 ppm; and Mo is present as a broad low level anomaly (10-15 ppm). Both correspond well to the areas of anomalous gold. Copper concentrations are erratic, ranging to 50 ppm. Scattered Sn (10-20 ppm) and Pb (30-100 ppm) anomalies occur near the gold zone but not usually within it.

This part of the Pilot Mountain system is dominantly quartz-sericite in marked contrast to the silica-alumina rich assemblages at Stops 14-16. Pods of pyrophyllite-rich altered rock do occur within this zone, but are small; andalusite has not been observed. The coherent gold anomaly is within the upper quartz-sericite alteration zone near the contact of the dacite porphyry with the volcanic rocks. The main body of dacite porphyry, which lies to the southeast, contains less intense sericite alteration accompanied by disseminated pyrite with no apparent metal anomalies. Gold mineralization in other subvolcanic porphyries is found in a similar position relative to the porphyry, and is accompanied by similar alteration and associated metals.

Stop 19: Parks Crossroads-type granodiorite

The Parks Crossroads-type granodiorite is well-exposed at this stop. The composition and texture of the pluton are highly variable. It contains 10-25% quartz, 50-65% plagioclase, a trace of potassium feldspar, and 10-40% mafic minerals. The latter is a mixture of amphibole, biotite, epidote, and chlorite; amphibole may have been the major pre-metamorphic mafic mineral. Textures in the pluton ranges from equigranular to distinctly porphyritic. Several xenoliths of a dark rock are visible in nearby outcrops.

The extent of hydrothermal alteration of this rock is not clear. Pervasive propylitization may be the product of green-schist facies metamorphism. In places as close to quartz grano-fels as 80 m, this rock has not experienced the extreme leaching of alkalis as found in the quartz granofels.

Interpreting the age of hydrothermal alteration at Pilot Mountain is dependent on the contact relationship between the granodiorite pluton and the rocks within the alteration system. There is no surface exposure of the contact. However, the grano-diorite pluton was intersected in the subsurface in a diamond drill hole northeast of this location and appears to intrude quartz-sericite altered volcanic rocks and dacite porphyry. A late, low-mafic granitic rock near Parks Crossroads clearly cuts the granodioritic phase of the pluton. The late intrusive phase contains potassic alteration and local fluorite enrichment, implying a relationship to the fluorine-rich alteration at Pilot Mountain. However, if our age interpretations are correct, it must have been emplaced later than the hydrothermal alteration.

STOPS 20-21

The Uwharrie and Tillery Formations

by

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As should be apparent by now, correlations along strike in the Carolina slate belt are risky. As we drive from Pilot Mountain southwest we will begin to enter the region covered in some detail in Figure 7, where workers have been able to consistently apply the stratigraphy formalized by Conley and Bain (1965) (Figure 25). Before we move on, it may be useful to review some of the problems with correlation of the metavolcanic rocks in the region.

Seiders (1981) carried the Uwharrie Formation as far north as Asheboro, where we spent last night. Using the correlation suggested by Schmidt and Klein above, a major unconformity must be present between Asheboro and Pilot Mountain. This unconformity will be between younger Uwharrie Formation and Albemarle Group rocks to the northwest and older Virgilina-correlative rocks to the southeast. We must cross this unconformity this morning and will cross it again as we head southwestward towards Monroe, North Carolina this afternoon.

To reiterate the basis for correlating the rocks in the Pilot Mountain area with those of the Virgilina area, their typically intermediate composition -- in contrast to the felsic-

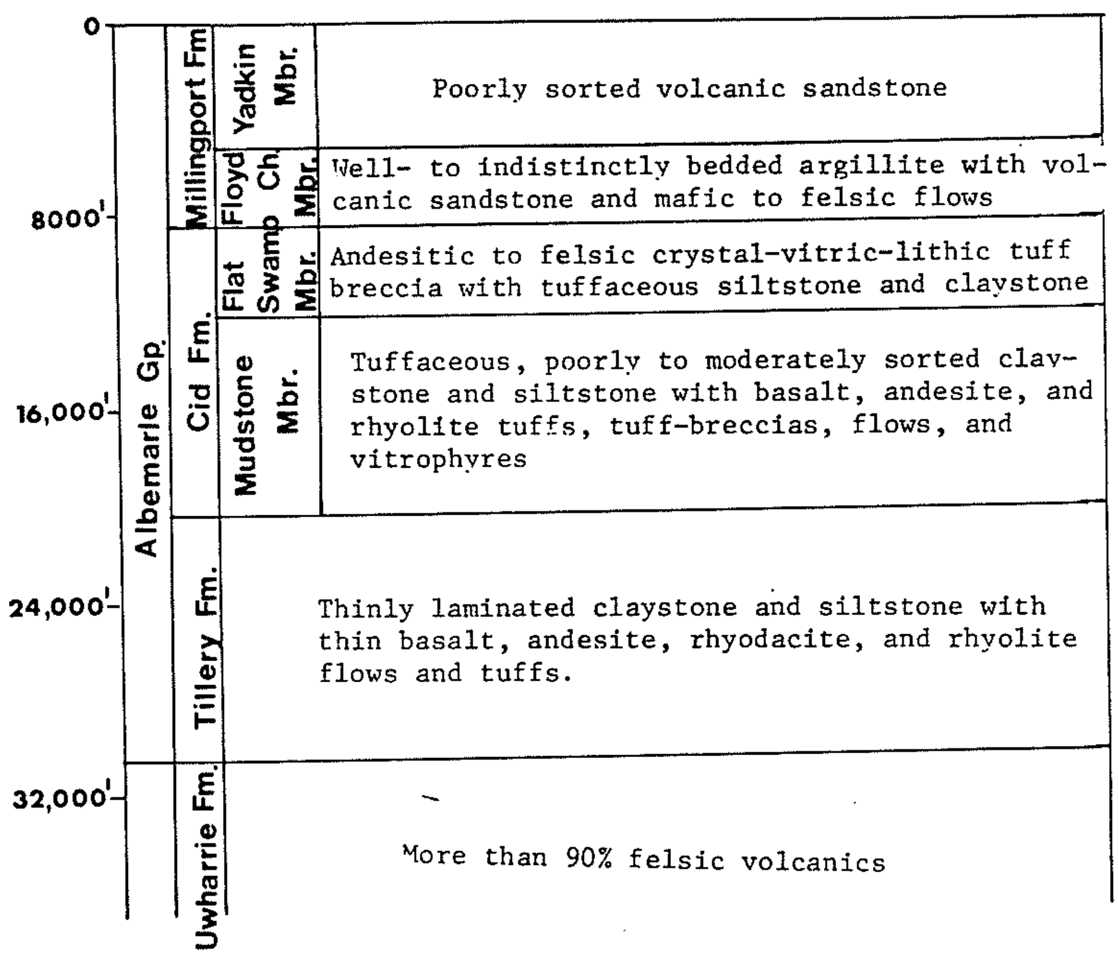


Figure 25: Stratigraphy of the Carolina slate belt units in the Albemarle, North Carolina 15' Quadrangle. From Conley, 1962a; Conley and Bain, 1965.

dominated, bimodal suite in the Uwharrie Formation -- is typical of Virgilina-type rocks to the north. The presence of a "Virgilina-fabric" requires that they be older than the Uwharrie Formation.

There are serious problems that remain unresolved. First, the unconformable contact between the Virgilina sequence and the Uwharrie-Albemarle sequence has not been directly observed -- though this is hardly surprising in the Piedmont and is clearly not a basis on which to disregard this model. However, it is worth noting that there is no <u>obvious</u> angular unconformity, in a regional sense, between the strike of the units in the Pilot Mountain area and those at Asheboro. This is significant since the unconformity proposed by Harris (1982) marks the Virgilina deformation. Second, by correlating the metavolcanic rocks of the northern Ramseur quadrangle with the Virgilina sequence, Harris implies a minimum age of 575-620 m.y. [The youngest rock known to be affected by the Virgilina deformation is 620 +/- 20 m.y. and the 575 +/- 20 m.y. Roxboro metagranite pluton is not affected by the Virgilina event.] Wright and Seiders (1981) obtained an age of 586 +/- 10 m.y. on the Uwharrie Formation near Asheboro and report no evidence of the Virgilina fabric. The Parks Crossroads pluton has been given a poorly constrained age of 566 +/- 46 m.y. (Tingle, 1982), which, nonetheless, makes it roughly time correlative with the Uwharrie Formation. The Parks Crossroads granodiorite, too, does not contain the Virgilina fabric. The geochronology and the tectonic fabric, thus, imply that the Parks Crossroads intrusive event is of Uwharrie "affinities." To the extent one wishes to view the Parks Crossroads pluton as having intruded "its own volcanic pile" or as related, in some genetic sense, to the synvolcanic alteration sequence at Pilot Mountain, a Virgilina age for the host rocks at Pilot Mountain becomes untenable and the unconformity disappears.

The question then remains moot as to whether the Pilot Mountain host rocks are time correlative with Virgilina-like sequences, which have been mapped in the Chapel Hill area and in northern portions of the Ramseur quadrangle, or whether they are a time equivalent of the Uwharrie Formation. Thus, as we proceed southwest we may cross an unconformity or, conversely, move either up-section or into a more felsic facies of a conformable volcanic sequence.

The route to the next two stops lies within the Uwharrie Formation, although very little outcrop will be visible on the drive. We will cross from the east to the west side of the Troy anticlinorium (Figure 7), which in this area is a southwest plunging anticline -- one of several regional folds with a wavelength of approximately 10 km. In this area the anticlinorium is cored almost entirely by Uwharrie Formation, although only about 1-2 km south of Stop 20 the Uwharrie Formation plunges beneath the Tillery mudstone, the oldest of the Albemarle Group metasediments. At the small town of Biscoe, North Carolina we will turn west. Six kilometers northwest of Biscoe is the Star mine and about six kilometers south is the Iola-Uwharra group of gold mines. These were described by Worthington and Kiff (1970) as lying very near the Uwharrie-Albemarle contact. Their paper emphasized for the first time the significance of the contact between the Uwharrie Formation metavolcanics and the Albemarle Group mudstones ("argillites") as the locus for disseminated gold mineralization in argillic- and silicic-altered metavolcanics of the slate belt. About 20 km west of Biscoe, we will cross the axis of the Troy anticlinorium. The location of stops 20 and 21 are shown in Figure 26.

Stop 20 - Uwharrie Formation

The road metal quarry at this stop is in the upper Uwharrie Formation, just west of the gap between Horse Trough Mountain on the north and Buzzard Mountain to the south (Figure 27). This locality is less than 200 m from the contact of the Uwharrie Formation with the Tillery mudstone of the Albemarle Group. This stop will allow you to see fresh felsic tuffs, typical of the upper Uwharrie Formation. These are dark bluish-gray to light-gray, massive, conchoidally fractured lithic-crystal and crystal tuffs. They weather spheroidally with a white, clayey weathering rind. The lithic fragments in this exposure of the Uwharrie Formation are sub-angular to rounded and consist predominantly of rhyolite and fine-grained felsite clasts up to 5 cm in diameter. Conley (1962a) reports lithic fragments up to 0.6 m in diameter and an abundance of flow-banded rhyolite fragments in the Uwharrie Formation. At this locality, there is

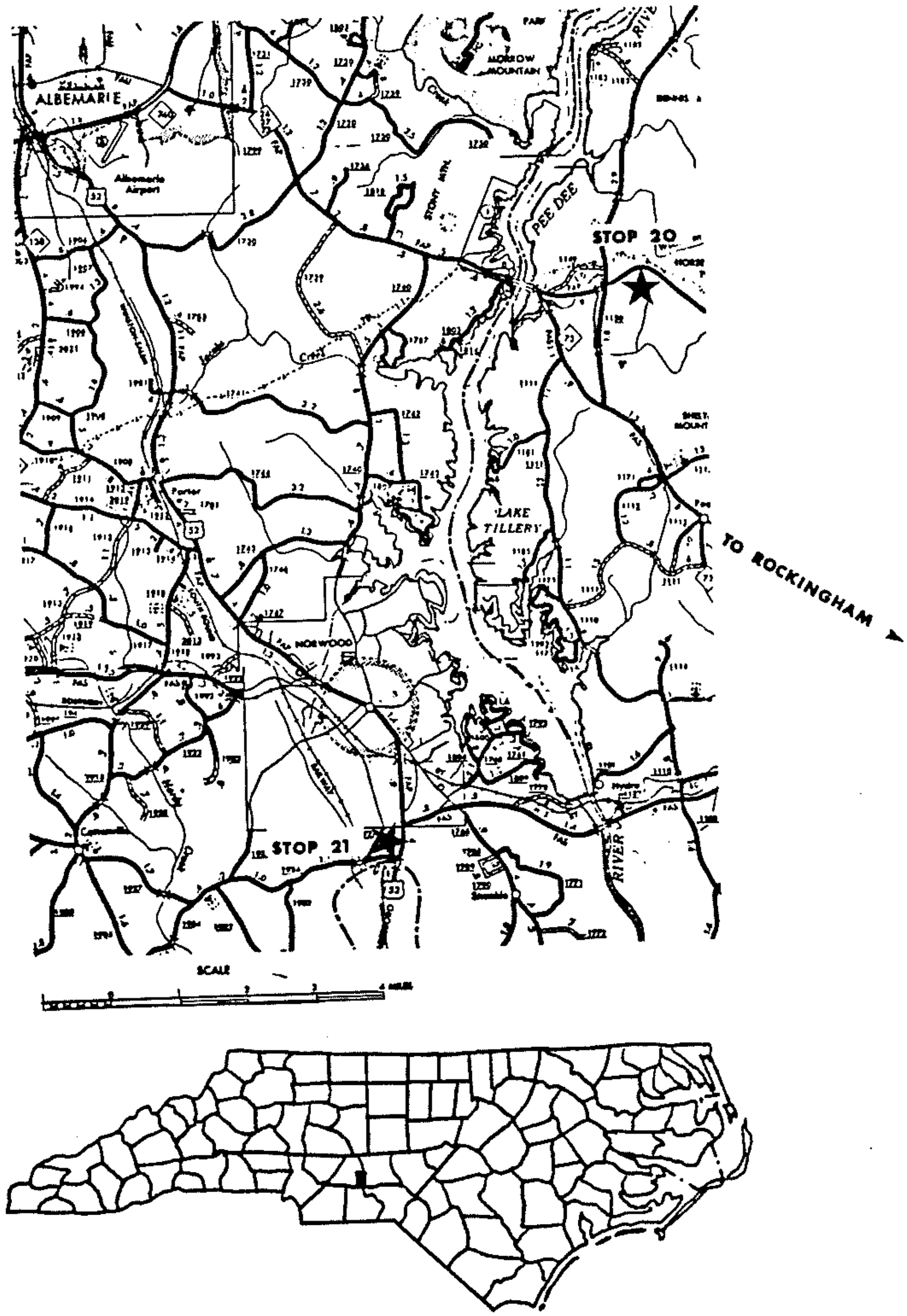


Figure 26: Location map for STOP 20, the Uwharrie Formation in Montgomery County, and STOP 21, the Tillery Formation in Stanly County, North Carolina.

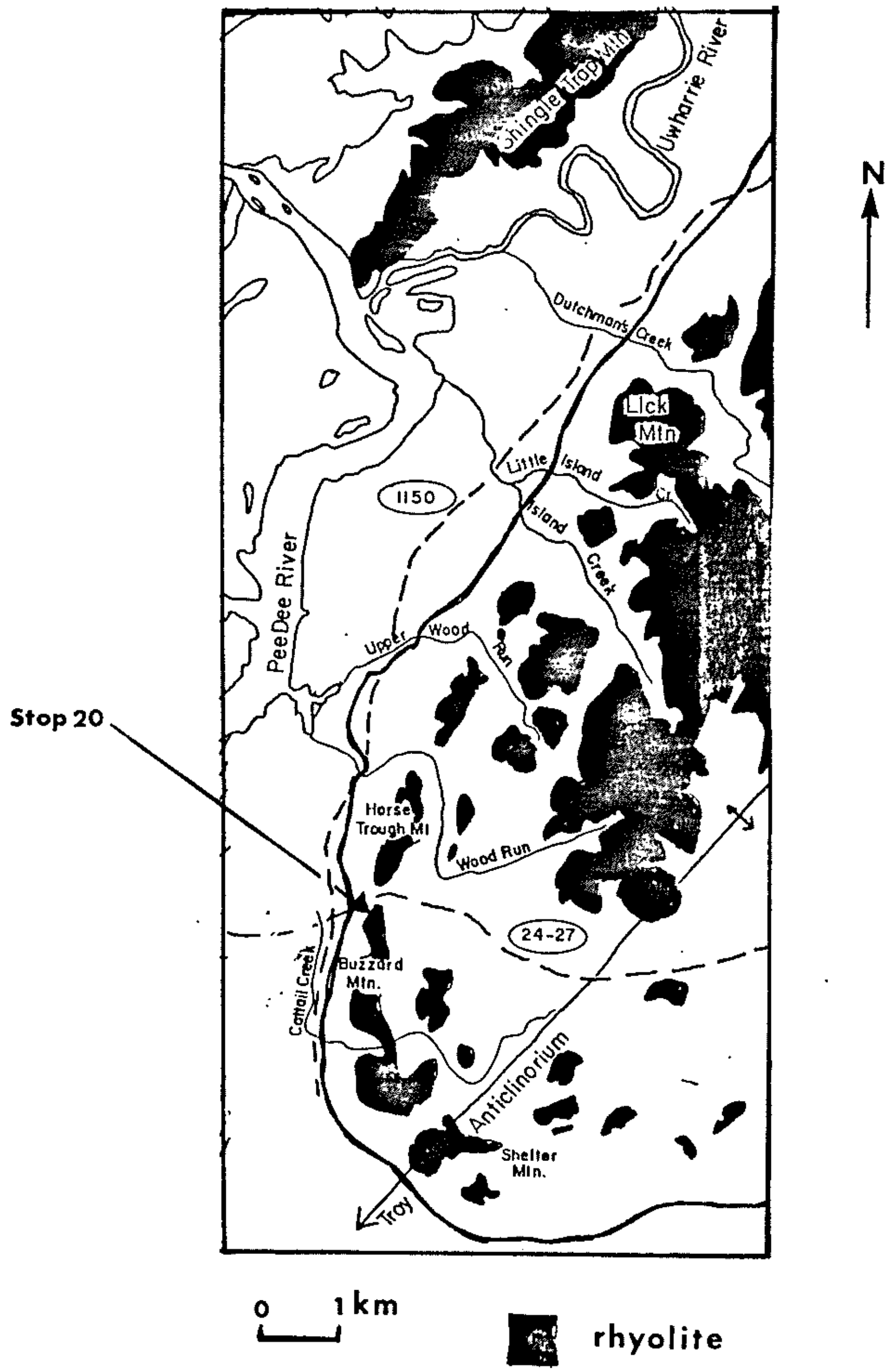


Figure 27: Outcrop areas of dense, commonly silicified and pyritized, rhyolites in the upper Uwharrie Formation on the plunging nose of the Troy anticlinorium (see Figure 7). Shingle Trap Mountain is in the Tillery Formation, overlying the Uwharrie. From Dover, 1985.

considerable variation in the abundance of lithic fragments. Some zones are very lithic-rich, almost clast-supported; others are relatively free of clasts. Typically, the Uwharrie Formation is 80-90% fine felsic groundmass. The phenocrysts are 50-90% quartz with oligoclase or albite and orthoclase or microcline (Conley, 1962a; Butler and Ragland, 1969; Dover, 1985). Much of the fine, aphanitic groundmass, particularly in the clast-free portions of the unit, is dusted with millimetersized pyrite crystals, suggesting that some of the dense, flinty nature of this outcrop may be due to silcification. BE CAREFUL WITH ROCK HAMMERS, this rock splinters easily.

Against the western wall of the quarry, in the south-western corner, you can see a 0.7 m wide, near vertical, basaltic dike which intrudes the Uwharrie Formation. This is undoubtedly a Triassic diabase dike which Conley (1962a) indicates are more common in the eastern portion of the Albemarle quadrangle.

Conley (1962a) and Butler and Ragland (1969) suggest a subaerial origin for the Uwharrie formation, based on lack of sorting, flattened pumice, presence of welded tuff units, and general absence of criteria for waterlain deposits. It should be noted that the obviously subaqueous Tillery mudstone lies only 200 m up-section and that the contact, though apparently sharp, is characterized by considerable intertonguing of mudstone and volcaniclastic rocks.

The high ridges on either side of the gap immediately to the east of this stop trend north-south, roughly parallel to the N-S strike here at the nose of the plunging Troy anticlinorium. The ridges were mapped by Conley (1962a) as "Younger Rhyolites," a unit later formalized as the Morrow Mountain Rhyolite (Conley and Bain, 1965) from exposures on Morrow Mountain about 6 km northwest of here, across the Pee Dee River (now Lake Tillery). His interpretation placed these rhyolites in profound angular unconformity on the Uwharrie Formation (see Figure 28). Recent mapping on Lick Mountain, 5.5 km north of this stop by Dover (1985) has shown that these ridge-defining rhyolite flows consist of generally conformable rhyolites with porphyritic and spherulitic textures. Many are flow-banded. It appears that these are best viewed as late Uwharrie rhyolite flows or siliceous domes similar to the Inyo domes in form and composition, if not in tectonic setting (Bailey and others, 1976).

Many of these late Uwharrie rhyolites appear strongly silicified and contain abundant, very fine-grained pyrite. Dissolution of this silicified rhyolite for chemical analysis almost always produces insoluble residues of pyrite - even when pyrite is not visible in hand specimen. Table 3 contains several whole rock analyses from the silicified rhyolites on Lick Mountain as well as several analyses from Uwharrie tuffs and the "Younger Rhyolites." The latter are from rhyolite-capped hills in the Tillery mudstone (Shingletrap Mountain and Thayer Hill) and from type Morrow Mountain rhyolite. Whole rock analysis of the dense siliceous rhyolites from Lick Mountain

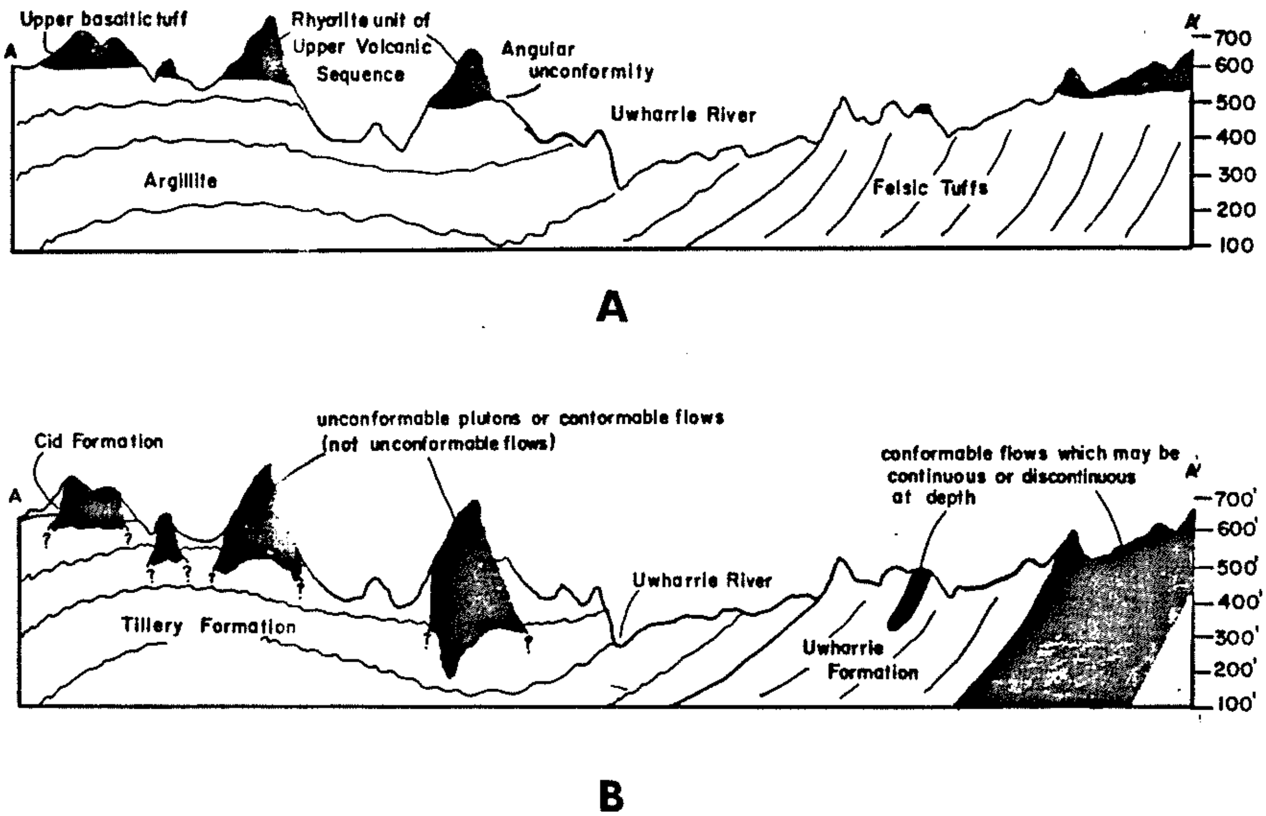


Figure 28: Two interpretations of the relationship of the rhyolites in the Uwharrie Formation and the upper Albemarle Group (see Figure 25 for stratigraphic relations). A: Interpretation of Conley (1962a) in which the Uwharrie rhyolites are equivalent to the latest Albemarle, Morrow Mountain Rhyolite. B: Interpretation of Dover (1985) which sees these rhyolites as late flows conformable within the Uwharrie Formation.

TABLE 3

Chemical analyses of upper Uwharrie Formation rhyolites and Morrow Mountain Rhyolite from the Albemarle Quadrangle

	LICK MOUNTAIN RHYOLITES		
	pyrite-rich	spherulitic	porphyritic
SiO_2	82.32	81.34	76.64
Al_2O_3	9.37	10.83	11.68
TiO_2	0.10	0.14	0.13
FeO [tot Fe]	3.67	2.42	4.15
MgO	0.11	0.08	0.11
CaO	0.08	<0.05	0.18
Na_2O	2.79	3.77	3.63
K_2O	4.08	3.37	3.62
MnO	0.07	0.05	0.09
(ppm)			
Rb	130	98	116
Sr	54	85	116
Ba	750	778	821
Zr	70	141	200
Y	30	25	54

	HORSE TROUGH MTN.		SHINGLETRAP MTN.	MORROW MOUNTAIN RHYOLITE
	pyritic	stop 20	flow-banded	
SiO_2	73.76	75.9	72.54	76.7
Al_2O_3	12.72	15.1	12.86	13.4
TiO_2	0.08	0.10	0.11	0.18
FeO [tot]	3.96	0.96	4.90	1.76
MgO	0.08	0.07	0.06	0.18
CaO	0.26	0.70	0.28	0.56
Na_2O	4.45	3.75	4.06	3.71
K_2O	3.39	1.90	4.03	1.96
MnO	n.d.	0.07	n.d.	0.03
(ppm)				
Rb	95		117	
Sr	45		45	
Ba	757		846	
Zr	111		117	
Y	42		49	

All analyses from the geochemistry laboratory, University of North Carolina. Stop 20 and Morrow Mountain Rhyolite from Butler and Ragland (1969). All others from Dover (1985) with assistance from Dr. S.A. Goldberg, Research Chemist.

run 73-82% SiO_2 with evidence of alkali, magnesium, and lime depletion (Table 3).

The silicification of late rhyolites in the Uwharrie Formation is significant in light of gold mineralization in proximity to the Uwharrie-Albemarle contact in this area (Figure 27). The Eldorado district, a cluster of late nineteenth century gold mines, including the Coggins, Sally Coggins, and Russell mines, is about 15 km north of Stop 20, in the Tillery mudstone. The Russell mine is noted for the "Big Cut," a pit 100 m x 50 m and up to 20 m deep from which ore averaging 0.1 oz/ton was removed (Pardee and Park, 1948). Pardee and Park (1948) describe the ores as:

> ...dense light bluish-gray quartz that has partially replaced sericite schist, retaining the foliated structure. Minute grains of pyrite are distributed through the quartz and locally are aggregated in bands. (p. 81)
> ...fine-grained quartz that has replaced the foliated country rock...[and] contains a small amount of pyrite. (p. 82)
> ...bounded lodes...of hard silicified rock. (p. 83)

The mineralization is all contained in the Tillery mudstone near the Uwharrie Formation contact. In addition to this cluster of deposits, a small mine, the Moratock mine, lies less than 500 m northeast of Stop 20. If time permits, one can walk about 100 m east on Highway 24-27 to a small dirt road that leads off to the north. Assuming that the land has not been recently posted, one can walk about 400 m north and northwest on this road to a series of overgrown trenches, pits, and dumps that were first mined in 1892 (Carpenter, 1976). The largest trench is about 30 m long, oriented N70oW with a 20 m long "tee" at the north end of the trench. Most of the rock in the pit is a dense, pink to white, "quartz-eye" rhyolitic tuff with a few quartz stringers and some exposures, particularly near the "tee" intersection of the trenches, of coarse-grained quartz. A channel sample from the trench as well as samples of the coarse quartz run <0.01 ppm Au. Float from north of the pit is a silicified tuff with abundant spherulites and possible lithophysae structures. Some of this material is very "sintery-looking."

In addition to this mine, it is interesting to note that many of the streams than drain westward off the late Uwharrie rhyolite-capped ridges were placer mined at various times in the late nineteenth and early twentieth centuries. Lick Mountain, in particular, was mined extensively along Dutchman Creek and a significant amount of pitting and trenching was carried out on the southwest flank of the ridge in silicified, pyritic rhyolite. About fifteen samples from this area of Lick Mountain were assayed with a range of Au values of 0.02-0.12 ppm. In this area, volcanic breccias, microcline-replacements after albite, thin sericite-quartz stringers and veinlets, and intergrown chlorite, sericite, quartz in the groundmass are suggestive of an epithermal system. Lack of outcrop prevents any detailed mapping in this area.

This area is an interesting one for gold exploration given:

1. Proximity to the Uwharrie Formation-Tillery mudstone

contact.

2. Historical gold mines in the vicinity.

3. Historical placer mining from creeks draining many of the ridges.

4. Silicification and pyritization associated with late Uwharrie rhyolite flows.

5. Occurrences of chlorite, sericite, microcline after albite, and brecciation in silicified rhyolites.

6. "Interesting" gold values.

Working against this area as a potential exploration target are:

1. Absence of any large scale propylitic or argillic alteration halos.

2. Very sporadic gold values.

3. The land situation, in that much of the land is in the Uwharrie National Forest and the streams drain into a major recreational area, Lake Tillery.

Stop 21 - The Tillery Mudstone

From Stop 20 we cross the contact of the Uwharrie Formation and the Tillery mudstone and remain in the mudstones until the next stop. The Tillery mudstone, the lowest unit of the Albemarle Group, has been subdivided by Gibson and Teeter (1984) into three informal memebers. The lowest unit is a silty to fine-sandy rhythmite with euhedral feldspar and quartz clasts, channel deposits of matrix supported pebbles, and cross-bedded coarse-grained sands. The middle member is clayey siltstone with rhythmic laminae and interbeds of fine to coarse sand with low-angle cross-bedding and some grading. The upper Tillery is not laminated and contains coarser sandy and pebbly mudstones. Gibson and Teeter interpret the environment of formation of the Tillery Formation as a nearshore, shallow shelf or tidal flat. They attribute many of the rhythmic features to strong tidal influences and the variation in grain size and presence of immature clasts to the effects of fan-delta (?) deposition associated with waning Uwharrie volcanism and volcanism within the Albemarle Group.

Stop 21 is in the middle Tillery Formation. This locality is Stop #6 of the 1984 Carolina Geological Society Field Trip (Gibson and Teeter, 1984). The text that follows is reprinted with the kind permission of Gail Gibson:

STOP #6. Rhythmically laminated siltstone of the Tillery Formation.

The rhythmically laminated clayey siltstone that is generally considered "typical" of the Tillery is composed of a lower, lighter colored portion that appears to grade upward into a darker colored portion. The grain size in thin sections so far examined from this outcrop is silt-sized with little normal grading as suggested by the color couplets. Grading here is mainly the result of the addition of finer grain sizes, in what is the darker part of a couplet, not a progressive decrease in grain size upward.

Upper and lower contacts of individual couplets are sharp, but frequently somewhat wavy. Individual couplets can easily be traced across the outcrop and there is no evidence of pinch and swell of laminations.

Most couplets are less than two to four millimeters thick, but there are many examples of couplets where the lighter part is as much as 12 cm thick. The grain size in couplets with thicker lighter colored parts is generally coarser and frequently the basal portion contains low angle tangential cross laminations of coarser material mixed with the silt. In addition, couplets with thicker lighter colored portions contain wavy, discontinuous parallel and non-parallel interlaminations of medium to fine sand-sized clasts.

Numerous intrastratal zones of deformation are present in this area. These appear to be post-depositional, pre-lithification features.

Interpretation - The Tillery has long been considered a quiet water deposit, as suggested by the laterally extensive bedding and relatively uniform fine grain sizes in this part of the section. Reports of graded bedding (Stromquist and Sundelius, 1969) in the Tillery plus the rhythmic repetition of light and dark colored bands suggest deep water turbidite deposits, probably distal turbidites.

However, in light of depositional environments suggested for the overlying McManus and Yadkin formations [equivalent to the Cid and Millingport Formations of Conley and Bain, 1965], the general absence of normal graded bedding, and data from the lower Tillery, an alternative interpretation is suggested -- that of a relatively shallow water environment that was usually isolated from coarse sediment influx, but was still influenced by tides.

The depositional environment was one in which silt sized material was washed from a shallower platform into a slightly deeper basin. With slack water periods, such as during high and low tide stages, pelagic sediments (clays) would settle to the bottom accounting for the dark layers of finer grained sediment within the silt. Occasional pulses of higher energy and extended periods of higher energy would account for the coarser grained layers and zones of low angle tangential cross laminations. (Gibson and Teeter, 1984, p. 33-34.)

From this stop we will continue, without additional interruption, to Monroe, North Carolina. We will remain west of the axis of the Troy anticlinorium within metasediments of the Mudstone Member of the Cid Formation (McManus formation).

DAY 3

The third day of the field trip, we will visit two old gold mines. The first will be the Nesbit mine in southern Union County, North Carolina. The Nesbit is about 15 km from the any other significant gold deposit or prospect. Production statistics are unknown. The second deposit is the Brewer mine, Chesterfield County, South Carolina, which, although a small producer (an estimated 22,000 oz), is noteworthy for good exposure of host rocks and mineralization and for proximity to the Haile mine, the largest single producer in the southeast. As noted in the Introduction, the Haile is currently in production and we hope it may be possible to make a quick visit to the property.

STOP 22

The Nesbit Gold Mine

by

Linda H. McKee
University of North Carolina at Chapel Hill

The Nesbit gold mine is located seventeen kilometers southwest of Monroe and 40 kilometers southeast of Charlotte, North Carolina. The mine lies in the northeast quadrant of the Unity, South Carolina-North Carolina, 7 1/2' quadrangle, in Union County, North Carolina. The location of Stop 22 is shown in

Figure 29. The mine is situated in Late Precambrian to Cambrian, altered metavolcanoclastic rocks of the upper Uwharrie Formation (Figure 6). In the immediate area of the Nesbit mine, the Uwharrie and Tillery Formations "resurface" in a series of broad, open, northeast-plunging folds (Figure 7).

Gold mining at the Nesbit mine commenced in the early 1800's and continued until the mid-1800's. The mine workings consisted of several small pits and a 32 m deep shaft with a 215 m tunnel which was oriented N60oE (Carpenter, 1976). The total amount of gold produced from the Nesbit mine was never recorded. Gold exploration at the Nesbit mine resumed in the early 1900's and has continued sporadically to the present. In 1981, Gulf Minerals Inc. evaluated the mine area from soil geochemistry, induced polarization and magnetic surveys, and seven drill holes in the mine area. Exploration for pyrophyllite has also been carried out in this century.

This paper is based on work completed for a Master's Degree in Geology at the University of North Carolina (McKee, 1985). The study included 1) surface geologic mapping, 2) logging core from five of the seven holes drilled by Gulf Minerals Inc., and 3) petrographic and X-ray diffraction analyses of unaltered and altered rocks from the mine area.

Geolgic Setting of the Nesbit Mine Area:

The geology in the mine area includes metamorphosed felsic volcaniclastic and sedimentary rocks of the upper Uwharrie

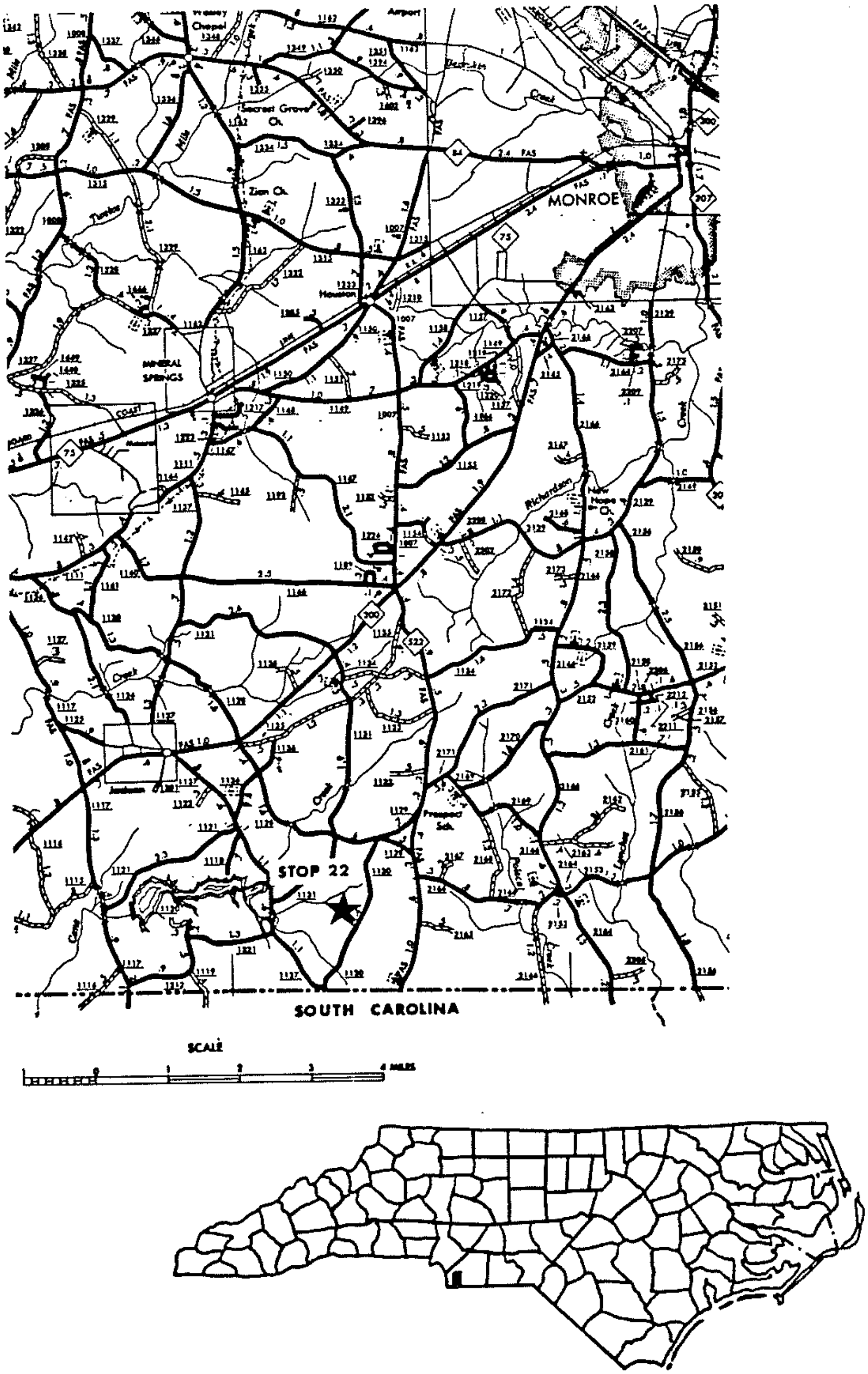
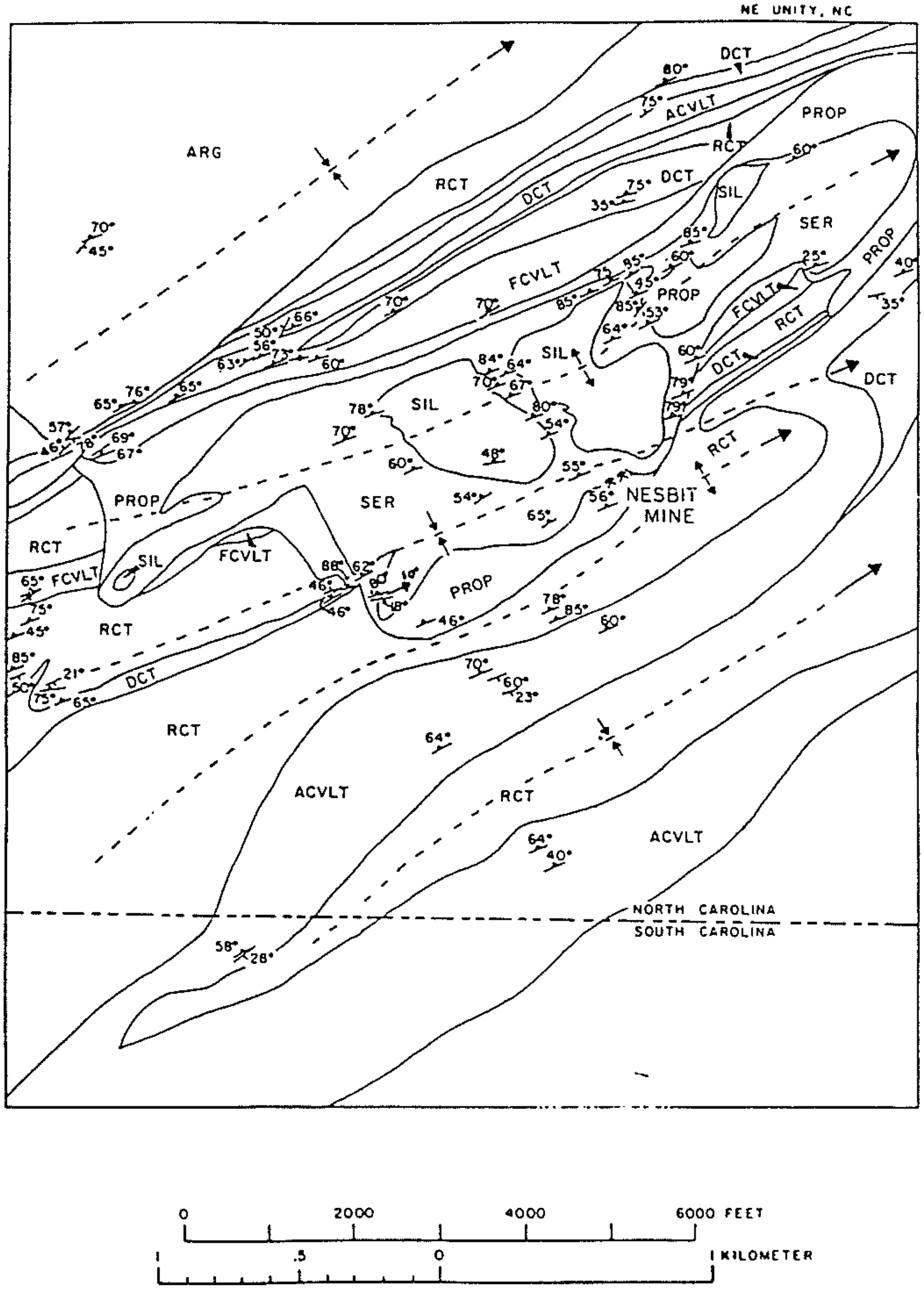


Figure 29: Location map for STOP 22, the Nesbit gold mine, Union County, North Carolina.

Formation and sedimentary rocks of the lower Tillery Formation (Figure 30). Figure 31 shows the general stratigraphy of the various units found in the mine area. The units below the andesitic crystal-vitric-lithic tuff are interpreted to be felsic flows and tuffs deposited in a subaerial, explosive volcanic setting. The units below the andesitic tuff are also the units that were locally altered by a hydrothermal system that deposited the gold. The andesitic crystal-vitric-lithic tuff, which exhibits characteristics of both subaerial and subaqueous deposition, consists of pyroclastic flows and reworked volcanic debris deposited in a transitional, subaerial-subaqueous environment. The felsic volcanic units above the intermediate tuff were also probably deposited in a subaqueous environment. The overlying argillite of the Tillery Formation were deposted below wave-base, probably in a submarine environment (Gibson and Teeter, 1984).

During the regional Taconic or Acadian tectonism, the units in the mine area were metamorphosed to upper-chlorite zone to lower-biotite zone of greenschist facies metamorphism. Biotite is found only in localized areas in some of the unaltered rocks. The units in the mine area were also folded into a series of small, open folds. From strike and dip measurements on bedding planes and the possible repetition of units seen in the mine area, five assymetrical folds are interpreted to be present in the mine area (Figure 30). The folds trend N65oE, plunge 5-10o NE, and have axial planes that dip 10-20o NW. These folds are



UNALTERED ROCKS

Tillery Formation

ARG = Argillite

Uwharrie Formation

RCT = Rhyodacitic crystal tuff
DCT = Dacitic crystal tuff
ACVLT = Andesitic crystal-vitric-lithic tuff
FCVLT = Felsic crystal-vitric-lithic tuff

ALTERED ROCKS

SIL = Silicic and advanced argillic zone rocks
SER = Sericitic zone rocks
PROP = Propylitic zone rocks

SYMBOLS

bedding plane
metamorphic cleavage
fold axis

Figure 30: Interpretive geologic map of the Nesbit gold mine area, Union County, North Carolina.

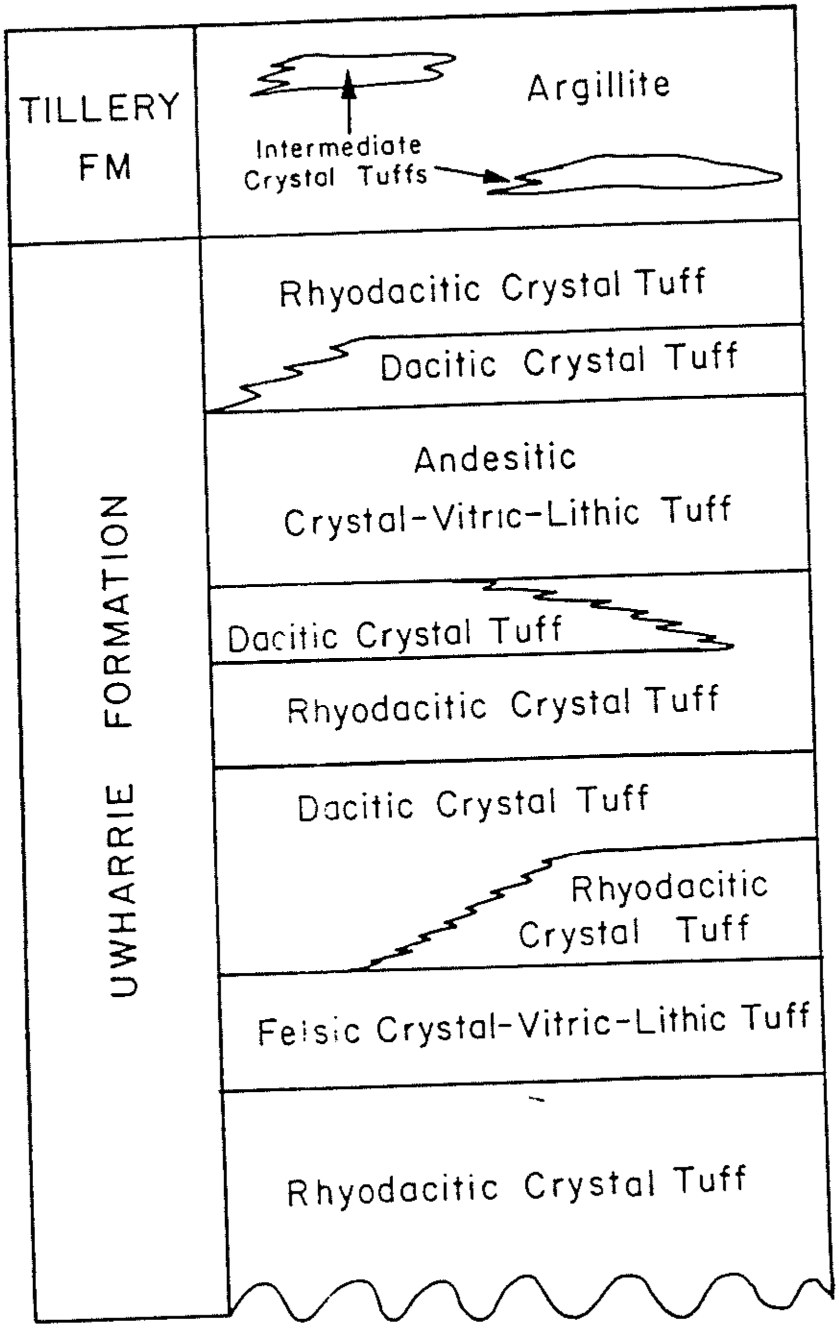


Figure 31: General stratigraphy of the rock units in the Nesbit gold mine area, Union County North Carolina.

concordant with the larger regional folds of the Carolina slate belt and are probably part of the Troy anticlinorium fold system (Figure 7).

Alteration at the Nesbit Mine:

Alteration of the Uwharrie Formation volcanic rocks in the Nesbit mine area, followed by metamorphism and weathering, has produced a distinct mineral assemblage as compared to unaltered volcanic rocks in the area. The altered area, which covers about five square kilometers, is clearly defined on the surface (Figure 32). In the subsurface, the altered zones are often separated by "screens" of unaltered rock, making interpretations of the geometry of the alteration zones difficult. The altered rocks are distinguished from the unaltered rocks by 1) mineralogy, 2) texture, 3) location on the geologic map (Figure 30), and 4) geochemical analysis of five altered samples. The altered rocks occur in three distinct zones that appear gradational to one another in surface mapping. They are classified according to the alteration classification of Rose and Burt (1979). From the most to the least altered rock, a silicic-advanced argillic zone, a sericitic zone, and a propylitic zone are interpreted to be present. Potassic alteration is not observed in the mine area and biotite was not part of the primary hydrothermal alteration assemblage.

Silicic zone - The silicic-advanced argillic alteration zone is the zone of most intense alteration. The altered rocks

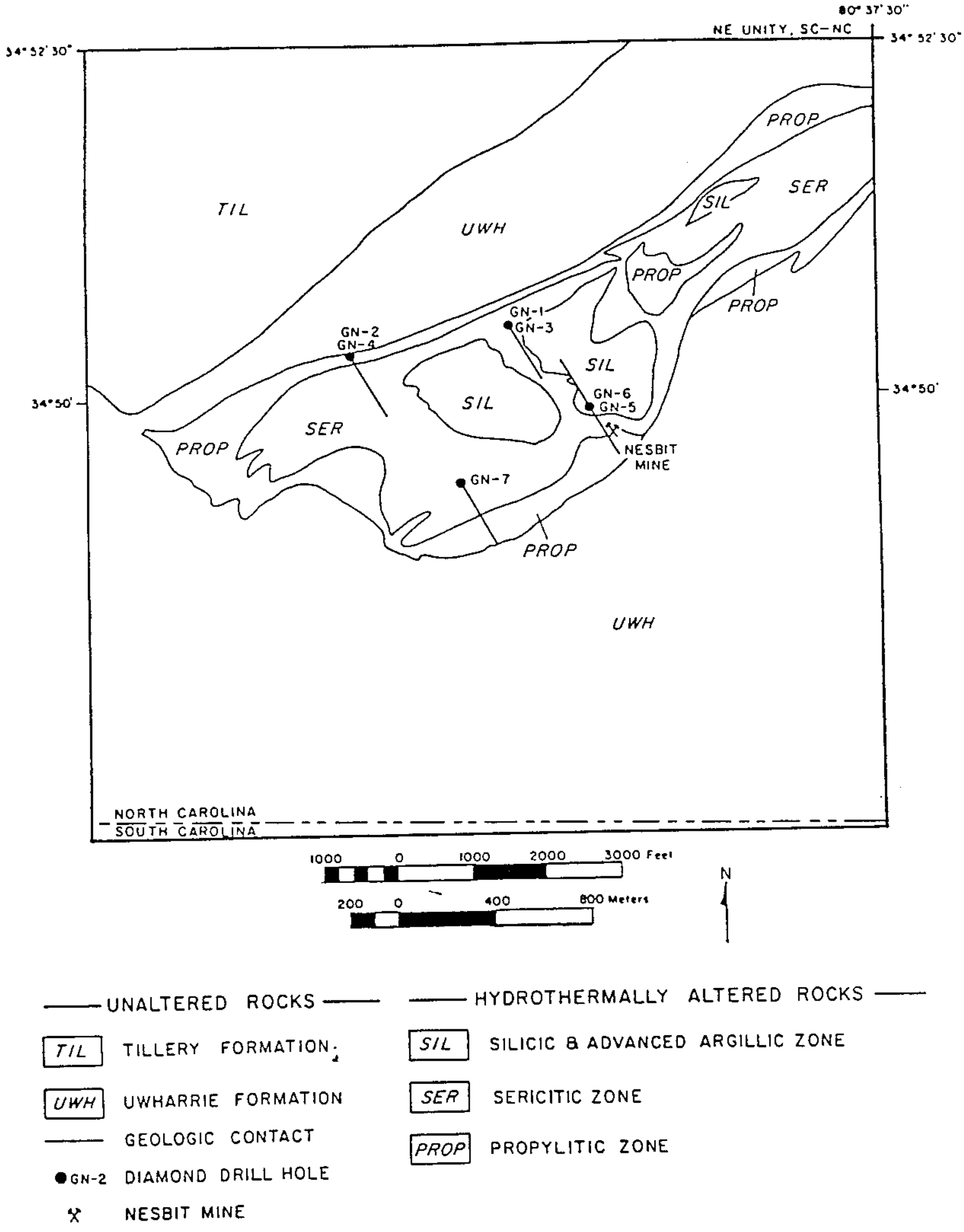


Figure 32: Map of the alteration zones surrounding the Nesbitt gold mine, Union County, North Carolina.

range from a dense, fine-grained, cherty quartz-rich rock to a bleached, white, friable and sugary quartz-rich rock. Varying amounts of kaolinite, muscovite, pyrophyllite, andalusite, and iron oxides are also found in thin, dusky-red veinlets that cut the siliceous altered rocks in a net-breccia texture. Numerous limonite- and hematite-coated vugs and pyrite casts are disseminated throughout the silicic zone rocks. Primary sedimentary and volcanic textures are not preserved.

Areas of advanced argillic alteration are found as small, isolated patches in the silicic zone and are characterized by a soft, friable, moderate-red rock with varying amounts of muscovite, pyrophyllite, andalusite, kaolinite, and quartz. The andalusite generally occurs as 0.5 to 1 cm long, strongly fractured, anhedral grains with fine-grained pyrophyllite located along fracture and cleavage planes and as rims around grains. The pyrophyllite occurs as fine-grained parallel aggregates or deformed radial aggregates that range in color from very light-grey to light-red to moderate-red. Pyrophyllite is sometimes associated with andalusite in the texture described above. The pyrophyllite and andalusite may represent original hydrothermal alteration assemblages or metamorphic assemblages of an altered protoliths.

The pyrophyllite also occurs as clear to very light-grey, radial aggregates 1 mm to 1 cm across. This texture is found exclusively in a six to twelve meter zone around quartz veins that cross-cut the altered area. These quartz veins are interpreted to be metamorphic in origin. This undeformed, radial pyrophyllite is interpreted to have formed by recrystallization of hydrothermal pyrophyllite or by reaction of hydrothermal kaolinite to pyrophyllite during regional metamorphism.

Sericitic zone - The sericitic zone, which is found around the silicic zone on the surface and in varying locations in four drill holes, is characterized by a moderate to strongly schistose, fine- to medium-grained, bleached-white quartz-muscovite schist with fine-grained, disseminated pyrite. The sericitic zone represents a less intensely altered area than the silicic zone. The gradational changes observed from the silicic zone to the sericitic zone include: 1)an increase in modal muscovite and chlorite, 2) the development of a metamorphic schistosity, 3) a decrease in the amount of modal quartz, hematite, and kaolinite, and 4) the disappearance of andalusite and pyrophyllite.

Propylitic zone - The propylitic zone, which is observed on the surface and in the subsurface, is the least intensely altered zone. On the surface, the propylitic zone is the outermost alteration zone and grades outward into unaltered metavolcanic rocks. It also surrounds the sericitic zone on the northern, western, and southern margins of the altered area, but not on the eastern and northeastern margins. The propylitic zone assemblage, which is very similar to the metamorphic assemblage of greenschist metamorphism, is characterized by a chlorite-epidote-calcite-rich rock that ranges from a strongly schistose, fine-grained phyllite or schist to a nonfoliated, moderate-yellowish-green to dusky-green, crystal-lithic-lapilli tuff. Most of the minerals in the felsic tuffs, the presumed protolith for these rocks, are partially to totally altered. The feldspars are replaced by epidote, clinozoisite, calcite, quartz, and sericite. Biotite and other mafic minerals are replaced by chlorite, epidote, and some calcite. Relect quartz crystals are rimmed by granular epidote.

Mineralization at the Nesbit Mine:

Based on 1) assay data from the drill holes, 2) assay data from a mine-dump sample, and 3) location of the mine shaft along the sericitic-propylitic contact, the gold mineralization at the Nesbit mine is interpreted to be mainly in pyrite grains in propylitic zone rocks at, or very near, the sericitic-propylitic zone contact. Visible gold was not observed. The gold values of the propylitically altered rocks range from <0.02 to 5.4 ppm. The gold mineralization was most likely penecontemporaneous with hydrothermal activity and was concentrated by the hydrothermal fluids that altered the rocks in the mine area. The gold may have been initially localized at the sericitic-propylitic contact or may have been remobilized during metamorphism.

Discussion:

The Nesbit gold mine is a small, epithermal gold deposit located in folded, felsic metavolcanic rocks of the Uwharrie Formation, near the Uwharrie-Tillery contact in the Carolina slate belt. From the lack of siliceous sinter, potassic alteration, porphyritic intrusive rocks, and extensive brecciation in the mine area, the gold mineralization and associated hydrothermal alteration probably represent an area below the silica cap and away from the central portion of a mineralized, synvolcanic hot-spring system. This environment is similar to hot-spring systems described by Berger and Eimon (1983) and Giles and Nelson (1983) (Figure 33). The hot-spring system developed during the waning stages of volcanic activity, now represented by the Uwharrie Formation, and was extinct prior to the deposition of the Tillery Formation mudstones. Figure 34 shows a general schematic cross-section of the geologic environment in the Nesbit mine area.

In comparison with other hot-spring gold deposits, the alteration pattern and mineral assemblages at the Nesbit mine are similar, but the location of the mineralization is different. In most systems, the precious metals are concentrated in the silicic zone, beneath a silica cap; but at the Nesbit, the mineralization is located (exclusively ?) at the boundary between the sericitic and propylitic alteration zones. In addition, the Nesbit mine does <u>not</u> exhibit repeated episodes of silicification and

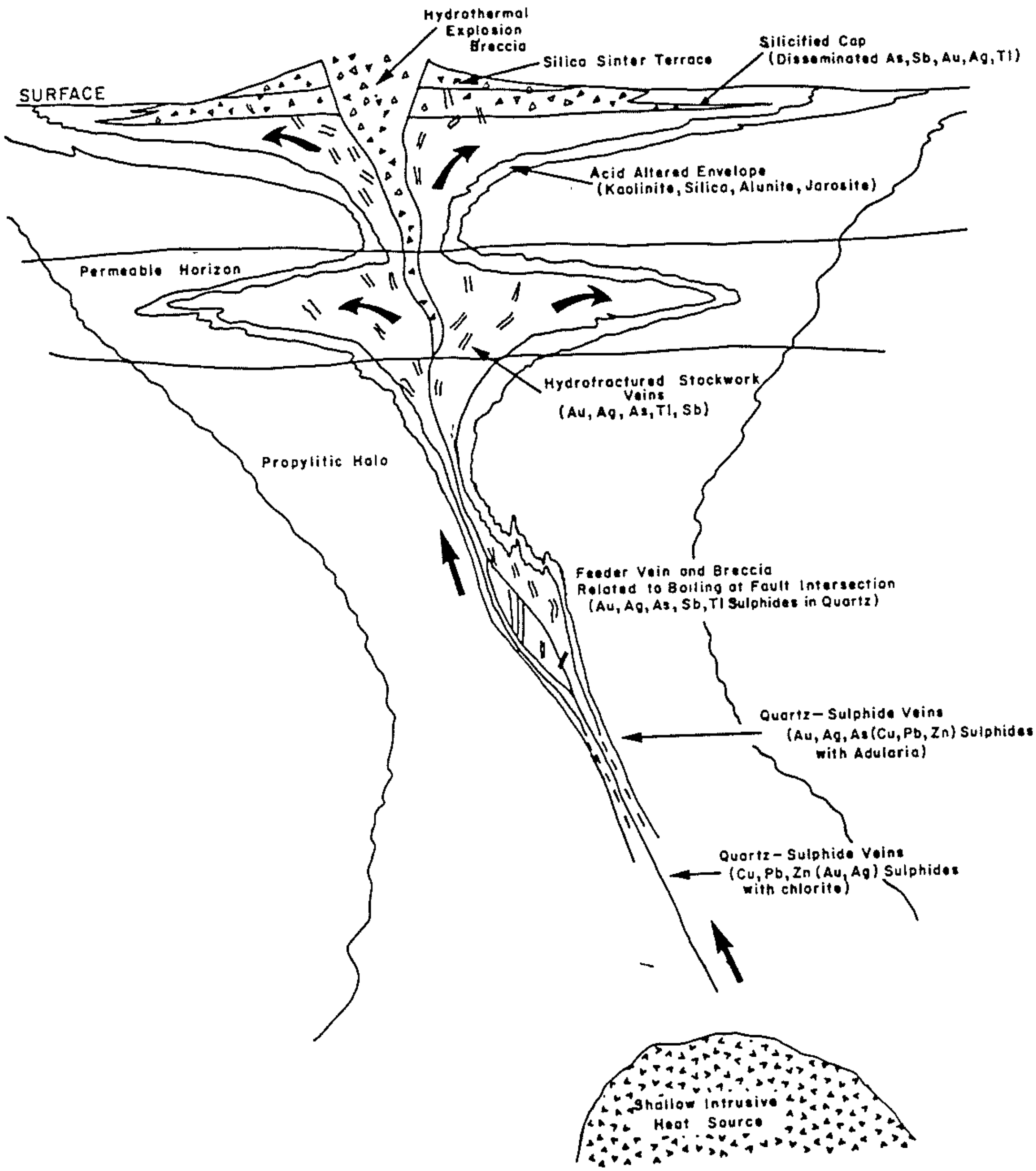


Figure 33: Schematic cross-section of a hot-springs type gold system. From Giles and Nelson, 1983; Berger and Eimon, 1983.

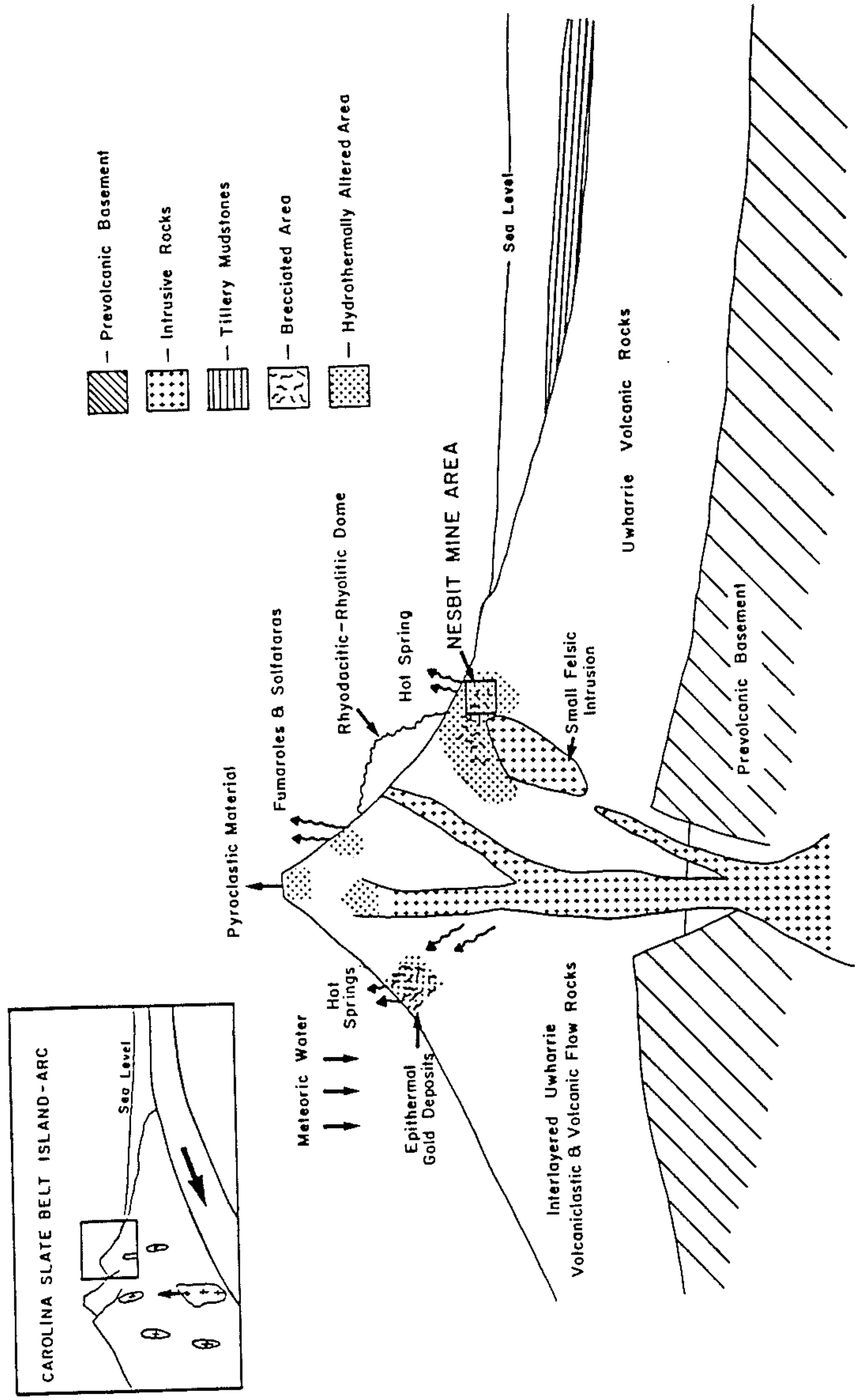


Figure 34: Model cross-section of the geologic environment of the Nesbit alteration-mineralization system.

brecciation which are seen in other epithermal gold deposits.

The hot-spring system that produced the alteration and gold mineralization is probably correlative with other mineralized hot-spring systems in the Carolina slate belt. Other epithermal gold deposits in the slate belt that have been interpreted to represent hot-spring-type gold deposits include the Brewer (Stops 23-26) and Haile mines in South Carolina (Spence and others, 1980; Cherrywell and Butler, 1984) and the Howie and Sawyer mines in North Carolina (Worthington and Kiff, 1970). The hot-spring systems that produced the alteration assemblages and precious metal concentrations at these mines and at the Nesbit mine developed in a similar geologic setting during the waning stages of volcanic activity now represented by the Uwharrie Formation (Stop 20). All these mines exhibit similar alteration patterns and mineral assemblages.

Field Guide to the Nesbit Mine:

The three stops in the Nesbit mine area (Figure 35) comprise a transect through the altered rocks of the Nesbit hydrothermal system, from the least to the most altered. We will start at the outer edge of the alteration system in the propylitic zone and proceed into the sericitic zone and end in the intensely altered rocks of the advanced argillic and silicic zones.

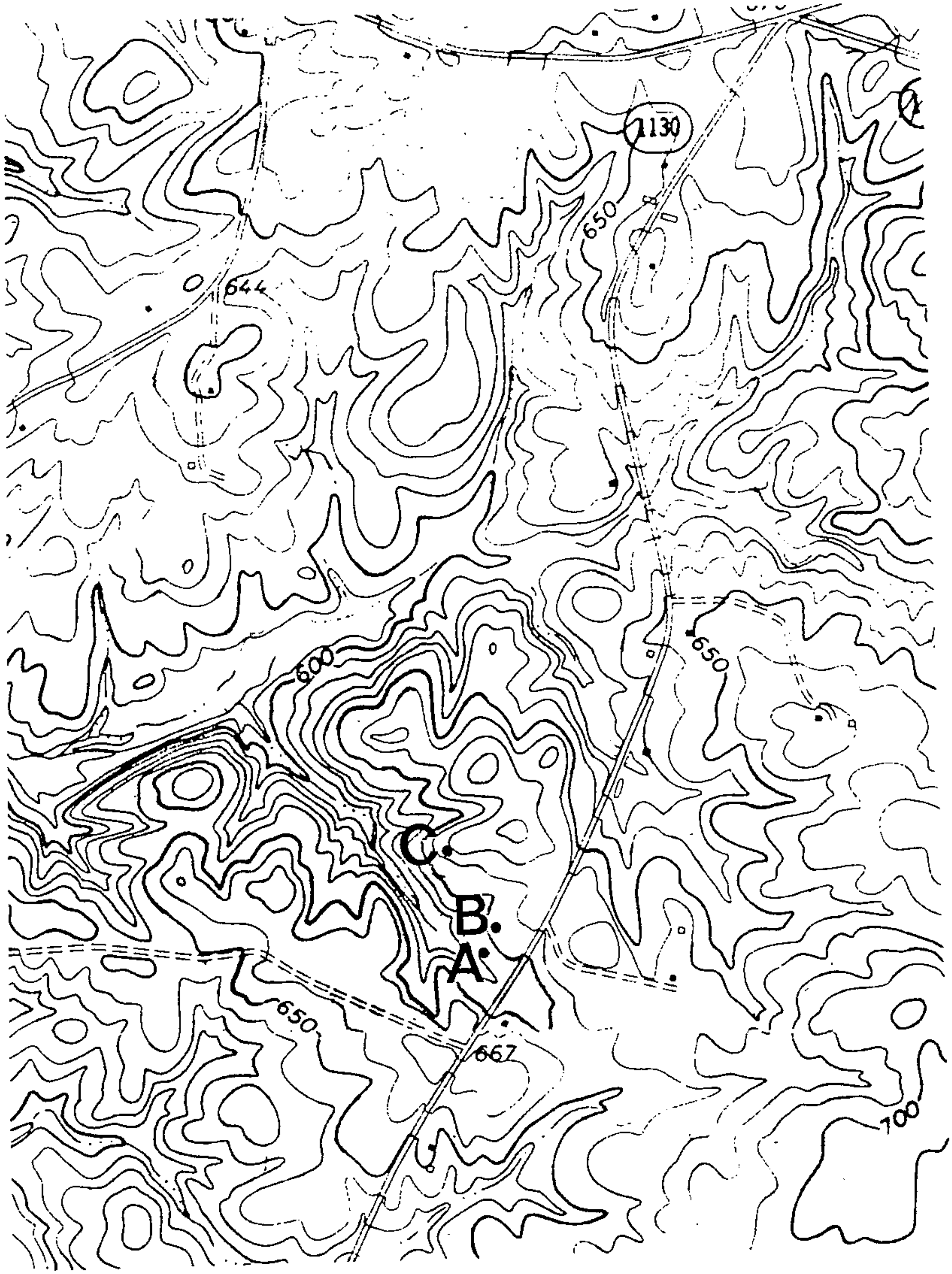


Figure 35: 1:12,000 scale map of specific outcrops to be visited at STOP 22, the Nesbit gold mine. STOPS 22A, 22B, and 22C are referred to in the text.

Stop 22a: Propylitically Altered, Rhyodacitic Crystal-Lapilli Tuff

This outcrop is a non-foliated, moderate-yellowish-green to dusky-green tuff. The tuff contains subhedral to euhedral, yellowish-green, 1 to 3 mm long altered feldspar grains and <2 mm long bluish quartz crystals set in a dusky-green fine-grained matrix rich in chlorite, epidote, calcite, and clay. Minor amounts of biotite, pyrite, and magnetite are also disseminated throughout the matrix. This outcrop is interpreted to be a propylitically altered rhyodacitic crystal-lapilli tuff and not an intermediate to mafic tuff. The reasons are 1) the matrix has been altered to chlorite, epidote, and calcite, 2) most of the feldspar grains have been partially altered to epidote, calcite, muscovite, and quartz, and 3) quartz crystals or grains are present and they are generally rimmed with granular epidote.

Proceeding from Stop 22a to 22b, note the small prospect pit at the base of the hill near the creek. This is a small pyrophyllite prospect pit dug on or near an outcrop of vein quartz. Prospectors would explore for pyrophyllite in areas where metamorphic quartz veins crosscut altered rocks.

Stop 22b: Nesbit Mine

The mine presently consists of three or four shallow pits with very little dump material around the mine. It is located on the interpreted contact between the sericitic and propylitic alteration zones. The material found on the dump usually includes float of sericitic zone rocks (quartz-sericite schist) and propylitic zone rocks (quartz-muscovite-chlorite phyllite). One sample found on the dump contained 5.4 ppm gold and is assumed to be the rock that was mined for gold. The sample is a quartz-muscovite-chlorite phyllite with up to 5% disseminated, 2-4 mm pyrite grains and is mineralogically and geochemically similar to the altered rocks found in the propylitic zone. Drill hole GN-5, which was drilled beneath the mine, intersected a quartz-muscovite-chlorite schist with 3-10% disseminated pyrite grains and 0.39 ppm gold. This sample is mineralogically and geochemically similar to the "ore" sample collected on the dump. The schist in drill hole GN-5 is probably the ore zone of the Nesbit mine.

On the way from stop 22b to stop 22c, walk up the short dirt road after crossing the field. At the end of the dirt road is the location site of drill holes GN-5 and GN-6.

Stop 22c: Advanced Argillic Zone Rocks

The outcrop at Stop 22c is part of the most intensely altered zone in the Nesbit area. The moderate-red to dusky-red rocks consist of fine-grained quartz, muscovite, andalusite, pyrophyllite, and kaolinite. Kaolinite is found only in surface samples and not in the core, implying that kaolinite is a weathering product of pyrophyllite, andalusite, and muscovite. In general, the andalusite and pyrophyllite are fine-grained, although small rosettes of pyrophyllite may be found near small quartz veins that cut through the rocks in this outcrop. Note the net-breccia or stockwork-type texture in places. Also note that primary minerals and textures are not recognizable.

STOPS 23-26

The Brewer Mine

text by

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University of North Carolina at Chapel Hill

Field Trip Leaders:

J.R. Butler, J.M. Stonehouse, D.R. Taylor

Geologic Setting:

This section of the guidebook summarizes the geology of the Carolina slate belt in the region straddling the North Carolina-South Carolina state line, which includes several of the most productive gold mines in the two states (Figure 36). The region is bounded on the west by the Gold Hill-Silver Hill shear zone and on the east by the Coastal Plain overlap. Rocks of the Carolina slate belt occur in two major depositional sequences, a dominantly volcanic lower unit (Uwharrie Formation) and a dominantly sedimentary upper sequence (Albemarle Group) (Figure 25). The rocks are deformed into folds with axes trending northeast and plunging in that direction (Figure 7). The plunge is consistent in most of the area of Figure 36, so that the youngest stratigraphic units are located in the northern part of the area. The plunges are mainly 5o to 10o to the northeast or east-northeast. In northeastern Union and northwestern Anson

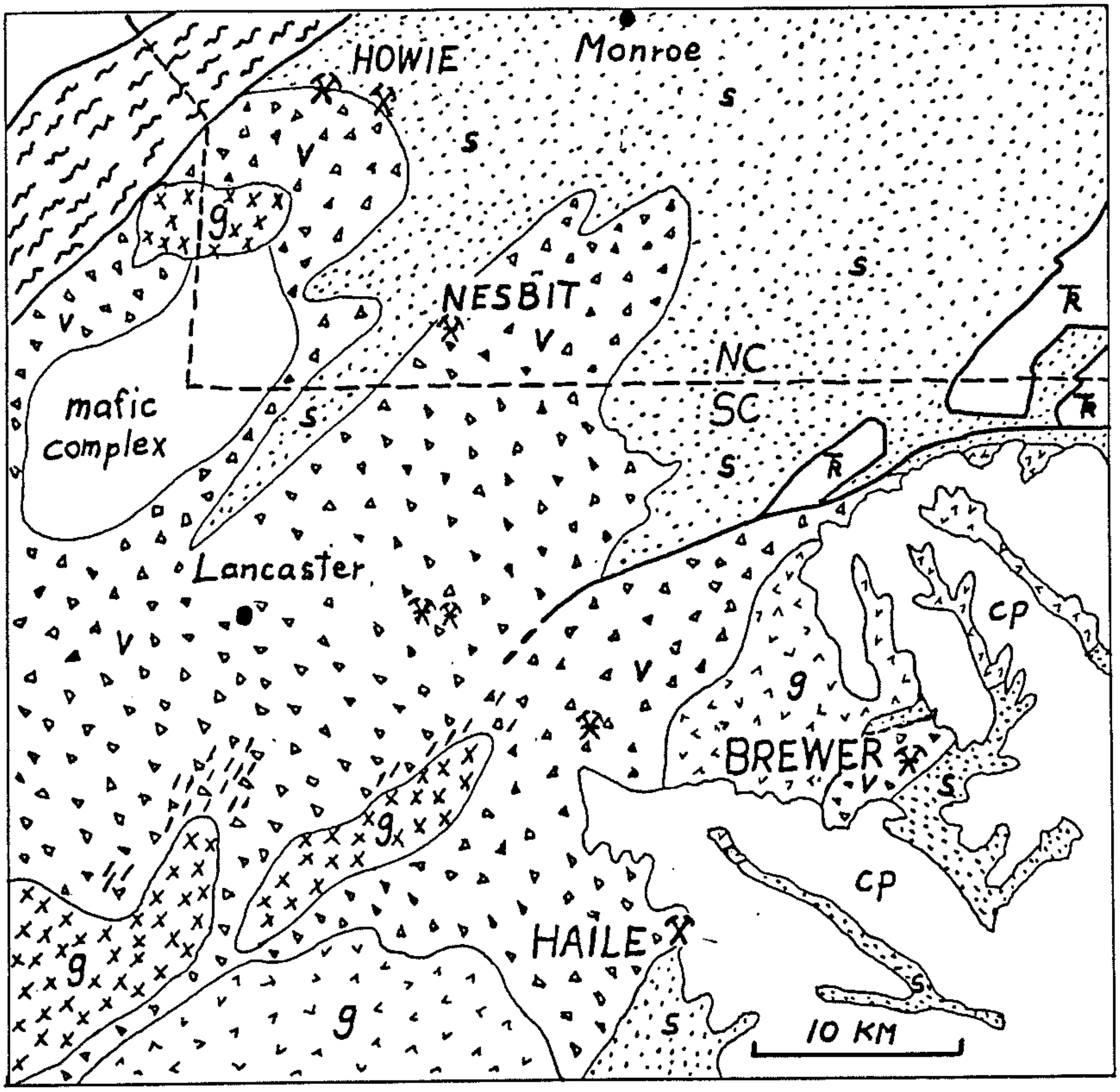

Figure 36: Geologic map of the central Carolina slate belt, South Carolina and North Carolina. Compiled from sources listed in the text. Symbols: V -- metavolcanic rocks (Uwharrie Formation), S -- metasedimentary rocks (Tillery and overlying formations), g -- granite plutons (crosses are Great Falls and older granites), Tr -- Triassic, cp -- Coastal Plain sediments, wavy lines -- Gold Hill-Silver Hill shear zone.

counties, North Carolina, there is a structural depression where the fold hinges are essentially horizontal. Farther northeast, the fold plunge is to the southwest, progressively older beds are exposed, and the Uwharrie Formation appears again in the core of the Troy anticlinorium (Figure 7). In the southwestern part of Figure 36, progressively older units and deeper parts of the volcanic pile are exposed, and intrusive rocks become more abundant. The Great Falls metagranite and related intrusions (Figure 36) may be the intrusive equivalents of felsic volcanic rocks near the top of the Uwharrie Formation.

Rocks of the Carolina slate belt have all been regionally metamorphosed and the metamorphic rank reflects the overall structure. The slate belt rocks in most of the region are chlorite grade, but the grade increases to the southwest, as deeper levels of the sequence are exposed. Biotite appears near Lancaster, South Carolina and sillimanite occurs in eastern Chester County (west of the area in Figure 36). Metamorphic zones are difficult to map in detail, because there are relatively few aluminous rocks in which typical index minerals can form. The increase in metamorphic grade and proportion of intrusive versus volcanic rocks southwestward from Figure 36 marks a transition from the Carolina slate belt into the Charlotte belt. In that region, there appear to be no major structural breaks between the two belts.

The contact between the Uwharrie Formation and the overlying Tillery Formation is a key horizon (Worthington and Kiff, 1970). The dominantly metavolcanic rocks of the Uwharrie (Stop 20) are overlain by the distinctive laminated to thinly bedded meta-mudstone of the Tillery (Stop 21). It is generally an abrupt and conspicuous change that is relatively easy to map, even through the typical landscape of deep weathering and thick vegetation. The change typically takes place over a few meters to a few tens of meters. Because laterally continuous marker units are rare, both above and below this contact, it is prime evidence for the structural pattern shown on Figure 36 and its recognition in the Brewer mine area was crucial to interpretations there, as explained below.

As regional mapping progressed, it became clear that the most productive gold mines in the region are situated along the contact (Figure 36). The Haile mine is the most productive gold mine in the eastern U.S. (Pardee and Park, 1948) and the Howie mine in North Carolina and the Brewer mine in South Carolina are among the main gold producers in their respective states. Several other smaller mines with unknown production, such as the Nesbit (Stop 22), are also located near the contact. The ore zones of the mines all appear to be within a few hundred meters of the contact, usually below it.

The folding and metamorphism of the Carolina slate belt took place in early to middle Paleozoic time. The fold pattern is disrupted mainly by three later events: 1) formation of the Gold Hill-Silver Hill shear zone (Devonian ?), 2) intrusion of the Pageland and other granite plutons about 300 m.y. ago (Pennsylvanian), and 3) formation of the Triassic grabens and associated faults. The location of Stops 23-26 is shown in Figure 37.

Brewer Mine Area:

The Brewer mine workings are located on a prominent, broad hill that rises more than 90 m above the stream valleys of Lynches River and Little Fork Creek. The hill is underlain by resistant siliceous rocks in a huge area of mineralized and hydrothermally altered felsic volcanic rocks and is partly capped by a thin layer of poorly indurated sands and gravels. The sediments are mostly less than 5 m thick and have been called Coastal Plain sediments, but they bear little resemblance either to the loose white sands of the Sandhills or to the reddish, cross-bedded indurated sands and gravels of the Middendorf Formation.

The Brewer mine is located on a northeast-plunging anticline that disappears under the Coastal Plain sediments in the Jefferson area. The axial surface of the anticline is inclined to the southeast, causing the southeast limb to be steep to overturned and the northwest limb to have gentler dips. An axial planar cleavage is ubiquitous in mica-rich rocks; regionally this cleavage dips northeast at moderate angles, typically about 60o. At the Brewer, a key structure is a subsidiary syncline, the Tanyard syncline, that is situated southeast of the axis of the main anticline. The Tanyard syncline is doubly-plunging and therefore has an outcrop pattern that is canoe-shaped. The

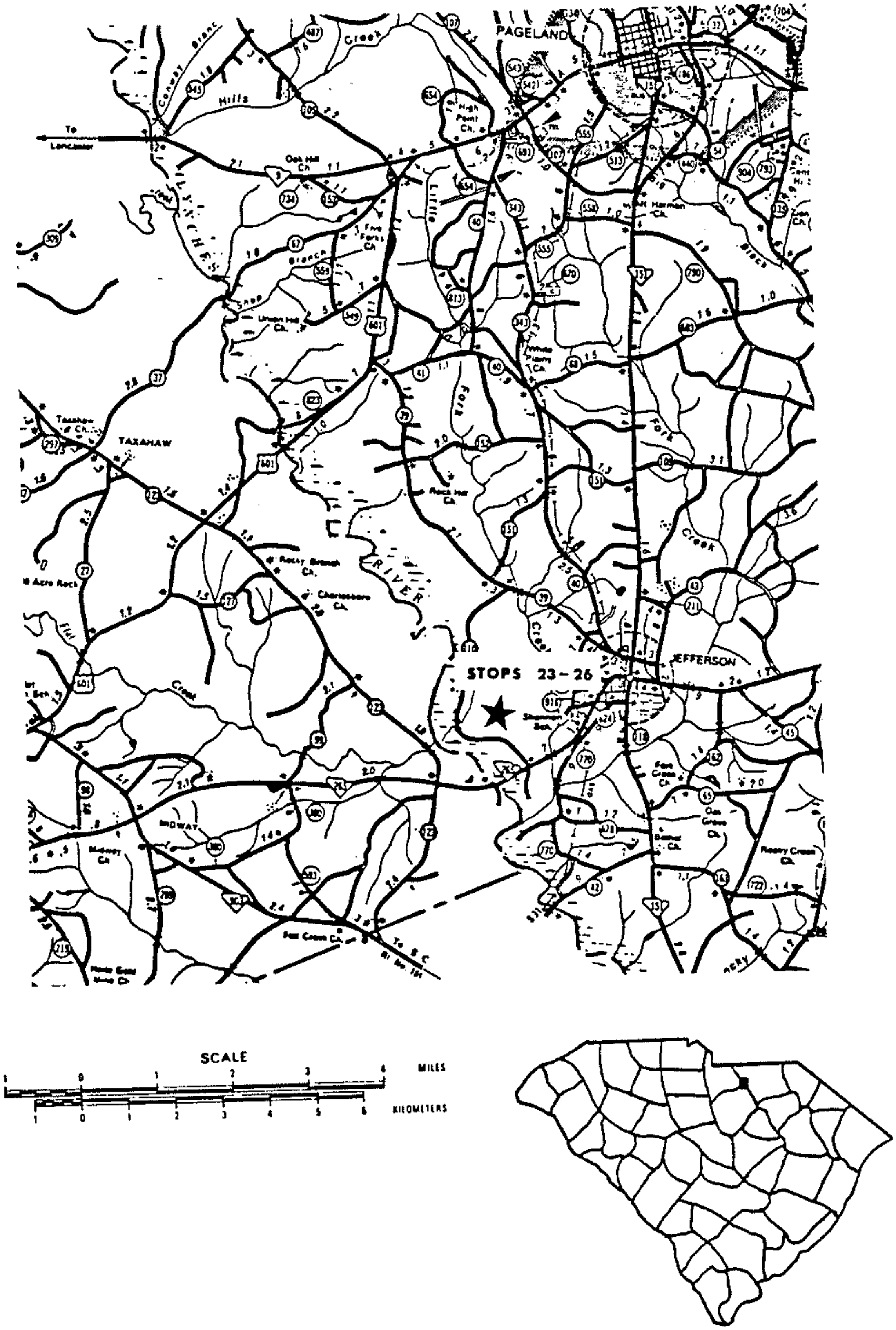

Figure 37: Location map for STOPS 23-26, the Brewer mine, Chesterfield County, South Carolina.

northwestern limb of the anticline is marked by mudstones of the Tillery Formation, just south of the Pageland granite contact. The Pageland granite batholith is one of a chain of plutons in the eastern Piedmont with ages of about 300 m.y. (Fullagar and Butler, 1979). The granite pluton contact-metamorphosed the Tillery and some of the underlying Uwharrie on the northwestern limb of the anticline, but it had no recognizable effect on rocks in the Brewer area.

Previous Work at the Brewer Mine:

Nystrom (1973) mapped the Jefferson 7 1/2-minute quadrangle, which includes the Brewer mine area, and presented a thorough discussion of the geologic setting of the Brewer mine. Regional geology is also described by Bell and others (1974). J.R. Butler (in progress) completed a reconnaissance geologic map of Chesterfield County.

Early descriptions of the Brewer mine are summarized by McCauley and Butler (1966). Geologists of the U.S. Geological Survey have conducted geologic reconnaissance and geochemical sampling in the Brewer area in recent years (Kinkel, 1970; Minard, 1971; Schmidt, 1978, 1985; Bell, 1982, 1984). Part of the work described here was first presented by Cherrywell and Butler (1984). An unpublished manuscript summarizing the oral presentation is available from the authors.

History of the Brewer Mine:

Lieber (1856, p. 60) stated that the Brewer mine was first worked by a miner named Fudge before the Revolutionary War; one of the shafts dug by Fudge was still recognizable at the time of Lieber's survey, more than 75 years later. The object of Fudge's mining is a mystery. The recorded first discovery of gold in the U.S. was in 1799 and the first production in 1801 (Pardee and Park, 1948). Iron was in great demand at the time Fudge was active and some ore in this region was produced from gossans -- so perhaps he was mining iron. Gold was discoverd at the Haile mine in 1827 or 1828 and, at about the same time, at the Brewer; gold was first produced at the Brewer in 1828 (Pardee and Park, 1948).

Mining at the Brewer was most intensive during three main periods - 1844-1862, 1879-1894, and 1934-1940 - although relatively few years have gone by without some prospecting or small-scale mining on the hill. Early references on the Brewer mine are cited and summarized by Pardee and Park (1948) and by McCauley and Butler (1966). After discovery in 1828, there was relatively little activity at the Brewer until 1844, when mining began in earnest (Tuomey, 1848). The owners followed the ruinous practice of leasing small plots to be mined on shares. A plot twelve feet (3.7 m) square was rented to one or more persons who paid 25 to 30% of the earnings to the owners (Tuomey, 1848). In 1844 and 1845, between 100 and 200 persons were continuously active at the mine. By the time of Lieber's visit in 1856,

"...every branch, bed, gulch, ravine or even declivity of the main hill, has been washed and rewashed," and "...the whole surface is torn up in the most extraordinary manner" (Lieber, 1856, p. 67). The main placer activity during this period was probably in the Tanyard placer, the West placer, and along the small stream below the Tanyard. Some of the lode deposit was mined from 1857 to 1862 and crushed in primitive arrastras and Chilean mills (Nitze and Wilkens, 1897, p. 145). The site of this activity is not well-known, but it may have included pits and shallow shafts near the present Hilford and Brewer pits. Activity declined because of the Civil War and was not renewed on a large scale until 1879.

Mining by hydraulic methods began in 1879 (Nitze and Wilkens, 1897). In the hydraulic mining, jets of water under high pressure washed loosely consolidated material of the "Coastal Plain" sediments and weathered parts of the altered volcanic rocks into sluiceboxes, where the gold was recovered. A five-stamp mill was built in 1885 and it was enlarged into a forty-stamp mill in 1888. In 1887, an adit (the present "drainage tunnel" at the bottom of the Brewer pit) was driven westward 320 m into the hillside under the main ore zone; the mine was opened from below by a raise, connected to the open-pit above (Nitze and Wilkens, 1897). These workings were enlarged to become the present Brewer pit. Narrow-gauge track was laid in the tunnel and ore was hauled to the mill by a small locomotive. The forty-stamp mill was located on Little Fork Creek, downstream from the lower portal of the tunnel. There is no recognizable dump of material from the Brewer pit; essentially all of it was taken out through the tunnel and milled. Nitze and Wilkens (1897) reported a considerable loss of gold into the tailings; concentrates from the mill ran $15 to $20 per ton and total cost of the operation averaged $1 per ton. A chlorination plant for removal of the gold by the Thies process was built in 1892 and operated for a short time in 1893 (Nitze and Wilkens, 1897, p. 145). Problems with tailings from the plant led to damage suits that were partly a cause of the mill being shut down (Graton, 1906, p. 90).

From 1894 until about 1934, the Brewer was worked sporadically on a relatively small scale. In 1904, the mine was being worked by a force of only six men, with the ore crushed in a ten-stamp mill (Graton, 1906, p. 90).

With the increase in the price of gold in 1934, mining activity increased at the Brewer and continued until 1940. In 1935, H.J. Hartman was operating a ten-stamp mill adjacent to what is now called the Hartman pit (Pardee and Park, 1948); most of the excavation of this pit probably dates from the 1934-1940 period. The U.S. Bureau of Mines reported production of placer gold from the Brewer in 1938, 1939, and 1940.

Quartz-rich rocks at the Brewer contain variable amounts of topaz. Topaz locally forms a massive, fine-grained, chert-like rock, and is widely distributed as fine, disseminated grains. The topaz is difficult to distinguish from quartz in hand specimens; it was tentatively identified by Graton (1906, p.90) but not positively identified until about 1935 (Pardee and others, 1937; Pardee and Park, 1948). In 1939 and the 1940's, the U.S. Bureau of Mines, Tennessee Valley Authority, and private companies investigated the Brewer deposit as a source of topaz for making mullite, calcium fluoride, and other products (Fries, 1942). In 1950-1951, the U.S. Bureau of Mines conducted an extensive drilling program to evaluate the topaz resources (Peyton and Lynch, 1953). The topaz pit is mainly a result of attempts to mine and beneficiate the topaz. Massive topaz is most abundant in the vicinity of the topaz pit and in a zone extending about 900 m northwest of the pit. Pardee and others (1937) reported massive zones of topaz as much as eight meters across.

Several companies have explored the Brewer area in the last 25 years. Within the last few years, Nicor Mineral Ventures and Newport Minerals Company have conducted extensive exploration and testing programs, including drilling and heap-leaching.

Total known gold production at the Brewer mine is about 22,000 ounces, which is 7% of the gold production in South Carolina. There was probably much unrecorded early production from placers, which is difficult to estimate.

Map Units:

Most of the Brewer mine is underlain by silicified, altered, and mineralized rocks derived mainly from felsic tuffs and flows of the upper part of the metavolcanic sequence (Uwharrie Formation). No unaltered metavolcanic rocks are seen in the mine area. About 1500 m north of the Brewer pit, there are felsic metavolcanic rocks that do not appear to be hydrothermally altered, but they are contact-metamorphosed by the Pageland batholith. The most abundant rock is massive, fine-grained, light-colored siliceous rock (quartz granofels of Carpenter and Allard, 1982) that is typically composed of more than 90% quartz. This is the main rock in the Brewer, Hartman, and Hilford pits. The rock is called siliceous aphanite where it is aphanitic and granofels where it is phaneritic. Normally, no structures are discernible in the rock, but in some places it is clearly a siliceous breccia. The breccia is best seen in the Brewer pit.

The siliceous aphanite grades outward from the mine area into sericite-quartz phyllite. All gradations can be found from nearly pure quartz to nearly pure sericite. The degree of development of slaty cleavage depends on the percentage of sericite; sericite-rich rocks have well-developed cleavage. According to Nystrom (1973), the siliceous rock underlies a nearly circular area about 2 km in diameter. The amount of pyrite in the siliceous rock and phyllite ranges widely; locally a zone of gossan developed from massive pyrite can be mapped.

Also, there are mappable zones of pyrophyllite schist. Overlying the siliceous rock and sericite phyllite is a sequence of metamorphosed siliceous sediments that is mostly laminated to thickly bedded conglomerate, sandstone, amd siltstone. The unit also includes several rocks that are critical evidence of the nature of the Brewer alteration system. The pebbly siliceous rock of this unit is the best marker bed in the Brewer system; it defines the pattern of the Tanyard syncline. The pebbly rock has well-rounded pebbles of fine-grained siliceous rock in a matrix of smaller clasts, quartz grains, and sericite. In both hand specimen and thin section, the pebbles are similar to the underlying siliceous aphanite. This is interpreted as evidence that silicification (and mineralization) took place before deposition of the mudstone of the Tillery Formation. The pebbly rock is probably part of an apron of debris formed by subaerial erosion of the upper part of the Brewer system. It is 2 to 5 m thick and is especially well exposed at the western end of the Tanyard syncline. Pardee and Park (1948, Plate 30) mapped four "beds" of quartz rock and silicified tuff; two of the beds are the pebbly rock repeated by folding.

In the northeastern corner of the Tanyard placer, the pebbly rock is overlain by a distinctive rock interpreted to be siliceous sinter (Figure 38). The rock occurs in layers 1 to 3 cm thick in which delicate rod-like structures are preserved. The siliceous sedimentary unit and the sinter are overlain by argillite, mainly laminated to thinly layered meta-mudstone. The

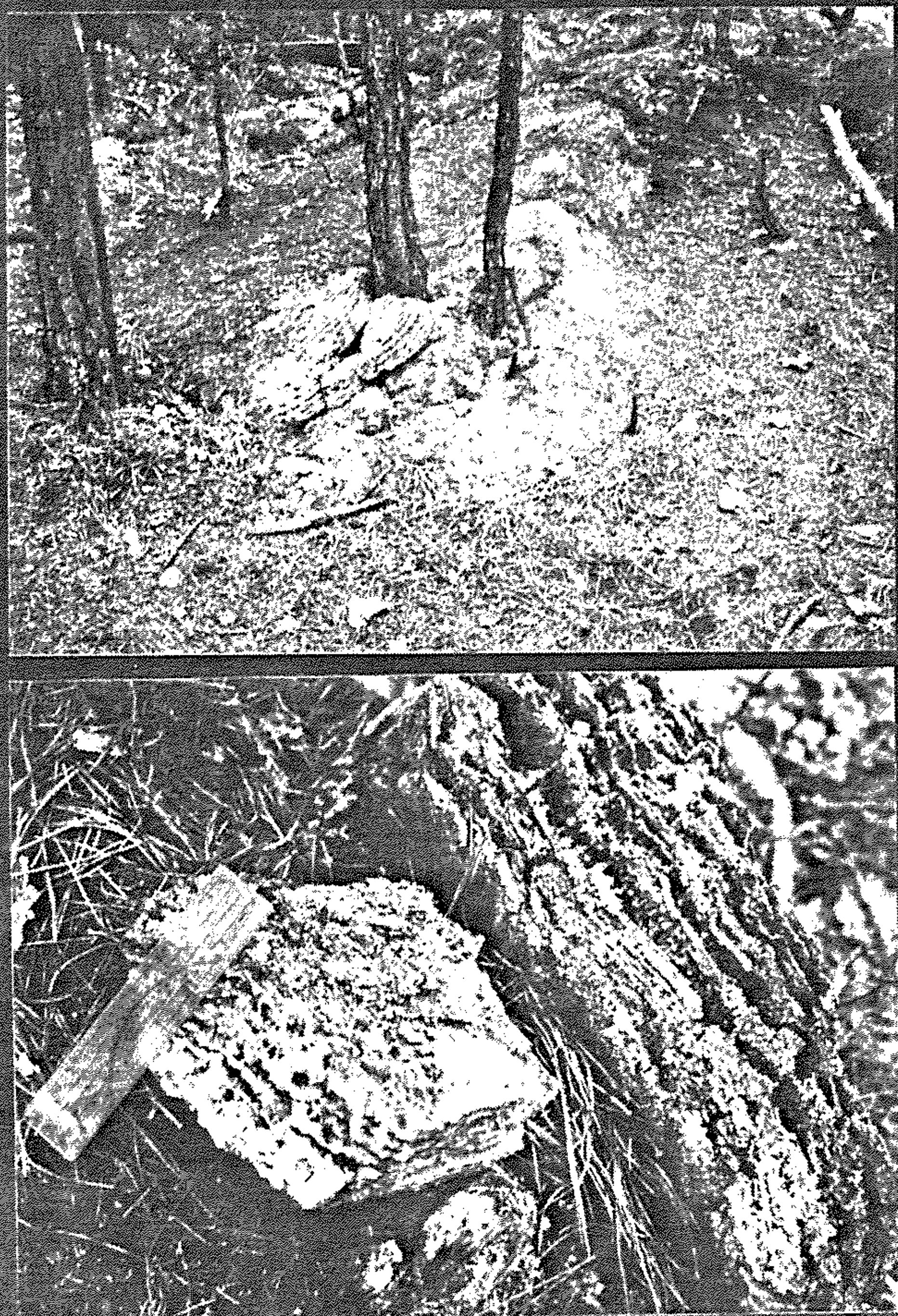

Figure 38: Photographs of sinter, Tanyard pit, Brewer gold mine, Chesterfield County, South Carolina. Photographs by C.H. Cherrywell. Top: Outcrop of sinter. Bottom: Close-up of sinter. Plastic scale is 15 cm.

lower part of the argillite may be slightly altered and mineralized (weathering makes it difficult to be certain), but the argillite in the core of the Tanyard syncline shows no evidence of silicification, alteration, or mineralization. The Brewer alteration system had expired before the mudstones of the Tillery Formation spread across the region in an environment of quiet marine deposition.

Three oval-shaped areas of siliceous breccias are mapped as breccia pipes, two west of the mine road and one along the road. The two west of the road form prominent outcrops surrounded by areas of very poor outcrop. Along the contacts of both, boulders of nearly pure pyrophyllite occur. The bodies are interpreted to be pipes of strongly silicified breccia, with zones of argillic alteration (metamorphosed to pyrophyllite) along the contacts. The area of breccia along the mine road is even less obviously a breccia pipe. It is clearly a siliceous breccia and is more intensely altered than the other two, but the contacts are harder to map.

The surficial materials are here shown as colluvium, rather than as "Coastal Plain sediments." They appear to be mainly locally derived, are probably nowhere thicker than 5 m, and are less consolidated and less obviously bedded than the Middendorf Formation in nearby areas. Just south of the Tanyard pit is an area of iron-oxide-cemented conglomerate and sandstone that was partly removed by hydraulic mining; this unit possibly can be correlated with nearby Coastal Plain sediments.

Structure:

The map pattern and attitudes of bedding and cleavage indicate that the structure south of the Hartman pit is a syncline-anticline pair (Figure 39). North of the Hartman pit there are no exposures showing bedding in the mine area, so surface control on structure is inadequate to draw fold hinges. The map by Pardee and Park (1948, Plate 30) shows dip reversals that define the Tanyard syncline, but they did little structural interpretation. No previously published map extends west of the mine road. The mining area here called the West placer was rediscovered during the early stages of the present mapping project. It is a pock-marked area of small pits a few meters across with adjacent waste piles, apparently the squares described by Tuomey (1848), and was not disturbed by later operations. If that is true, perhaps Pardee and Park did not map the West placer because it had been inactive for many years. The West placer area provides some of the best evidence for the Tanyard syncline. Unsilicified and unaltered argillite crops out at several places along the stream and the pebbly siliceous rock can be traced around the hinge of the syncline.

Slaty cleavage in the Brewer area is well developed in rocks with a significant mica content, but is commonly not discernible in the siliceous aphanite and granofels. The cleavage normally strikes northeast to east-northeast and dips 40 to 60 degrees to the northwest. At many locations in the region, the slaty cleavage is seen to be axial planar to mesoscopic folds, therefore it is interpreted to be axial planar in the Brewer area. Bedding-cleavage relations in the mine area are consistent with this interpretation. Axial surfaces of folds are inclined to the southeast, making southeastern limbs of anticlines steep to over-turned and the northwest limbs more gently dipping. Bedding-cleavage relations and graded bedding in outcrops and drill cores near the gate at the base of the hill indicate that the fold limb in that area is locally overturned. The fold pattern is consistent with that in the Haile mine area (Bell, 1980), 13 km to the southwest, and that farther north and northeast in Chesterfield County (J.R. Butler, unpub. map).

Pardee and Park (1948) describe small-scale faults and probably fault breccia in and near the Brewer pit, but did not show faults on their map (Plate 30). Faults are probably important in the mine area, but none could be deciphered during the surface mapping.

Mineralogy and Petrology:

Alteration and metamorphism have obliterated the original textures in most of the rocks. Regional metamorphism is at chlorite grade. Quartz-rich rocks mainly have fine granoblastic texture, and the phyllitic rocks lepidoblastic texture. Both were probably extensively recrystallized during metamorphism. The quartz-rich rocks contain various amounts of topaz and pyrite. A number of other minerals are reported from the ore zones: native gold, enargite, bismuth ochre (bismite), native

Figure 39. Geologic map of the Brewer gold mine area, Chesterfield County, S.C.

EXPLANATION

Qal	Quaternary alluvium
cg	Iron-oxide cemented gravel and sand
co	Colluvium and other surficial deposits
vq	Vein quartz
as	Argillite and siliceous metasedimentary rocks, undivided ar- argillite ts- siliceous metasedimentary rocks
ls	Layered siliceous sinter
ps	Pebbly siliceous rock
g	Gossan; weathered massive pyrite and quartz
si	Massive siliceous rock; quartz granofels and aphanite
pm	Pyrophyllite- and sericite-rich rocks
qp	Sericite-quartz phyllite and schist

Mineral localities

- • P Pyrophyllite
- • K Kyanite
- • D Dickite

Symbols

- Mine waste, tailings
- Edge of pit
- Edge of fill
- Breccia
- 45 Bedding
- 50 Slaty cleavage

Field Trip Stops

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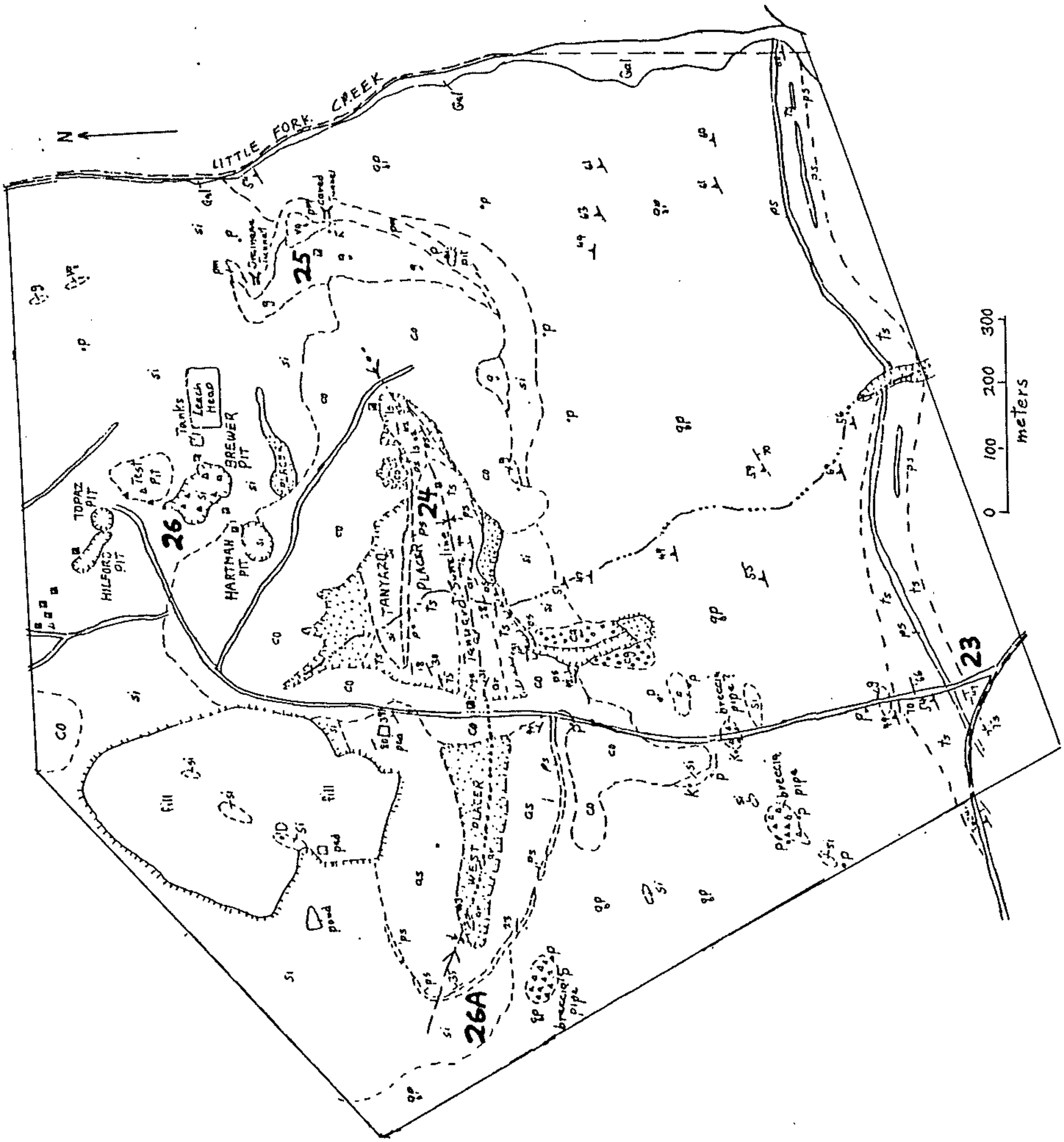
N
LITTLE FORK CREEK
TOPAZ PIT
HILFORD PIT
HARTMAN PIT
BREWER PIT
Tanks
Leach Heap
Test Pit
TANYAZO PLACER
WEST PLACER
breccia pipe
fill
pond
26
25
24
23
26A
0
100
200
300
meters

bismuth, cassiterite, covellite, chalcanthite, sulfur, andalusite, kyanite, chalcopyrite, ilmenite, and rutile (McCauley and Butler, 1966, and earlier references). In recent years, probable tellurides (Bell and Larson, 1984), dickite (Henry Bell, pers. comm.), and diaspore (Schmidt, 1985) have been reported. In the ledges of siliceous rocks away from the ore zones, Pardee and Park (1948) found epidote, iron oxides, chloritoid, zoisite, rutile, feldspar, and zircon. The phyllitic rocks are mostly sericite, quartz, and pyrite; locally they are rich in pyrophyllite. During the present study, andalusite was confirmed by X-ray diffraction in samples from the vicinity of the Tanyard pit. Kyanite was observed at many localities and is especially abundant in the gossan unit east of the Tanyard pit. It is difficult to be certain which minerals are relict from the hydrothermal alteration and which are due to regional metamorphism. Topaz and most of the quartz are interpreted to be due to the hydrothermal alteration, although the quartz is extensively recrystallized. The kyanite and at least part of the pyrophyllite are considered to be metamorphic. No biotite is seen in the mine area, but it occurs to the north in the contact-metamorphic aureole of the Pageland batholith. The distribution of biotite indicates that contact metamorphism in the mine area was no higher than chlorite grade, and no textural or mineralogical changes can be attributed to it. Also, K-Ar dates on muscovite from the Brewer tunnel were not reset by contact metamorphism (Bell and others, 1972). On the other hand, intrusion of such a large body of magma so near to the Brewer must have caused at least some increase in temperature and extensive movement of fluids through a large volume of rock for a very long time. Geologic relations at the Brewer indicate that the pre-argillic hydrothermal system was extinct long before the intrusion of the granite, but re-mobilization of some materials cannot be ruled out.

Quartz veins are common in the Brewer area, as in most other parts of the Carolina slate belt. Coarse vein quartz is especially abundant in the Tanyard pit. Regionally, quartz veins are observed to be concentrated near the Uhwarrie-Tillery contact, which explains their abundance in the pit. The quartz veins are dominantly coarse milky quartz, but locally contain limonite or pyrophyllite. Pyrite is rare in the veins and they apparently do not contain significant gold, judging from a few assays and the lack of interest by miners. The quartz veins are interpreted to be mainly or entirely due to regional metamorphism.

Discussion:

The evidence presented here indicates that the Brewer mine area is a large, near-surface hydrothermal system at the top of the Uwharrie Formation that was extinct before the deposition of the overlying Tillery Formation. The main area of mineralization was possibly localized by one or more large breccia pipes, but silicification destroyed much of the textural evidence. The system was capped by a thin but extensive layer of conglomeratic debris now seen as the pebbly siliceous rock, and siliceous sinter is locally preserved. The gold mineralization is mainly (exclusively ?) in the central, intensively silicified core. Advanced argillic alteration developed as patches within the main silicified zone and peripheral to it. Massive pyrite was deposited adjacent to the main silicified zone at depths of 30 to 200 m below the paleosurface and above a prominent zone of advanced argillic alteration; these units may have been stratigraphically controlled. Laterally and downward, the rocks grade into sericite schist, metamorphosed from a very extensive zone of sericitic alteration whose boundaries are still poorly known. Spence and others (1980) developed a hot-spring exhalative model for gold mineralization at the Haile mine and Worthington and others (1980) applied this model to the Brewer mine. The evidence described here is in agreement with the hot-spring model. Schmidt (1985) tentatively classified the Brewer as a porphyry gold system and suggested that it represented a moderately deep level of erosion into the system. If the "sinter" in the northeastern part of the Tanyard pit is indeed a siliceous sinter deposited at the top of the Brewer system, then the level of erosion is not as deep within the system as Schmidt suggested. Much more detailed work is necessary before the system can be adequately described and interpreted.

Field Guide to the Brewer Mine:

General Statement - The vehicles will stop near the gate at the entrance to the Brewer mine. The first stop is a few meters north of the gate. The locations of main interest are shown on Figure 39 and are described below. This guide emphasizes the surface geology, especially as it pertains to the sequence of events and interpretation of the environment of deposition. The guide begins at the top of the Brewer system in a peripheral area and proceeds downward, then goes back to the top of the main system in the Tanyard pit and again proceeds downward. Most of the information from the drill cores and the gold analyses and assays are still restricted information.

Stop 23 - The first outcrop along the road north of the gate is pebbly siliceous rock. This is the top of the Uhwarrie Formation and the top of the Brewer hydrothermal system. Bedding, including graded bedding, indicates that the average dip is about 60o southeast and that the tops are to the southeast. Thinly-bedded argillite above the pebbly rock is poorly exposed in the drainage ditch just downhill from the pebbly rock and west of the gate. The beds on the limb of the fold are locally vertical to overturned, as seen in the cores and in outcrops along the paved road west of the gate. From the first outcrop, we will proceed uphill (down-section) through sericitically altered rocks and some intensely silicified rocks. About 40 m north of the pebbly rock, there is an iron-oxide-rich rock with rectangular lighter patches as much as 5 cm across; in thin section, the patches have some relict kyanite grains. This rock is the intensely weathered equivalent of the massive pyrite and pyrite-kyanite rock that outcrops south and east of the Tanyard pit (mapped as "gossan" in that area). Below the iron-oxide-rich rock is some pyrophyllite-rich schist and much strongly sericitized schist. Near the top of the hill, the road crosses an area of breccia interpreted to be a mineralized pipe. Farther north, the road traverses the fold limb into the core of the Tanyard syncline. Just north of the lone oak tree beside the road, a side road to the east goes across the Tanyard pit. The West placer is in the wooded area along the stream valley west of the lone oak tree.

Stop 24 - The Tanyard pit is the probable site of discovery of gold at the Brewer and the main workings until the lodes were discovered. Most of the pit area is severely disturbed, but several outcrops in the roads and gullies are critical to interpretations described here. In the eastern part of the pit, siliceous sediments and the overlying argillite can be seen. The metaconglomerate, with siliceous clasts probably derived from the silicified zones to the north, is interbedded with finer-grained sediments and micaceous beds. A wide range of bedding attitudes and exposed small folds indicate that subsidiary folds are developed in the Tanyard syncline.

In the northeastern corner of the Tanyard pit, there are several low mounds in which bedded siliceous sinter is exposed. **PLEASE DO NOT HAMMER ON THE SINTER OR REMOVE PIECES OF IT.** The sinter is thinly layered and composed mostly of quartz and kaolinite. As we are near the unconformity below the "Coastal Plain sediments," these rocks have been exposed to intense chemical weathering in the Cretaceous-Tertiary and in the Recent. It is hard to decipher the mineralogy of alteration versus metamorphism versus weathering. Kaolinite could be produced by any one of the processes. The sinter shows remarkable preservation of delicate structures. Layering in the sinter defines an open syncline, as recognized by Pardee and Park (1948). The sinter apparently was protected from strong deformation by the huge mass of siliceous rock that it overlies and from replacement and recrystallization by its simple mineralogy. Just southeast of the sinter along the edge of the pit are exposures of the pebbly siliceous rock, which underlies the sinter. Proceeding to the east, one climbs from the pit onto a flat area underlain by colluvium or "Coastal Plain sediments."

Stop 25 - On the steep upper slopes of the Little Fork Creek valley, the gossan unit is fairly well exposed. It is underlain by a poorly exposed unit mostly expressed by scattered float of nearly pure pyrophyllite schist. The schist is exposed in a pit south of this locality. It probably grades downward into nearly pure sericite schist that is exposed at the lower portal of the drainage tunnel from the Brewer pit. The gossan is the result of weathering of a pyrite-rich unit that grades from massive pyrite to disseminated pyrite in siliceous rock. Kyanite appears near the middle of the unit and increases in percentage downward. Near the bottom of the main outcrops is a spectacular kyanite-pyrite rock. From this stop we will follow the road back toward the west to the Brewer pit.

Stop 26 - The Brewer pit is the best place to see siliceous breccia with pyrite, enargite, and native gold, but it is dangerous. **PLEASE USE EXTREME CAUTION IN AN AROUND THE BREWER AND OTHER PITS.** A steep trail near the north end of the pit goes part way down. Do not attempt to climb all the way to the bottom without climbing equipment. Near the top of the pit, the walls are made of a friable sandy material that, with slight pressure, crumbles into a white sand (Pardee and Park, 1948). The white sandy material contains free gold and constituted the main ore in some of the early workings. Farther down, the walls of the pit are hard gray quartz aphanite and granofels with disseminated grains and local patches of pyrite and enargite. A breccia texture is obvious in many parts of the pit. The clasts are white to medium gray, massive, fine-grained quartz; some have "eyes" of glassy quartz, but relict textures are rare. Many samples of free gold have been taken from the pit and we will probably find some more.

Until gold assays from recent exploration and development are made available, the estimates of ore grade must depend on published reports. By far the largest volume of lode ore was produced from the Brewer pit. Nitze and Wilkens (1897, p. 144) reported that the better grades of ore from the Brewer pit assayed about 0.25 to 0.35 oz./ton and the average ore assayed about 0.15 oz./ton. At the time of Graton's survey, the average grade of ore being mined also assayed about 0.15 oz./ton (Graton, 1906, p. 92). Assays of samples collected by Pardee and Park (1948, p. 110-111), Kinkel (1970, p. 5), and Minard (1971, p. 9) had the following gold values: Brewer pit, 0.045 to 0.36 oz./ton; Hartman pit, 0.01 to 0.06 oz./ton; and Topaz pit, 0.017 to 0.12 oz./ton.

Near the Topaz pit is the best place to collect samples of the distinctive gray, massive topaz. The connection, if any, between topaz and gold mineralization is not known. Pardee and Park (1948) concluded that gold and sulfide minerals were deposited after the development of the sericite schists; the mineralization was followed by formation of the barren quartz veins and the development of topaz. Fries (1942, p. 66) reported that "irregular topaz veinlets half an inch thick cut across the foliation" and that narrow veinlets of white quartz cut the massive topaz rock (p. 67). Many of the pits and shafts appear to be located near but not within the main areas of massive topaz. The tentative conclusion here is that topaz formation postdates main pyrite-gold mineralization, but predates regional metamorphism.

Stop 26a - If time permits, we will walk from the mine road westward through the woods to the western end of the Tanyard syncline. The pebbly siliceous rock forms prominent, nearly continuous outcrops that define the hinge of the syncline. Unaltered argillite crops out in the small stream just east of the fold nose and quartz-topaz-pyrite aphanite about 50 m west of (stratigraphically below) the pebbly rock. An oval area of siliceous breccia south of the hinge is mapped as a pipe. This pipe is considered a small-scale analog of the main Brewer system; there is a central area of intensely silicified breccia bounded by a narrow zone of pyrophyllite schist (advanced argillic alteration) which grades outward into an extensive zone of sericite schist (sericitic alteration). The pebbly rock must have been only a few tens of meters above this level. In contrast to the larger system, there is little pyrite or gold mineralization in the pipe.

This ends our visit to the Brewer mine area.

From the Brewer mine, we proceed to Lancaster, South Carolina for the night. For the first few kilometers, the hills are capped by Coastal Plain sediments and the valleys are in slate belt rocks or granites. After the last Coastal Plain outlier, the highway crosses a thick section of felsic to intermediate metavolcanic rocks. Metamorphic grade increases westward, from chlorite zone to upper biotite zone at Lancaster. Granite intrusions appear west of Lancaster and the metamorphic grade rises to sillimanite in eastern Chester County, thirty kilometers west of Lancaster. Metavolcanic units can be traced from the Carolina slate belt into the Charlotte belt without a major structural break.

DAY 4

On the final day of the field trip we will cross from the Carolina Slate belt into the Kings Mountain belt to look at a high grade equivalent of the advanced argillic alteration seen at Snow Camp, Glendon, and Pilot Mountain and to see, as well, a stratabound barite deposit. Lancaster, South Carolina where we will spend Saturday night, is at the western margin of the Carolina Slate belt. We drive west from Lancaster, crossing almost immediately into the Charlotte belt. We cross the Catawba River and drive north through York, South Carolina. About 10 km northwest of York, we enter the Kings Mountain belt. We cross the Kings Mountain shear zone and are in the "eastern facies," the Battleground Formation of Horton (1984). The most characteristic feature of the Kings Mountain belt in this area is the appearance of prominent monadnocks, which rise as much as 250 m above the Piedmont surface. These monadnocks are held up by quartz-kyanite rock. Figure 40 is a location map for the two stops in the Kings Mountain belt.

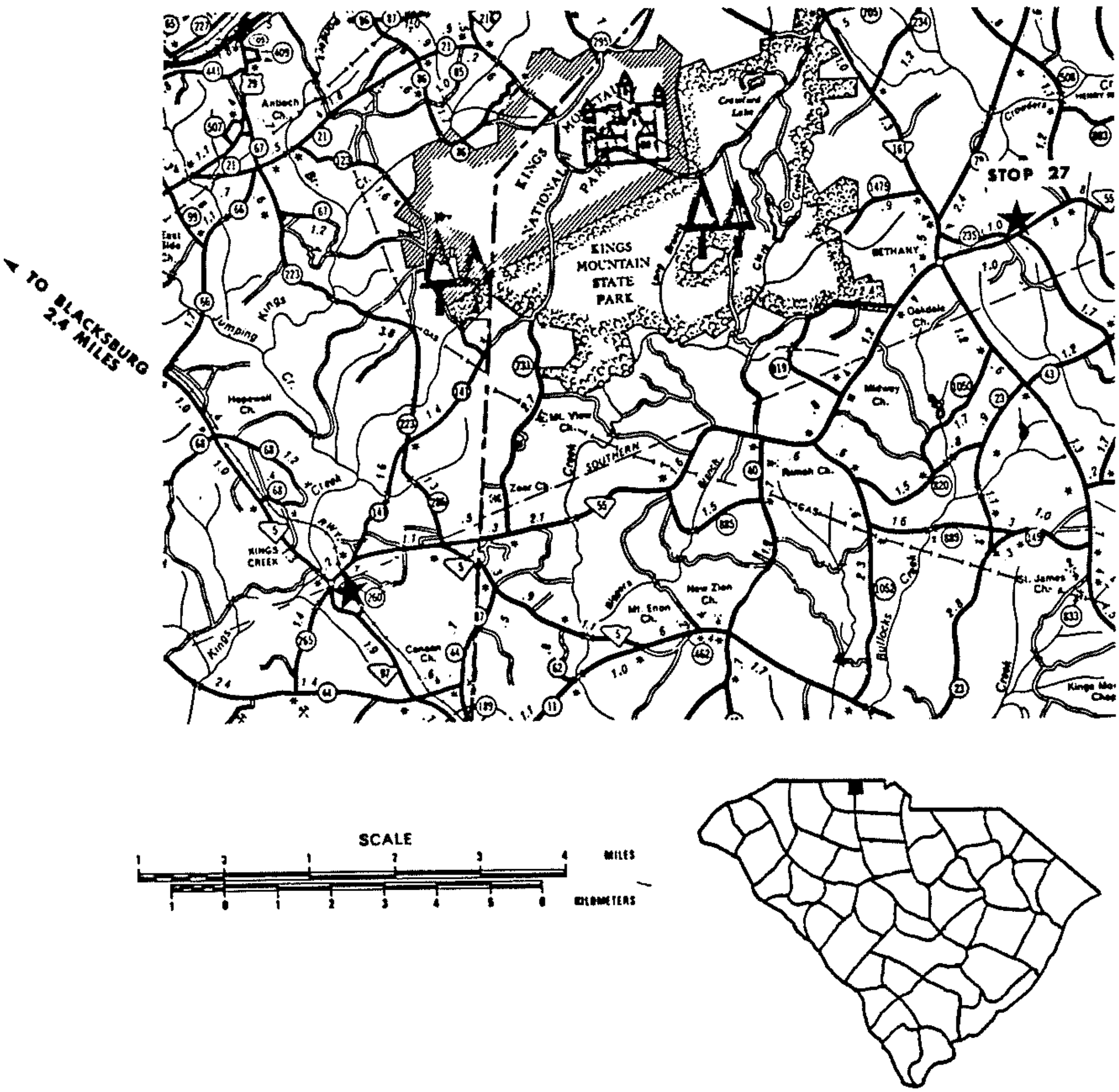

Figure 40: Location map for STOP 27, Henry Knob kyanite deposit, York County, and STOP 28, Kings Creek barite deposit, Cherokee County, South Carolina

STOP 27

Henry Knob Kyanite Deposit

by

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Henry Knob is one of a half-dozen kyanite deposits in a district that runs from about 6.5 km north of the North Carolina-South Carolina state line to Henry Knob, which is the southernmost of the deposits. The deposits include Crowders Mountain, The Pinnacle, and the Will Knox, Shelton, and Ryan-Purcley properties in North Carolina and Henry Knob, South Carolina. The geology of the district has been described by Keith and Sterrett (1931), Kesler (1955), and Horton (1981). A number of important studies of the alumino-silicate-rich rocks are available, including, in addition to the references above, Espenshade and Potter (1960). Most of the discussion below is based on the work of Espenshade and Potter (1960) with input from Butler and Horton (pers. comm., 1985).

As shown in Figure 41, the Henry Knob deposit is one of a linear set of deposits whose location is controlled by major, northeast plunging folds. The westernmost fold, in the vicinity of The Pinnacle, is an overturned syncline, the Sherrars Gap synform, with a northwest dipping axial surface. The eastern fold, the South Fork antiform, appears to control the location of the Henry Knob occurrence as well as a number of other kyanite

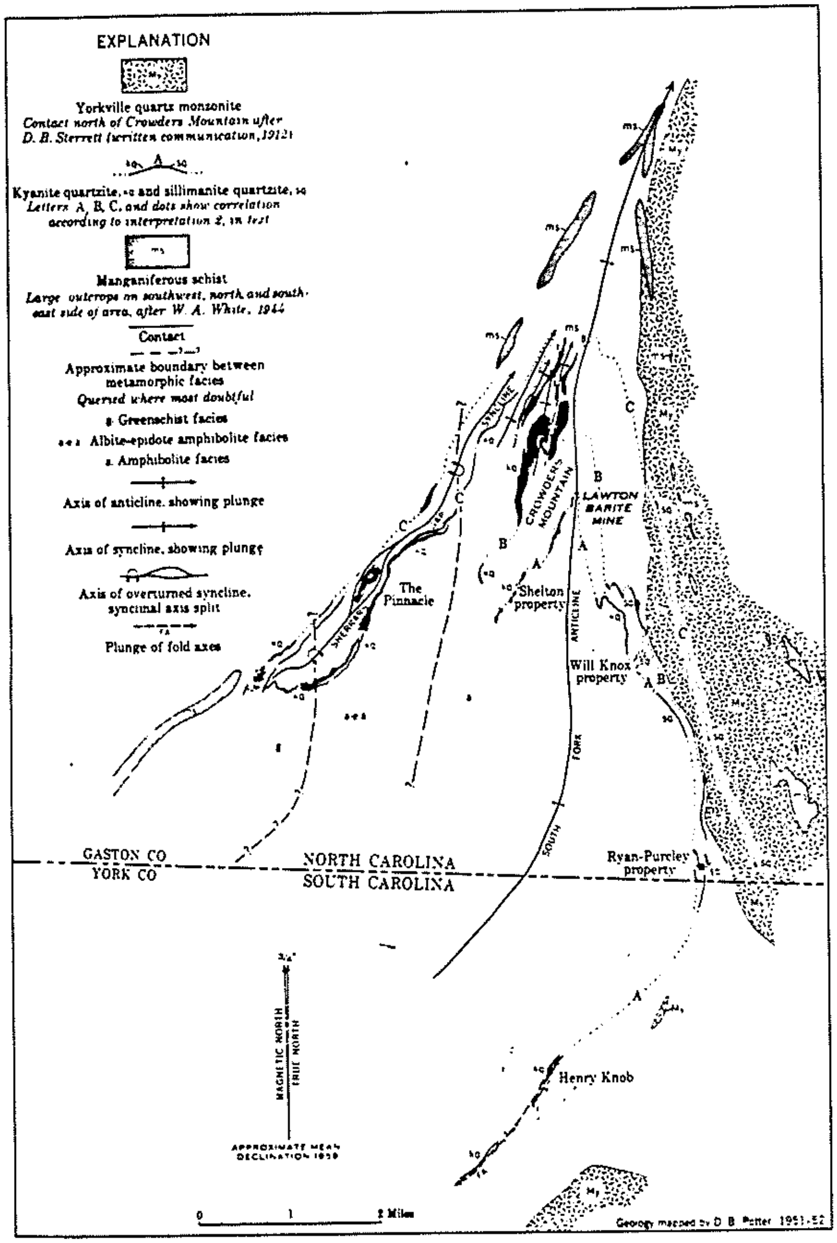

Figure 41: Regional distribution of the "kyanite quartzite" and associated mineralized rocks in the Crowders Mountain-Henry Knob area of the Kings Mountain belt. From Espenshade and Potter, 1960, p. 67.

occurrences to the north. The general strike of the Henry Knob kyanite body is parallel to the inferred axis of the South Fork anticline and to the N30oE attitude of the S_1 cleavage in the surrounding schists (Horton and Butler, pers. comm., 1985).

Henry Knob itself stands 100 m above the surrounding countryside. The host rocks of the Henry Knob kyanite deposit are quartz-sericite schists of the Battleground Formation (Horton, 1984). Horton describes these quartz-sericite rocks as overlying dacitic to andesitic metavolcanic rocks in the lower part of the Battleground Formation. In general, the lower Battleground rocks are viewed as moderately reworked crystal tuffs, a few coarser lapillistones (Murphy and Butler, 1981), and metasedimentary rocks. The metavolcanic rocks generally grade upward into a dominantly metasedimentary sequence that includes the quartz-sericite schists, high-alumina rocks, and least three, mappable metaconglomerate units. In addition, the Jumping Branch Manganiferous Member, a fine-grained equigranular coticule rock, is found up-section of the quartz-sericite schists that host the Henry Knob deposit. The metamorphic grade is amphibolite facies, generally increasing from west to east with highest grades northeast of Henry Knob in the vicinity of the contact with Charlotte belt rocks.

The quartz-kyanite rock (kyanite quartzite of Espenshade and Potter, 1960) forms a set of complex, en echelon lenses of gray, massive to foliated quartz-kyanite-pyrite rock (Figure 42). The bodies strike N30oE. Individual lenses range from less than 100

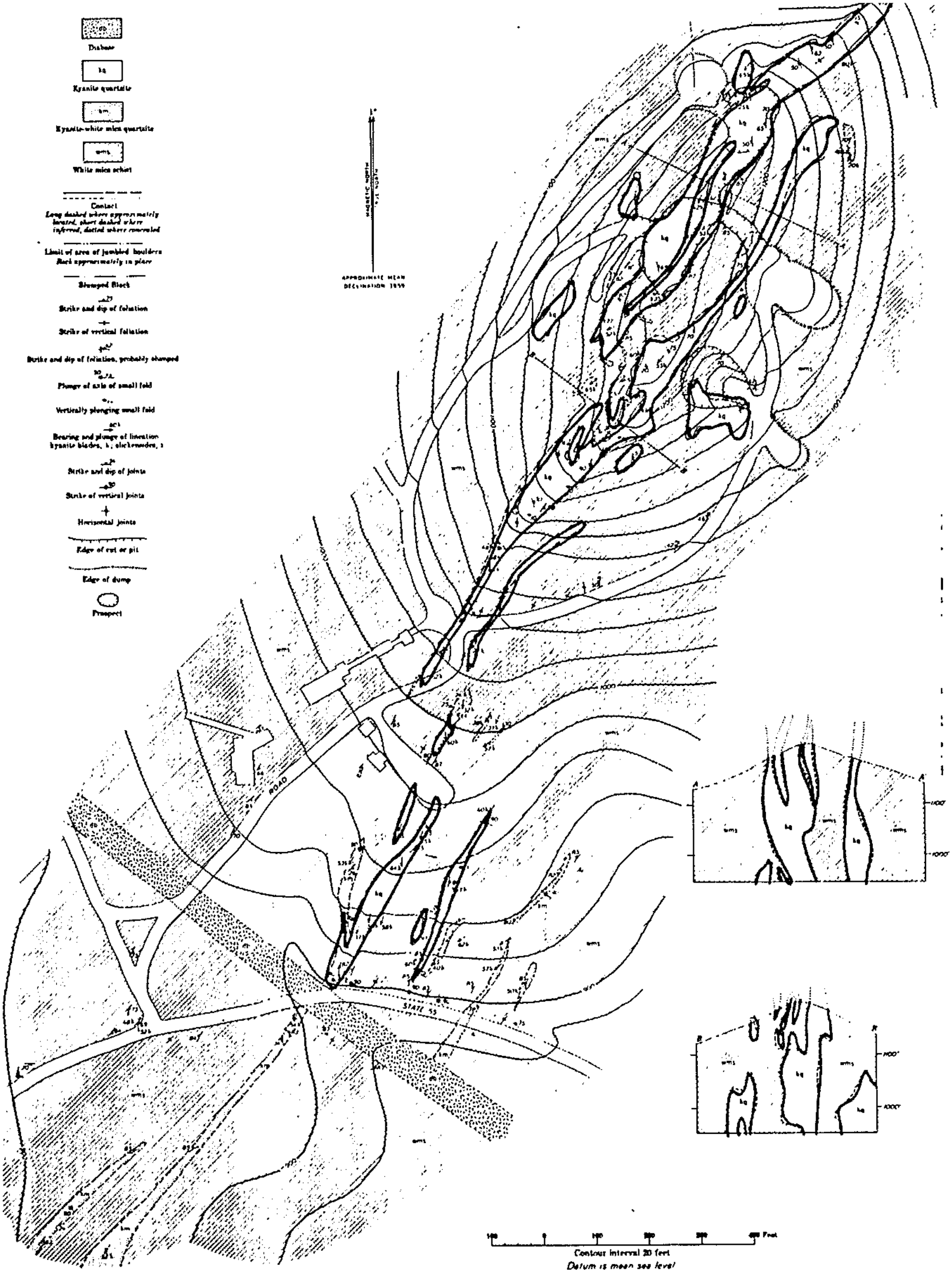

Figure 42: Geology of the Henry Knob kyanite deposit; kyanite-quartz rock is highlighted. From Espenshade and Potter, 1960, Plate 10.

m to about 400 m long with thicknesses of three to thirty meters. They dip steeply to vertically; Espenshade and Potter (1960) show crosssections with down-dip extents of as much as 300 to 350 m. Espenshade and Potter (1960) indicate that the beds may well lie on the limbs of isoclinal folds and, thus, may be tectonically thickened.

Modal analysis indicates that the "average" kyanite-quartz rock consists of 65.5% quartz, 27.6% kyanite, and 6.9% pyrite with minor amounts of rutile, white mica, and barite. Lazulite, topaz, and pyrophyllite (?) are also reported by Espenshade and Potter (1960). Kyanite occurs as equigranular crystals (up to 1 cm long) and in complex, branching veinlets and seams (Espenshade and Potter, 1960) in a fine- to coarse-grained siliceous matrix.

The hanging and footwall rocks consist of pyritic quartz-sericite schist. Within the schist are bands of pyritic siliceous aphanite, which often show boudinage. The quartz-sericite rock commonly contains clots of andalusite, often retrograded (?) to pyrophyllite. Espenshade and Potter (1960) also report kyanite, staurolite, and tourmaline in the quartz-sericite rock. Southwest of the mill site, near the parking area at the foot of the hill, a northwest-trending diabase dike, about 15 m thick, can be seen (see Figure 38).

Mining here commenced in 1935 (Espenshade and Potter, 1960) and continued through 1969 (Horton and Butler, pers. comm.) During peak production, from about 1948 until 1969, about 1000 tons of kyanite ore were mined monthly. The rock was crushed and concentrated by flotation at a mill on the site.

Espenshade and Potter (1960) described the ore as a kyanite quartzite. They noted that, although the quartz-kyanite rock at any given deposit showed little variation in texture or mineralogy, there are significant differences between deposits within the district. The kyanite quartzites grade along strike into kyanite conglomerates, micaceous kyanite schist, and kyanite schist. Interlayers of kyanite quartzite with staurolite quartzite and with kyanite-staurolite-chloritoid schist are seen near Crowders Mountain. Kyanite quartzites are also interbedded with ferruginous quartzite at several locations. Apatite, pyrophyllite, tourmaline, and dolomite are reported (Espenshade and Potter, 1960). At higher metamorphic grades, the alumina-rich rocks are quartz-sillimanite schists with textures and mineralogy otherwise similar to the kyanite-quartz rock (Espenshade and Potter, 1960).

The Henry Knob and other kyanite-quartz rocks of the Kings Mountain district are very similar to those of the Willis Mountain district, Virginia (Espenshade and Potter, 1960) and Graves Mountain, Georgia (Espenshade and Potter, 1960; Radcliffe, 1976; Carpenter and others, 1980). The major difference may be in the higher pyrite content of the Henry Knob occurrence. No known gold mineralization is present in the vicinity of Henry Knob. The gold deposits of the Smyrna district lie about ten kilometers southwest of the Henry Knob deposit. Other alumina-rich deposits in the district, particularly Crowders Mountain, are associated with nearby stratabound barite and manganiferous rocks.

The most likely genetic scheme for the Kings Mountain type alumina-rich deposits is a metamorphosed, advanced argillic and argillic alteration system associated with synvolcanic, hot-spring activity during deposition of the Battleground Formation. The morphology, host rocks, mineralogy, and metamorphic history support such a model. Espenshade and Potter (1960) favored a sedimentary origin (thus their name kyanite quartzite). They based their preference on:

1. The stratiform, stratabound nature of the quartz-kyanite rocks.
2. The compositional banding and layering of the aluminosilicate-rich rocks with staurolite-, sericite-, and iron-rich rocks.
3. The gradation of the kyanite-quartz rock along strike, with kyanite conglomerate, kyanite schist, and chloritoid-kyanite schist.
4. The high-alumina nature of the rocks and the absence of any source (or mechanism ?) for aluminum enrichment.

None of their arguments are inconsistent with a hot-springs model in which alteration is controlled by primary porosity/permeability in a metavolcanic/metasedimentary suite. The presence of abundant pyrite, as well as topaz, lazulite, and tourmaline, is clear evidence for hydrothermal acitivity even without considering the alumina-enrichment of the kyanite-quartz rocks. It appears very likely that the Henry Knob deposit is a high grade equivalent of Snow Camp, Glendon, or Pilot Mountain.

The bus will park at the base of the hill. As you walk up the road, on your left will be the old mill site, very little of which is left except for a few foundations. On your right is the site of the mine office, now the trailer-headquarters of the Henry Knob Park -- a privately owned park dedicated to the arcane pleasures of motocross racing (O tempore, o mores). From the mill site, you can see the dumps and tailings ponds from the kyanite milling operation as well as a spectacular view to the northwest of the rest of the Kings Mountain kyanite district. At the southwestern end of the long ridge on the horizon is Kings Mountain itself, which is formed by quartz-kyanite rocks exposed primarily on the southeastern limb of the isoclinally overturned Sherrars Gap syncline. Kings Mountain is the site of the Battle of Kings Mountain in 1780 and is, today, a National Historical Park. Following the ridge line to the northeast, although this is not, in fact, a continuous ridge, you may see Crowders Mountain which is distinct for its radio tower. Along the southeastern flank of Crowders Mountain are a series of stratabound barite lenses known collectively as the Lawton barite mine.

Continuing up the road, the road to the left leads onto the northwestern highwall of the pit (Figure 40). The road to the right curves northwestward and enters the pit at the southern end. From here you can climb to the southeastern highwall. The pond in the pit is mute testimony to the pyrite content of the Henry Knob ore and to the environmental difficulties which plagued the operation.

STOP 28

Kings Creek Barite Deposit

by

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The Kings Creek barite deposit lies 13 km southwest of Henry Knob along the eastern limb of the South Fork antiform (see Figure 41). This is the best exposed of a number of barite occurrences in the metavolcanics of the lower Battleground Formation. Posey (1981) suggests that these barite horizons mark a single stratigraphic horizon within the Battleground Formation. The best descriptions of the Kings Creek barite mine are those of Keith and Sterrett (1931), Van Horn and others (1949), and Sharp and Hornig (1981). Much of the following discussion is based on their work and the author particularly wishes to thank W.E. Sharp for his permission to quote freely from his work (Sharp and Hornig, 1981).

The barite horizon at Kings Creek is hosted by quartz-sericite schist of the Battleground Formation. This rock consists of 50% quartz, 28% sericite, 10% albite with lesser amounts of epidote, pyrite, magnetite, chlorite, and garnet (Godfrey, 1981; Sharp and Hornig, 1981). The garnets may be spessartine-rich (Sharp and Hornig, 1981). Interfingering with the quartz-sericite rock, particularly to the north of the mine, are chloritoid schists consisting of quartz, sericite, and chloritoid with muscovite, chlorite and graphite (?). Thin layers of saccharoidal quartzite with sericite are found throughout the quarry. These units are viewed by Godfrey (1981) and by Sharp and Hornig (1981) to be altered vitric-crystal and crystal-vitric tuffs and, possibly, associated exhalites of the Battleground Formation.

The barite occurs as both concordant and discordant layers with respect to the schistosity of the quartz-sericite schists. Wilson (1958, p. 41) describes the barite as either:

> 1) massive barite of either 80-90% $BaSO_4$ in veins ranging from a few inches to many feet in thickness, and in pods of varying size, one of which is estimated to have yeilded well over thirty thousand tons of barite; 2) disseminated barite consisting of small nodules that range in size from a fraction of an inch up to several inches; and 3) impregnated schist. This latter fades in the degree of impregnation as it recedes from the massive zones and ranges from 50% or more in close proximity to the veins of massive ore to as little as 8 or 10% as it nears the barren zones between mineralizations.

Both foliated and non-foliated barite can be observed. Foliated barite contains quartz and sericite (which caused problems with marketing the Kings Creek barite). The barite layers commonly show boudinage. The barite may contain minor sulfides, particularly hematite after pyrite and galena. Milky quartz veins, 1 cm to 10 m in width, cross-cut the area. Some veins are folded; others are not. Vugs in the quartz veins may contain pyrite and knots of tourmaline (Sharp and Hornig, 1981).

The barite deposit at Kings Creek lies on the southeastern flank of the South Fork antiform and are presumed to be upright. Two foliations striking N36oE and dipping 26o and 58o SE are observed in the quarry. A late crenulation of these earlier cleavages is commonly observed in the quarry.

The Kings Creek barite is viewed as being a synvolcanic exhalative rock by Sharp and Hornig (1981) and Posey (1981). Their reasoning is variously based on the clear, pre-deformation deposition of the barite, its stratabound and apparently strati-form character, the regional distribution of barite horizons as well as alumino-silicate-rich rocks, manganiferous rocks, and Algoma-type iron formations in the Battleground Formation of the Kings Mountain belt. Except for a few localities of sulfide facies iron formation, no massive sulfide horizons have been described from this area.

Barite was first recognized in York County, South Carolina in the early 1880's (Van Horn and others, 1949). Production of barite at Kings Creek began as early as 1885, but significant mining and processing awaited the arrival of the railroad in 1910. Early mining was confined to pits along the eastern slope of the hill. Underground mining began soon thereafter from an incline that reached a depth of 65 m (Van Horn and others, 1949). Sporadic production continued for nearly 35 years. In 1949, Industrial Minerals of York, South Carolina purchased the property and converted the mine to the present-day surface operation. Significant mining of barite ceased in the mid-1960's when a new crushing plant was built one kilometer north on the railway line and production shifted from beneficiation of locally produced barite to marketing of imported colemanite. With the exception of an occasional sericite shipment, no mining is carried out on the property at present (L.G. Wilson, pers. comm.).

Figure 43 shows Sharp and Hornig's outcrop map of the Kings Creek deposit and the location of the mine buildings. The best barite exposures are in the western pit which can be entered from the dirt road that crosses the railroad tracks and heads to the west on the north side of the blue storage building. Excellent barite country rock exposures and contact relations can be seen on the floor of the pit. The host-rock is well-exposed in the drainage (?) cut on the east side of the pit. A large quarry which exposes extensive fresh quartz-sericite rock lies about 300 m east of the west pit. One can gain access either by climbing over the railroad right-of-way or from the dirt road that heads east from the parking area. Barite is not as common in this pit, but periodically, during removal of sericite, pods of fresh barite are exposed and excellent host rock-barite relations can be observed. The east pit is an area of active, though periodic, mining -- BE CAREFUL.

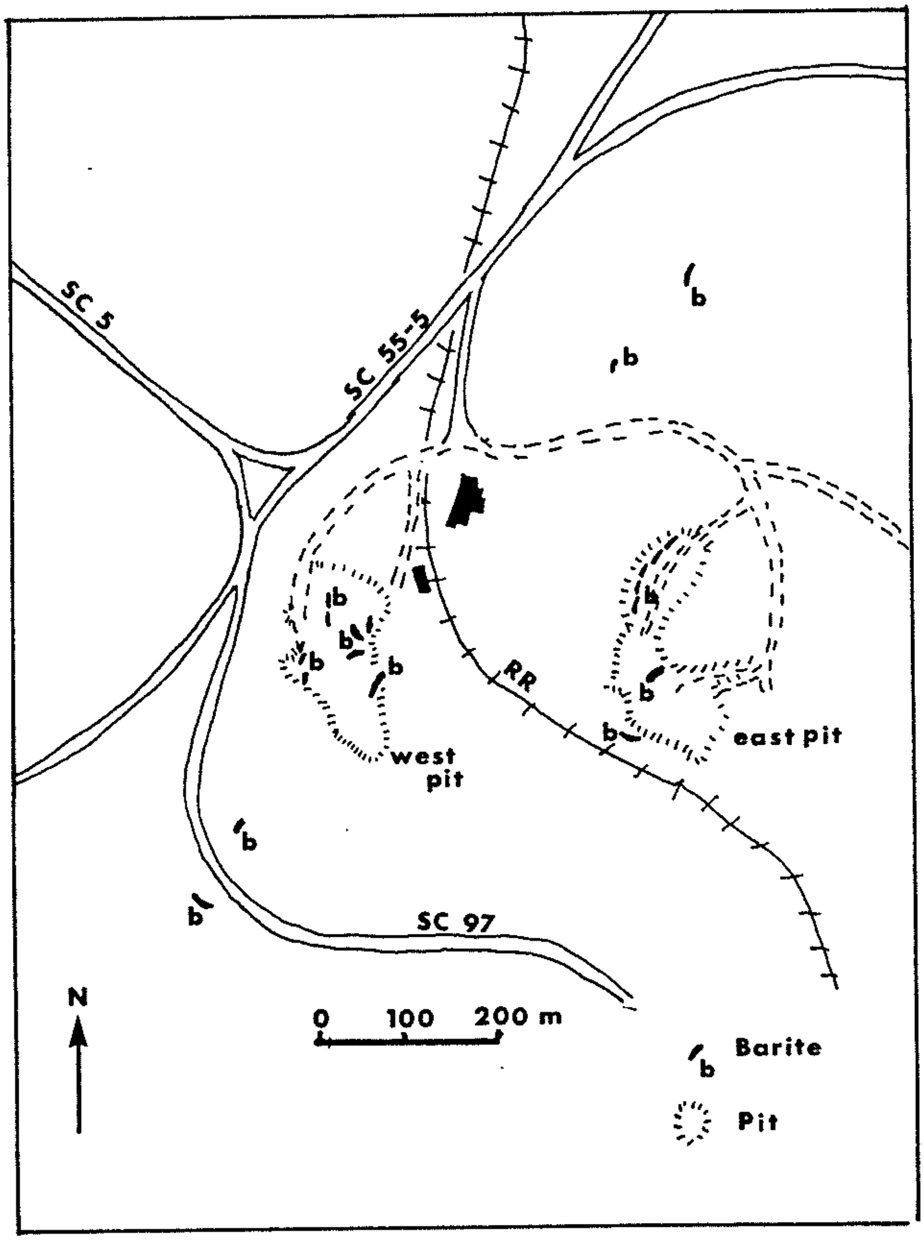

Figure 43: Sketch map of the distribution of barite in the Kings Creek barite deposit, Cherokee County, South Carolina. From Sharp and Hornig, 1981.

This is the final stop. From Kings Creek, the vehicles will head north to I-85 and then northeast to Douglas Airport, south of Charlotte, North Carolina. The drive along I-85 is very nearly on the Kings Mountain shear zone of Horton (1981). To the west, most of the terrain is Inner Piedmont, while on the east is the Kings Mountain belt. Kings Mountain and Crowders Mountain (the one with the radio tower) will be prominent landmarks to the east of the highway. About four to five kilometers north of the North Carolina-South Carolina state line you will be able to see dumps from the spodumene-bearing pegmatite mined by the Foote Mineral Company on the west side of the interstate.

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APPENDIX 1

MILEAGE LOG

DAY 1 -

	MILEAGE	
Leave Raleigh Inn on US 70 East.	0.0	0.0
At intersection of Raleigh Beltline, take US 1 west.	2.0	2.0
Follow US 1 west to US 64. Turn right (W) towards Pittsboro.	9.6	11.6
Stay on US 64 west of Pittsboro, turn right on NC 87 north towards Burlington.	21.6	33.2
Take NC 87 north to State Road (SR) 1549. Turn left.	6.3	39.5
Take SR 1549 to SR 1553. Turn left (W).	4.3	43.8
Follow SR 1553 to SR 1003. Turn right (N).	2.9	46.7
Follow SR 1003 to SR 1339. Turn left.	1.9	48.6
SR 1339 turns to SR 2351 at the Alamance County line.	0.5	49.1
Continue on SR 2351 to SR 2352. Turn left (W).	0.5	49.6
Follow SR 2352 to dirt access road to Snow Camp pyrophyllite deposit (STOP 1).	2.4	52.0
From STOP 1, continue west on SR 2352 to SR 1004. Turn left (S).	1.7	53.7
Follow SR 1004 south into Chatham County to US 64 in Siler City. Turn right (W).	13.1	66.8

	MILEAGE	
Take US 64 west to US 421 south. Turn left (S).	0.5	67.3
Take US 421 south to SR 1006. Turn right (S).	0.8	68.1
Follow SR 1006 into Moore County.	14.5	82.6
Continue on SR 1006 to STOPS 2-10.	1.1	83.7
Return north on SR 1006 to SR 1600. Turn left (W).	0.6	84.3
Take SR 1600 west to NC 22. Turn right (N).	6.4	90.7
Take NC 22 north to the intersection with NC 42 and continue on NC 42-22 north and west.	2.4	93.1
Follow NC 42-22 north to Coleridge. At Coleridge, stay on NC 42 (turn left).	9.6	102.7
Take NC 42 west to US 64, just east of Asheboro. Turn left (W).	12.2	114.9
Follow US 64 west to Best Western Executive Inn. At the intersection of US 64-NC 49.	2.8	117.7

END OF DAY 1

DAY 2 -

Retrace yesterday's route. Take US 64 east to NC 42. Turn right (E).	2.8	2.8
Follow NC 42 east to SR 2611 at Grantville. Turn left (N).	6.1	8.9
Take SR 2611 north to SR 2607. Turn right (E).	2.3	11.2
Follow SR 2607 a short distance and bear right on SR 2664.	0.2	11.4

	MILEAGE	
Follow SR 2664 to a dirt road where we will leave the bus to walk across Pilot Mountain, STOPS 11-18.	0.8	12.2
The bus will meet us on SR 2659, south of Pilot Mountain. Take SR 2659 south to SR 2656. Turn left (E).	0.4	12.6
Take SR 2656 east to the intersection with NC 22. SR 2656 turns into SR 2628 before you get to NC 22.	4.5	17.1
Continue on SR 2628 north to Parks Crossroads. Turn right (E) on SR 2642.	2.2	19.3
Go east on SR 2642 to dirt drive into quarry. Turn left to STOP 19.	1.2	20.5
Return to SR 2642 and turn right (W). Follow to Parks Crossroads. Turn left on SR 2628.	1.2	21.7
Follow SR 2628 across NC 22 to NC 42 (SR 2628 turns to SR 2656 en route). Turn right (W).	6.8	28.5
Take NC 42 west to intersection with SR 2911 at Grantville. Turn left (S).	1.8	30.3
Follow SR 2911 about 1.2 mi. where it turns to SR 2845. Continue on SR 2845 to the intersection with US 220. Turn left (S).	8.7	39.0
Follow US 220 south to NC 24-27 east of Biscoe. Turn right (E).	12.3	51.3
Follow NC 24-27 west to quarry on left, as road descends into Pee Dee River valley. STOP 20.	19.6	70.9
Continue on NC 24-27 west to SR 1740. Turn left (S).	2.8	73.7
Follow SR 1740 south to US 52 intersection at Norwood. Turn left (S).	7.3	81.0

	MILEAGE	
Take US 52 south to SR 1934. Turn right (W).	2.7	83.7
Follow SR 1934 approximately .05 mi to STOP 21.	0.05	83.7
Return to US 52 and turn right (S).	0.05	83.8
Continue on US 52 south to US 74 in Wadesboro. Turn right (W).	16.0	99.8
Continue on US 74 west to Holiday Inn, Monroe, at intersection of US 74 and NC 200, on left-hand side of road.	26.0	125.8

END OF DAY 2

DAY 3 -

Leave the Holiday Inn, turn left on US 74-601 (W).	0.0	0.0
Continue on US 74-601 under overpass and turn right onto cloverleaf to NC 75-200-84S.	1.2	1.2
Follow NC 75-200-84 to Lancaster Avenue, where NC 200 S goes off to the right. Follow NC 200 S.	1.3	2.5
Follow NC 200 S to the hamlet of Roughedge. Turn left (S) on NC 522.	5.5	8.0
Continue on NC 522 S to intersection with SR 1129. Turn right (W).	3.2	11.2
Take SR 1129 to intersection with SR 1130 (Tom Greene Rd.). Take "gentle," not hard, left (S).	0.7	11.9
Follow SR 1130 S to dirt road on right side of road. STOP 22. Bus will have to move on to find a parking place.	1.2	13.1

	MILEAGE	
Leave the Nesbit mine, continuing on SR 1130 south to the South Carolina state line. Continue into South Carolina on gravel road to intersection with SR 29-28. Turn left (E).	1.9	15.0
Continue on SR 29-28 to SC 522. Turn right (S).	0.7	15.7
Take SC 522 to SC 9. Continue across SC 9, heading south.	3.8	19.5
Continue on SC 522 south to intersection with SR 29-123. Turn left (E).	2.1	21.6
Follow SR 29-123 through the hamlet of Taxahaw to the intersection of SC 265. Turn left (E) on SC 265.	13.4	35.0
Stay on SC 265 across Lynches River, enter Chesterfield County, and continue to intersection with SR 13-110. Turn left (N).	1.3	36.3
Follow SR 13-110 north to intersection with gravel road on the right, which leads up the hill through the gate to the Brewer mine. STOPS 23-26.	0.5	36.8
Leave the Brewer mine, returning south on SR 13-110 to SC 265. Turn right (W).	0.5	37.3
Continue on SC 265 across Lynches River, into Lancaster County, to intersection with SC 903 at the crossroads of Midway. Turn right (NW).	5.4	42.7
Follow SC 903 to intersection with SC 601. Bear left on SC 601-903.	2.0	44.7
Bear right on SC 903 (W)	0.1	44.8
Continue on SC 903 west to intersection with US 521-Bypass, just east of Lancaster. Turn right, down ramp onto US 521-Bypass.	14.7	59.5

		MILEAGE
Follow US 521-Bypass to exit for US 521 north. Take exit ramp.	2.6	62.1
Turn left, south, on US 521-Business, cross overpass, and turn right into Carriage Inn, Lancaster, South Carolina	0.2	62.3

END OF DAY 3

DAY 4 -

Leave Carriage Inn parking lot, Lancaster South Carolina. Turn left (N) on US 521	0.0	0.0
Follow US 521 north to intersection with SC 5. Bear left on SC 5 (W).	7.2	7.2
Continue on SC 5 across the Catawba River into York County, through Rock Hill, to the intersection of SC 5 with US 321-Business in York, South Carolina. Turn right (N).	28.6	35.8
Follow US 321 north to the intersection with SC 55 in Clover, South Carolina. Turn left (W) on SC 55.	9.7	45.5
Follow SC 55 west to the intersection with SR 46-508. Turn right (N).	4.1	49.6
Turn right again, immediately, into the parking lot of Henry Knob Park. STOP 27.	0.1	49.7
Leave parking lot, turn left, and return to SC 55. Turn right (W).	0.1	49.8
Continue on SC 55, cross into Cherokee County, to SR 260 just east of Kings Creek. Turn left just before the RR crossing into the parking area at the Kings Creek barite deposit. STOP 28.	10.1	59.9
Leave parking area, turn left on SC 55 to intersection with SC 5 in Kings Creek. Turn right (NW).	0.2	60.1

		MILEAGE
Follow SC 5, north, to intersection with US 29 just east of Blacksburg. Turn right (E).	5.7	65.8
Continue on US 29 east, following signs for I-85 N to intersection with I-85. Follow I-85 N and signs to Kings Mountain and Charlotte, North Carolina.	4.5	70.3
Follow I-85 N to Billy Graham Pkwy. in Charlotte and follow signs to Douglas Airport.	37.0	107.3

END OF TRIP.

APPENDIX II

Some mineral compositions, mineral reactions,
mineral stability diagrams,
and
several items of potentially useful information
to stimulate discussion
and resolve arguments

1. MINERALS

A number of the minerals found in these metamorphosed high-alumina deposits may be unfamiliar to many. The formulas of some of the more unusual are presented below along with a triangular diagram from the system SiO_2-Al_2O_3-F_2O_{-1}-H_2O from Barton (1982).

Aluminum hydroxides -

Gibbsite	$Al(OH)_3$
Disapore	$AlO(OH)$

Aluminum silicates -

Kaolinite	$Al_2Si_2O_5(OH)_4$
Halloysite	$Al_2Si_2O_5(OH)_4 \cdot 2H_2O$
Pyrophyllite	$Al_2(Si_2O_5)_2(OH)_2$
Dickite	$Al_2(Si_2O_5)_3(OH)_6 \cdot 1.5H_2O$

Other high-alumina phases -

Alunite	$KAl_3(SO_4)_2(OH)_6$
Topaz	$Al_2SiO_4(F,OH)_2$
Lazulite	$(Mg,Fe)Al_2(OH)_2(PO_4)_2$
Chloritoid	$(Fe,Mg)_2Al_2(Al_2Si_2O_{10})(OH)_4$

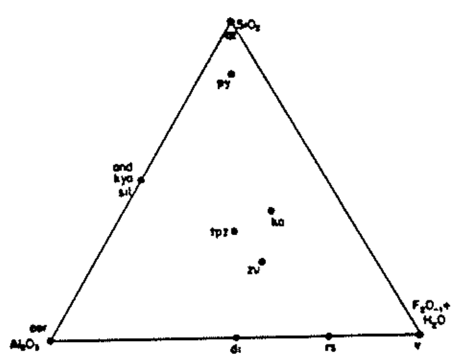
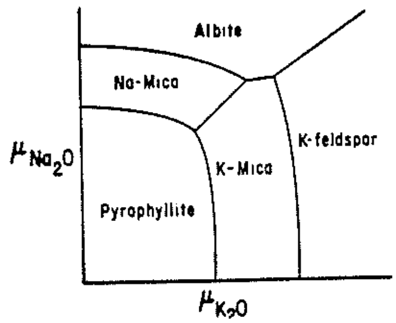


Fig. 3. Projection of the compositions of some of the phases in the Al_2O_3–SiO_2–H_2O–F_2O_{-1} system (parallel to the join H_2O–F_2O_{-1}). Abbreviations (used throughout this paper) are: tpz = topaz, and = andalusite, cor = corundum, di = diaspore, ka = kaolinite, kya = kyanite, py = pyrophyllite, qz = quartz, rs = alkali-free ralstonite, sil = sillimanite, v = vapor, zu = chlorine-free zunyite.

2. STABILITY OF PYROPHYLLITE

Generally, pyrophyllite (kaolinite, diaspore) is stable as a function of extreme alikali depletion and low temperatures.



Source: Rose and Burt, 1979, p. 189.

At low m(KCl)/m(HCl) (alkali-depleted) conditions, temperature will favor the less hydrous phase. Thus, the low temperature mineral will be kaolinite, followed by diaspore, followed anadalusite. Pyrophyllite is the high-SiO_2 phase and corundum is only found in highly SiO_2-deficient systems at higher temperatures.

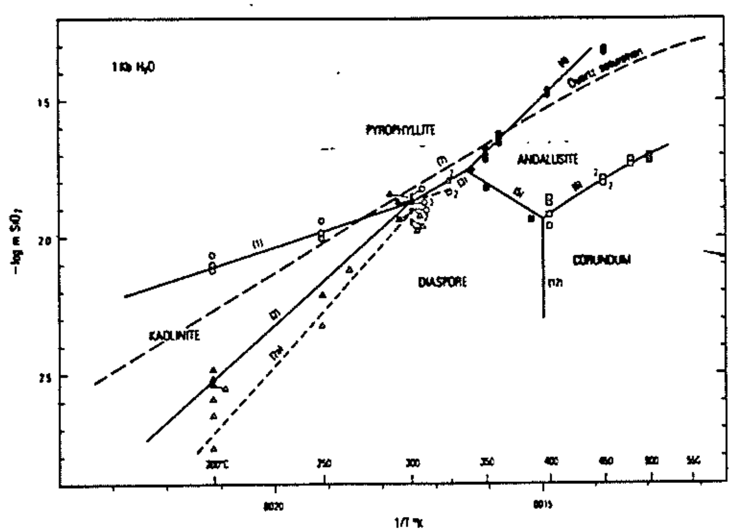


FIG. 1. Stability relationships in the system Al_2O_3-SiO_2-H_2O at 1 kb H_2O. Symbols: O, kaolinite-pyrophyllite; ●, pyrophyllite-andalusite; △, kaolinite-boehmite; ▲, kaolinite-diaspore; □, andalusite-corundum; ■, andalusite-diaspore; and ▽, pyrophyllite-diaspore.

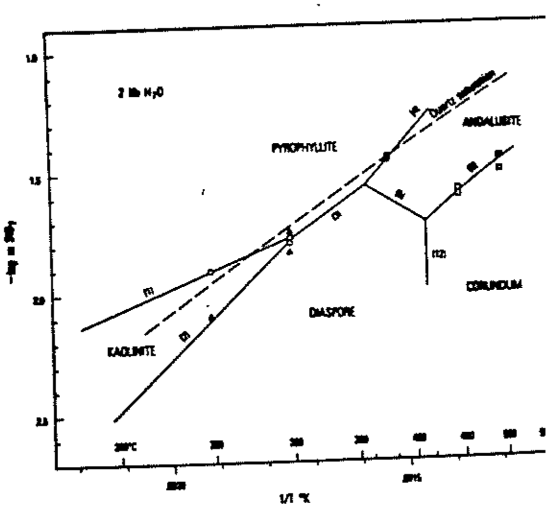


FIG. 2. Stability relationships in the system Al_2O_3-SiO_2-H_2O at 2 kb H_2O. Symbols are the same as in Figure

Source: Hemley, Montoya, Marinenko, and Luce, 1980. General equilibrium in the system Al_2O_3-SiO_2-H_2O and some implications for alteration/mineralization processes. Econ. Geol., v. 75, p. 210-228.

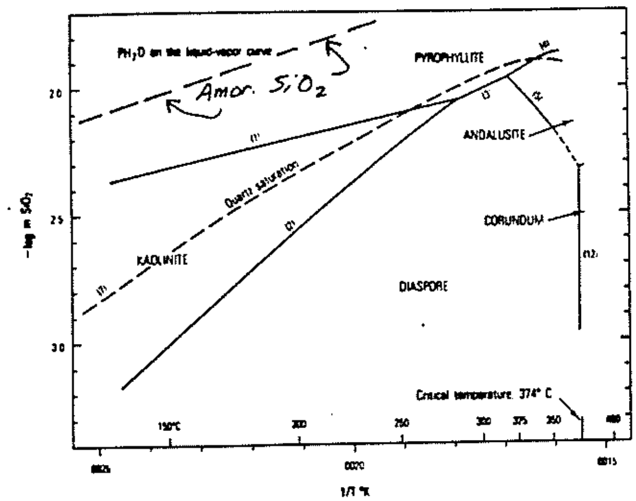
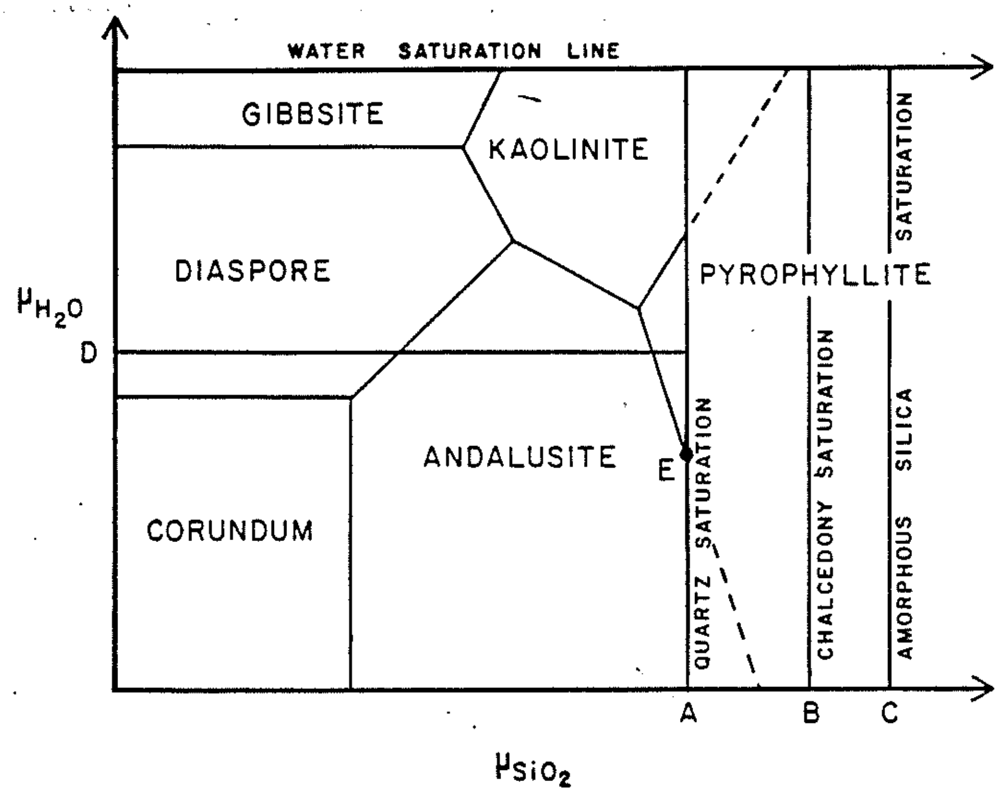


FIG. 3. Stability relationships in the system Al_2O_3-SiO_2-H_2O along the liquid-vapor curve.

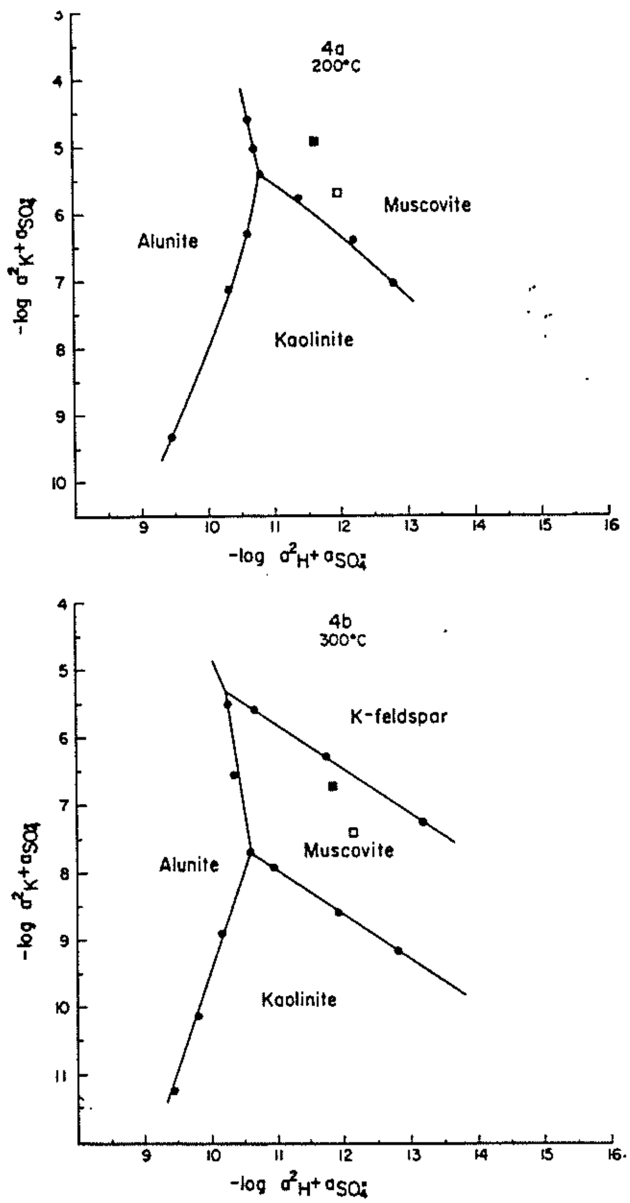
All the diagrams above imply that pyrophyllite is only stable with quartz at relatively high temperatures (>250°C). These are not wholly unreasonable for deep geothermal systems, but we should remember that these are metamorphosed alteration assemblages and much of the quartz could be recrystallized amorphous SiO_2. The diagram of Hemley and others (1980) has been modified above to show the amorphous SiO_2 saturation limit based on calculated values from Fournier's work. Pyrophyllite is indeed stable at very low temperatures in hydrothermal solutions saturated with amorphous SiO_2.

This phenomenon is demonstrated below.



3. ALUNITE STABILITY

Alunite, as one would expect, is stable over other potassium-aluminum silicates and aluminum silicates as a function of $m(K^+)$ and $m(SO_4^=)$. Clearly, then, oxidation of reduced sulfur shallow, mixed water regimes would favor alunite. Temperature has a relatively minimal effect on alunite stability.



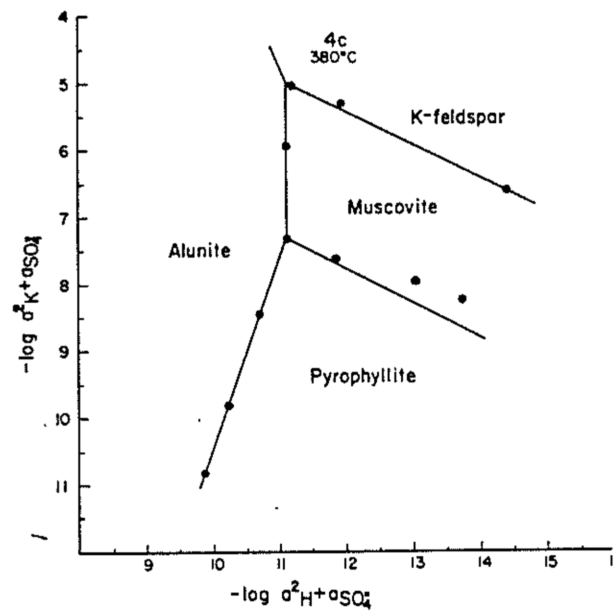
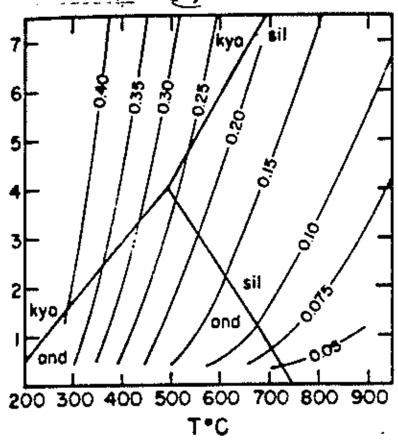


FIG. 4. Calculated stability relations. ● From e
nental results of Fig. 3 using conductance dat
Thermodynamic calculations of invariant point at 1
■ Same at 1,000 bars.

Source: Hemley, Hostetler, Gude, and Mountjoy, 1969. Some stability relations of alunite. Econ. Geol., v. 64, p. 599-612

4. TOPAZ STABILITY

Topaz stability is not well-constrained, but the recent work of Mark Barton has moved us along. Rosenberg corrected Sykes and Moody's minimum temperature of the Hillsborough pyrophyllite deposit (Orange County, North Carolina) upwards to 560°C. Barton (1982) demonstrates that Rosenberg's topaz compositions were metastable and too fluorine-deficient. Topaz is clearly stable at low pressure and temperature, though the low P-T variety is hydroxyl-topaz, not fluor-topaz.



From Barton, 1982. Isopleths of hydroxyl-topaz in topaz solid solution. Based on the reaction: Andalusite + H_2O ---> topaz.

The two analyzed topazes from the slate belt are:

	Calculated wt.% based on b cell parameter	OH/F+OH
Hillsborough (Sykes and Moody)	~ 15.47% F	0.52
Brewer (Ribbe and Rosenberg)	15.97	0.46

With andalusite present, this places a maximum temperature of 300°C on the topaz-andalusite assemblages at these two locations.

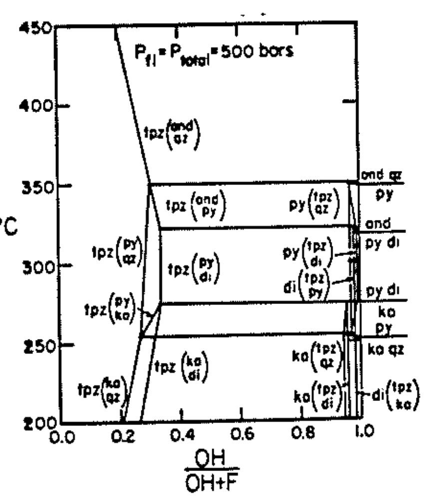


Fig. 5. Schematic temperature *versus* OH/(OH + F) diagram showing some, but not all, of the reactions which limit topaz compositions in the system Al_2O_3–SiO_2–H_2O–F_2O_{-1} at 500 bars total pressure. The lines represent the compositions of the various phases coexisting with the phases in the parentheses (*i.e.*, tpz(py,qz) is the projected composition of topaz in equilibrium with pyrophyllite and quartz). The abbreviations are the same as for Fig. 3.

Barton's Figure 5 shows that at a pressure of 500 b, the topaz isopleths are very steep with temperature regardless of assemblage and not a good geothermometer. In addition, whether topaz is in equilibrium with py-qz, and-qz, ka-qz, or di-qz, there appears to be a <10% difference in the OH/F+OH due to the limited solution of F in these other phases.

4. The following diagrams, sketches, models, and data are all from Henley, Truesdale, and Barton, 1984, (Fluid Mineral Equilibria in Hydrothermal Systems, Reviews in Economic Geology, vol. 1, SEG) and presented without comment for use in discussions on the trip.

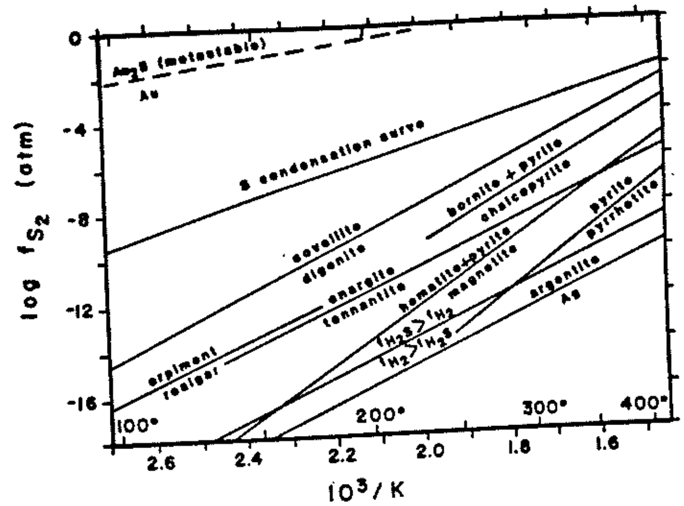


Figure 8.6. Log f_{S2} - 1/t diagram showing sulfidation reactions among minerals and emphasizing those equilibria typical of high sulfidation states. The figures inside the lower margin are °C.

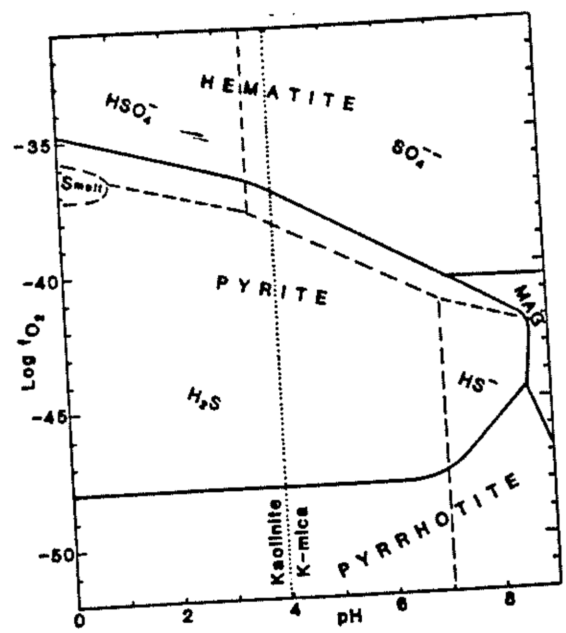


Figure 8.4. Log f_{O2} - pH diagram for 200°C. This is a base on which to plot nitrogen equilibria, alunite reactions, and the position of the CO_2 - CH_4 buffer, as discussed in the section titled "Nitrogen as an Oxidant?". The Kmica - kaolinite curve is taken from Hemley et al. (1969) so as to make it as consistent as possible with the alunite equilibria (see discussion in Chapter 6). Log a_{K^+} is -1.25.

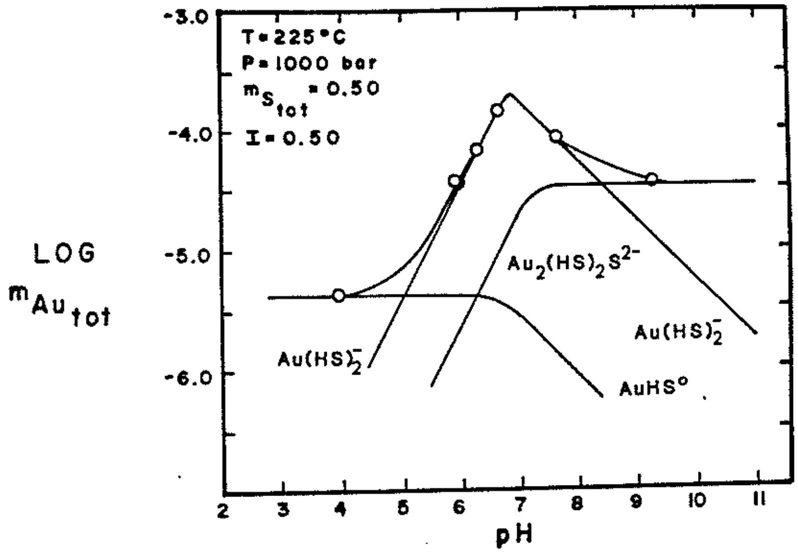


Figure 9.1. Calculated solubility curves for three thio-gold complexes compared with experimental data at 225°C and 1000 bars pressure (redrawn from Seward, 1973).

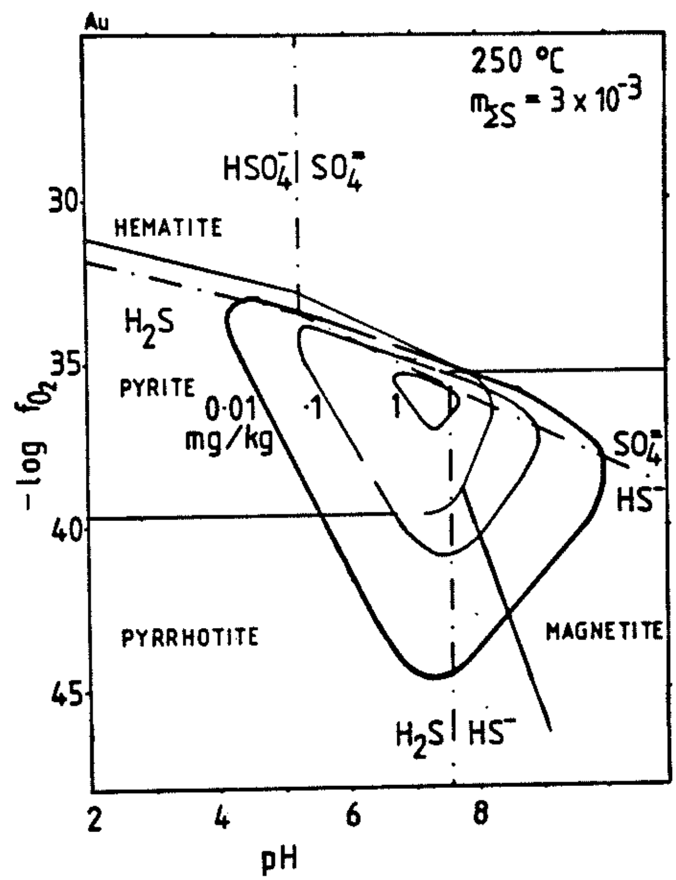


Figure 9.2. f_{O_2} - pH diagram at 250°C showing the stability fields of the principal sulfur species and solubility contours for gold in mg/kg as $Au(HS)_2^-$, see text

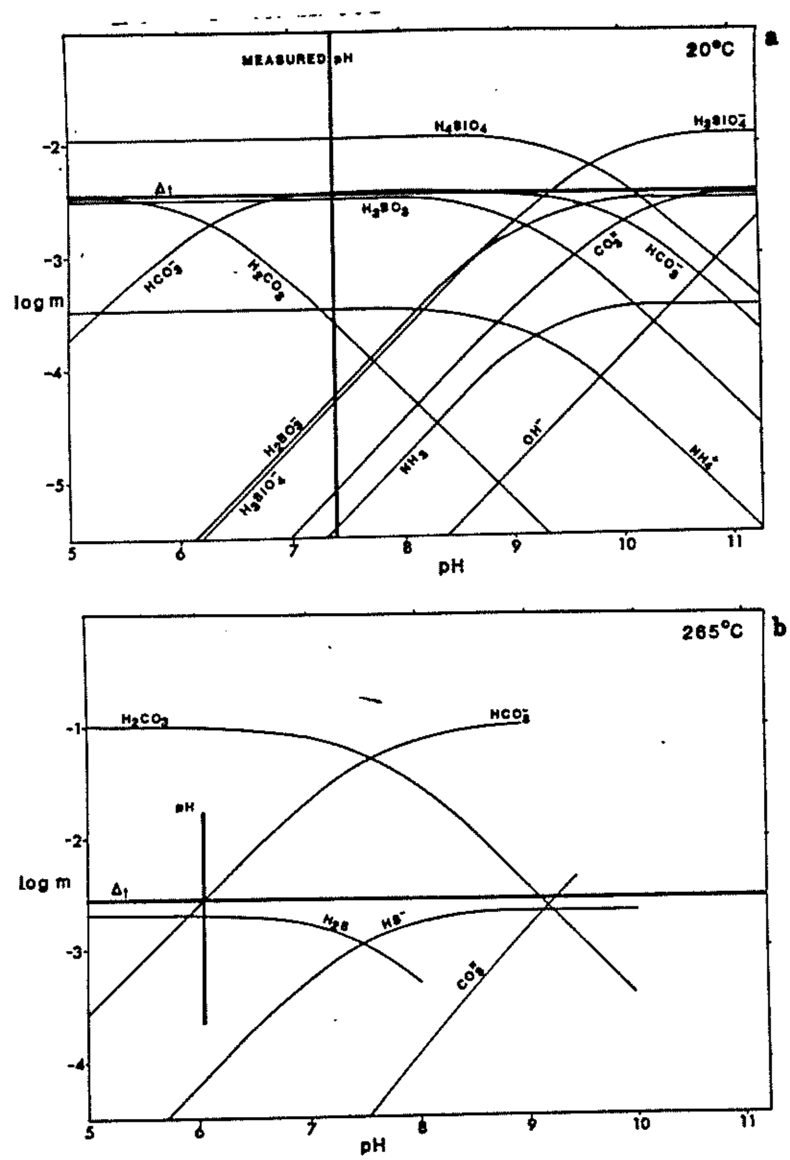


Figure 7.4. Log molality vs pH diagrams for the principal weak acid-base species in water from Broadlands BR22: a) water sample at 20°C, b) reservoir fluid at 265°C.

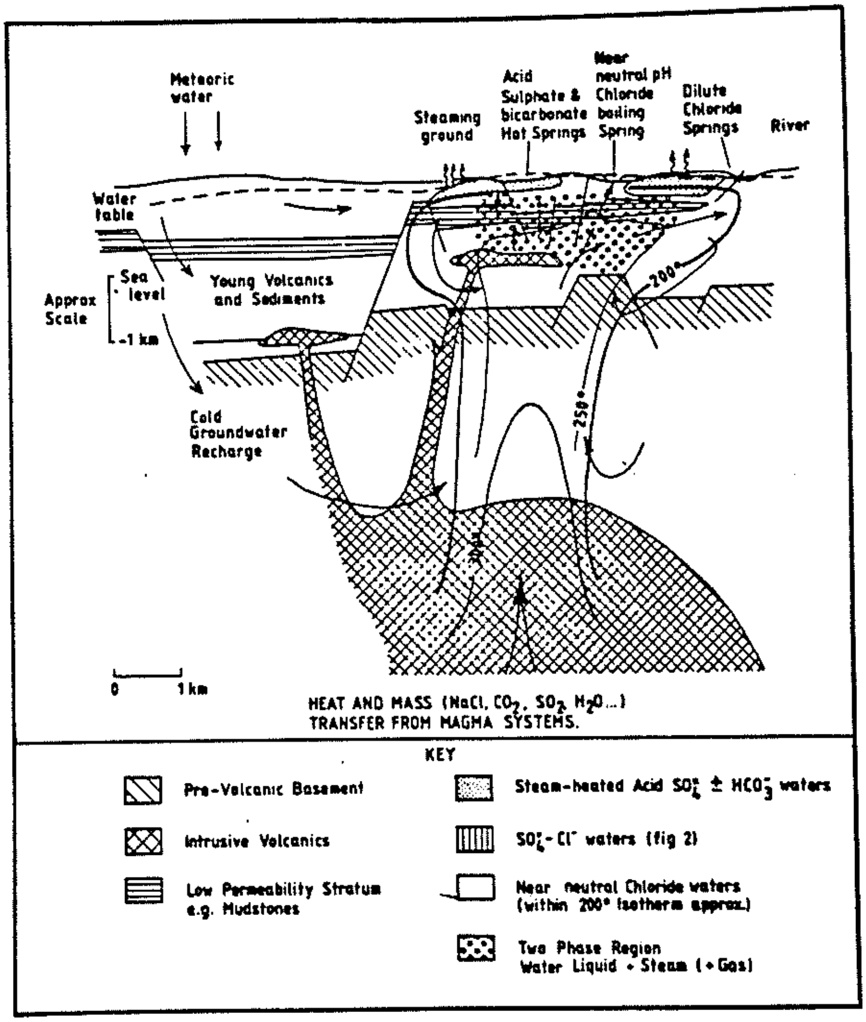


Figure 2.3. Schema of the main features of a geothermal system typical of those in silicic volcanic terranes. The system is supplied by ground-water in this case derived from meteoric water. Heat, together with some gases, chloride, water and some other solutes, is assumed to be supplied by a deeply buried magmatic system and results in a convecting column of near-neutral pH chloride water with two phase conditions in the upper part of the system. Steam-separation processes give rise to fumaroles and steam absorption by groundwater, with oxidation of H_2S at the water table, gives rise to isotopically enriched steam-heated acid sulfate and bicarbonate waters. Mixing may occur between the deeper chloride waters, steam-heated waters and fresh groundwater to give a range of hybrid waters. Outflows from the deep chloride system occur either as boiling alkaline springs often associated with silica terrances, or after mixing with cold groundwaters, as near-neutral pH relatively dilute chloride springs. (Reproduced from Henley and Ellis, 1983, with permission.)

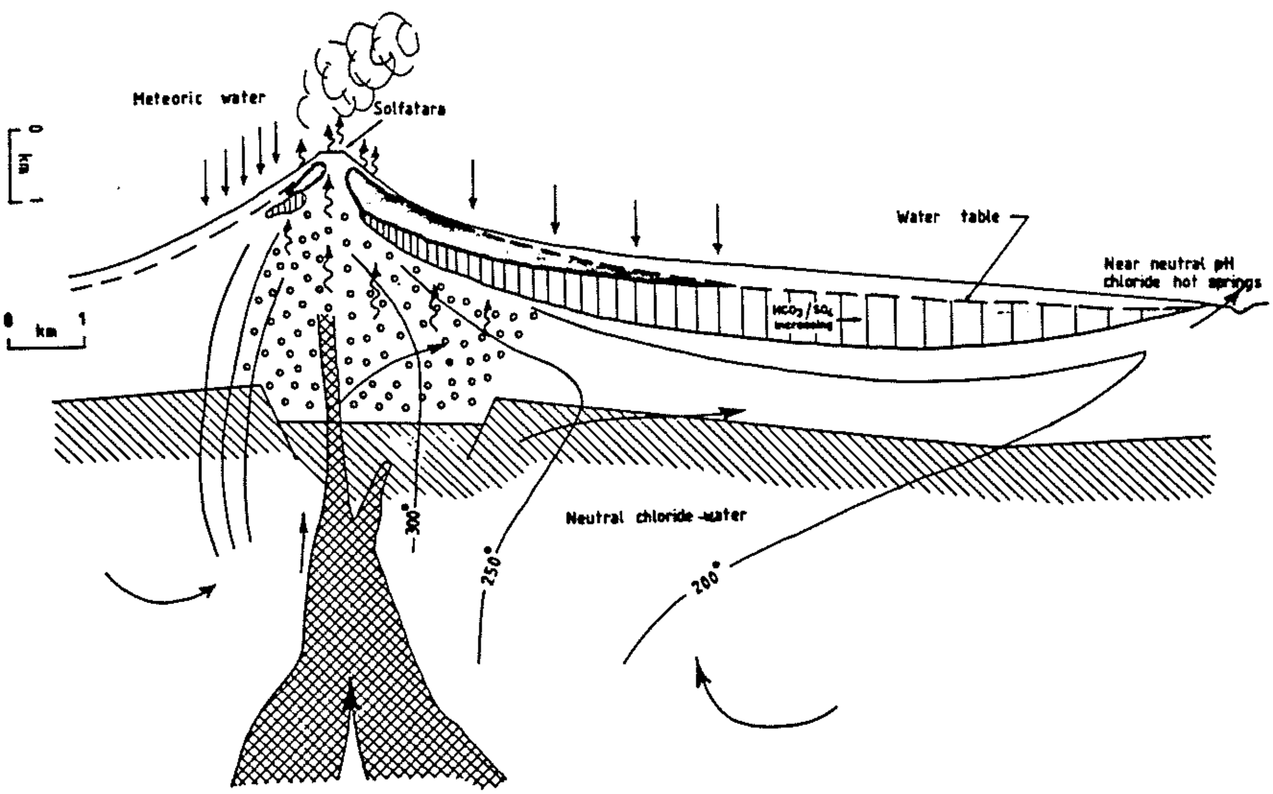


Figure 2.4. Schema of a geothermal system typical of active island-arc andesite volcanoes. Lower permanent water tables in tropical regions and the high relief of the volcanic structures result in a scarcity of chloride water discharges except at some distance from the upflow center. The latter may be revealed by fumaroles, intense rock alteration and steam-heated, often perched, aquifers. Near-surface condensation of volcanic gases and oxidation result in acid sulfate waters in the core of the volcano and an acid crater lake may also form (see Plate 4). (Symbols as for Figure 2.3.) (Reproduced with permission from Henley and Ellis, 1983.)

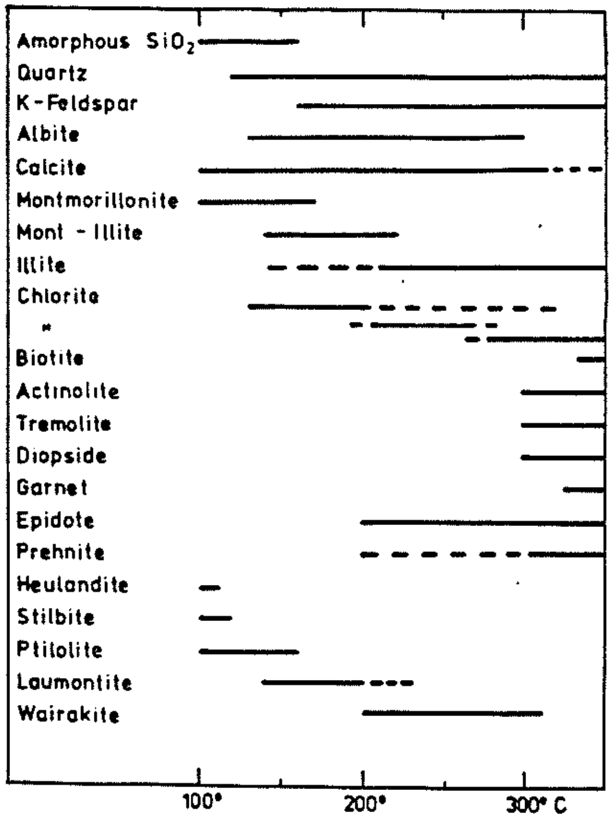


Figure 6.1. Generalized summary of the temperatures over which alumino-silicate alteration minerals have been observed in active geothermal systems. The three chlorite stability ranges indicate the transition from swelling through mixed layer to non-swelling chlorite with increasing temperature. Phases which occur in the surficial sulfate zone are not included; e.g., alunite, kaolinite, cristobalite....(Reproduced with permission from Henley and Ellis, 1983)

Table 2.2— Major element analyses of spring waters from a number of geothermal areas (in mg/kg)

Location	Spring Temp (°C)	$pH_{20°}$	Na	K	Ca	Mg	Cl	B	SO_4	total HCO_3^-	SiO_2
Wairakei (NZ)											
Champagne Pool	99	8.0	1070	102	26	0.4	1770	21.9	26	76	294
Tauhara (NZ)											
A.C. Spring	70	5.9	56	14	14	6	8	0.1	105	375	230
Terraces; Iron Spring	76	7.3	403	46	–14–		537	9.8	105	276	250
Spa; Fissure Spring	95	8.0	820	59	–24–		1342	24	62	44	169
Spa Fumarole Condensate	98	2.5	30	2	16	>3	<7	–	–	–	–
Broadlands (NZ)											
Ohaaki Pool	95	7.1	860	82	2.5	0.1	1060	32	100	679	338
Waimangu (NZ)											
Frying Pan Lake	67	3.8	545	49	10.5	–	762	6.5	320	193	380
Ngawha (NZ)											
Jubilee Bath	50	6.5	870	79	8	2.5	1336	1020	500	333	186
Cerro Prieto (MEX)											
Spring N29	89	7.6	5120	664	357	4.6	8790	–	31	65	73
Tongonan (PHIL)											
Banati Springs	98	8.25	1990	211	86	0.4	3397	34.5	74	7	278