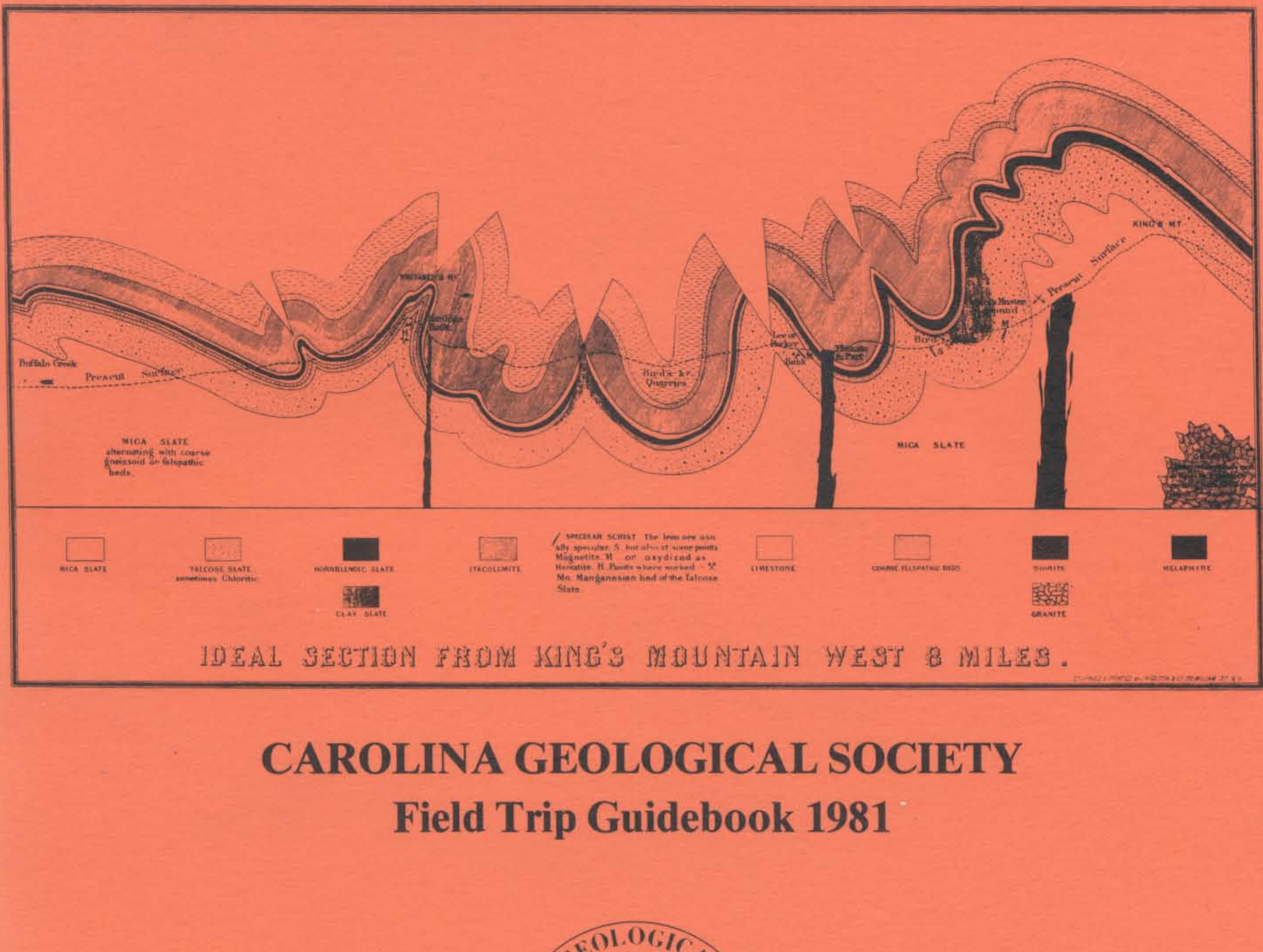
Geological investigations of the Kings Mountain belt and adjacent areas in the Carolinas

edited by

J. Wright Horton, Jr., J. Robert Butler, Daniel M. Milton



CAROLINA GEOLOGICAL SOCIETY

Field Trip Guidebook 1981

October 24-25, 1981

Gaffney, South Carolina

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FIELD TRIP GUIDEBOOK

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GEOLOGICAL INVESTIGATIONS OF THE KINGS MOUNTAIN BELT AND ADJACENT AREAS IN THE CAROLINAS

Edited by

J. Wright Horton, Jr.
U.S. Geological Survey, 928 National Center, Reston, VA 22092

J. Robert Butler
Department of Geology, University of North Carolina,
Chapel Hill, NC 27514

Daniel J. Milton
U.S. Geological Survey, 928 National Center, Reston, VA 22092

Front cover: Lieber's idealized cross section of the Kings Mountain belt from Kings Mountain westward for 8 miles. (Lieber, Oscar M., 1856, Report on the survey of South Carolina; being the first annual report: Columbia, S.C. 136 p.)

Copies of this guidebook can be obtained from:

South Carolina Geological Survey
Harbison Forest Road
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Foreword

Since the days of Oscar Lieber in the last century, the Kings Mountain belt, with its unusual variety of rock types and mineral wealth, has been a magnet for geologists. Many of us have felt that the good exposure (by regional standards) and coherent stratigraphy hold the promise of a key to the puzzle of the southern Appalachians. This volume contains the most detailed and complete coverage of the Kings Mountain belt ever assembled. We feel it reflects impressive progress in understanding the internal character of the belt and indicates that at least a start has been made toward placing the belt within the wider context of the Appalachians. This is an appropriate time for a meeting of the Carolina Geological Society, one of the largest regular gatherings of southeastern geologists, to be held in the Kings Mountain belt. The important unanswered questions, controversies, and different interpretations should generate some stimulating dialogue on the field trip.

The papers in the volume, which cover the entire Kings Mountain belt (Fig. 1), are arranged roughly in order from north to south with some clustering of papers on related topics. There is a tight group of papers in the area between Gaffney and Kings Mountain (Fig. 1), which is now the best known segment of the Kings Mountain belt, and a corresponding lack of papers on the area of South Carolina between Laurens and Jonesville, the largest unknown segment.

We would like to express special thanks to the authors for their cooperation and for exceeding our expectations with their outstanding contributions, and to Norman K. Olson, State Geologist of South Carolina, for his enthusiastic support.

J. Wright Horton, Jr.
J. Robert Butler
Daniel J. Milton

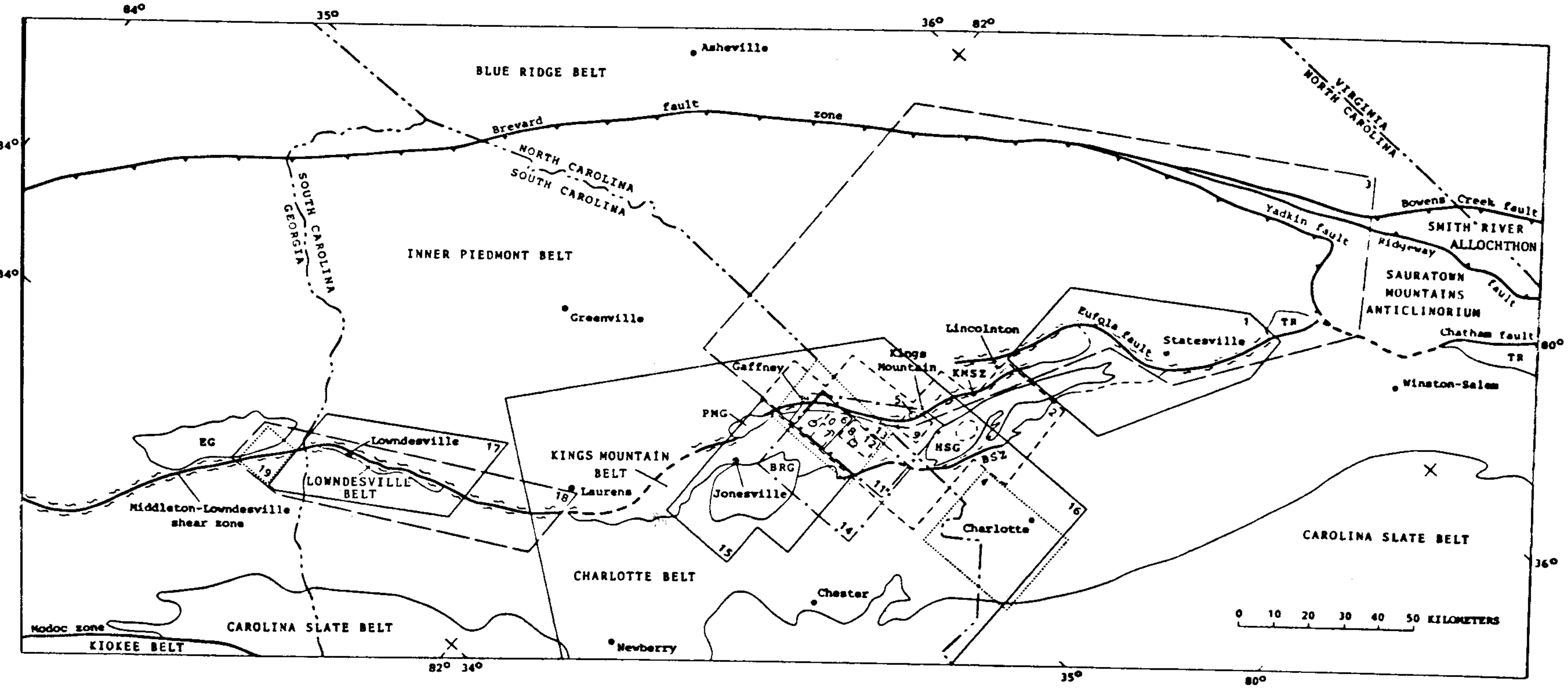

Figure 1. Index to papers in this volume: (1) D. J. Milton, (2) J. W. Horton, Jr., (3) R. Goldsmith, (4) F. A. Wilson, (5) J. S. White, (6) J. R. Butler, (7) M. F. Schaeffer, (8) C. F. Murphy and J. R. Butler, (9) N. A. France and H. S. Brown, (10) R. D. Hatcher, Jr., and B. K. Morgan, (11) H. H. Posey, (12) W. E. Sharp and C. A. Hornig, (13) B. G. Moss, (14) J. P. Gregory, (15) S. M. van Gelder and H. Y. McSween, (16) P. D. Fullagar and S. A. Kish, (17) V. S. Griffin, (18) A. E. Nelson, (19) R. W. Rozen. The synthesis paper by Horton and Butler is not plotted. Geological features on the map were adapted from these papers. KMSZ=Kings Mountain shear zone; BSZ=Boogertown shear zone; HSG="High Shoals" granitic gneiss; PMG="Pacolet Mills" granite; BRG="Bald Rock" granite, EG=Elberton Granite.

Dedication

This volume is dedicated to Thomas L. Kesler, an outstanding economic geologist, whose work in the Kings Mountain region was critical to development of one of the world's largest supplies of lithium and whose mapping provided major insights to the complex stratigraphy and structure.

Kesler was born in Salisbury, North Carolina, and received his early geologic training at the University of North Carolina at Chapel Hill, where he was awarded the B.S. degree in 1929 and the M.S. degree in 1930. His industrial experience was mainly with Shell Petroleum, U.S. Steel, Foote Mineral, and Engelhard Minerals and Chemicals. He worked for the U.S. Geological Survey for about ten years, conducting major studies in the Kings Mountain belt of the Carolinas and in the Cartersville area of Georgia. Kesler was a wide-ranging private consultant in recent years. He is now enjoying a peripatetic "retirement" based in Bellevue, Washington.

In 1955, Kesler led a field trip in the Kings Mountain belt and contributed to "Guides to Southeastern Geology," published by the Geological Society of America in conjunction with the 1955 Annual Meeting in New Orleans. The volume was a major breakthrough in regional geology. He was leader of the Carolina Geological Society field trip in the Kings Mountain belt in 1956, which was based at the Carrol Hotel in Gaffney and included three stops that were essentially the same as stops 2, 4, and 12 of this year's trip. The Carolina Geological Society elected Kesler its president for 1958.

Kesler's work is characterized by careful and thorough observations. He is an independent thinker willing to attack conventional views when they run counter to what he has seen. Those of us now working in the Kings Mountain belt have regularly used Kesler's publications, but few of us have had the benefit of his incisive observations and questions. He would have trimmed, if not scalped, some of the fuzzy views expressed herein.

The northern termination of the Kings Mountain belt

Daniel J. Milton, U.S. Geological Survey, National Center, MS 928, Reston, Virginia 22092

The Kings Mountain belt in North Carolina comprises two strips of stratified rock flanking the High Shoals granitic gneiss of Horton and Butler, 1977 (Figure 1). The western strip is easily traced to a point just east of Bandy by the occurrence of such diagnostic lithologies as quartzite, dolomitic marble, and iron formation, as well as schists and amphibolites. Straight trends, steep dips, and shallow-plunging lineations very likely mask a complex internal structure; the abrupt northeast termination of the quartzite that forms Anderson Mountain suggests a south-plunging isoclinal synform. The straightness and abruptness of the western boundary, marked generally by the juxtaposition of fine-grained graphitic schist on the Kings Mountain side and coarse-grained, commonly tourmaline-rich schist, but locally Cherryville quartz monzonite and pegmatite, on the Inner Piedmont side, suggests continuation of the Kings Mountain shear zone beyond the limit of Horton's detailed mapping, although no exposure like that of field trip stop 6 has been found.

The High Shoals granitic gneiss extends as a continuous pluton to, or almost to, the Catawba River opposite Duke Power State Park. A small body of porphyritic granite just west of Barium Springs appears to be an outlier of High Shoals along the projected trend of the main body. The eastern strip of the Kings Mountain belt is composed largely of schist, a less distinctive lithology and a poor outcrop maker, and is accordingly more difficult to trace. The Boogertown shear zone, which forms the eastern boundary in southernmost North Carolina, can be traced discontinuously only to a point slightly south of the Gaston-Lincoln County line (J. W. Horton, personal commun.). Farther north, an apparently unsheared granite body lies astride the projected position of the Kings Mountain-Charlotte belt boundary. Beyond the granite, particularly east of the Catawba River, is a monotonous northeast-trending sequence largely composed of fine-grained biotite and hornblende gneisses of indefinite affinities, although the increasing prevalence of muscovite schist westward and the presence of quartzite near Duke Power State Park (Conrad, 1964) and coticule (spessartine-quartz rock) at East Monbo are suggestive of Kings Mountain affinities for the rocks on the extended trend of the eastern strip and the High Shoals.

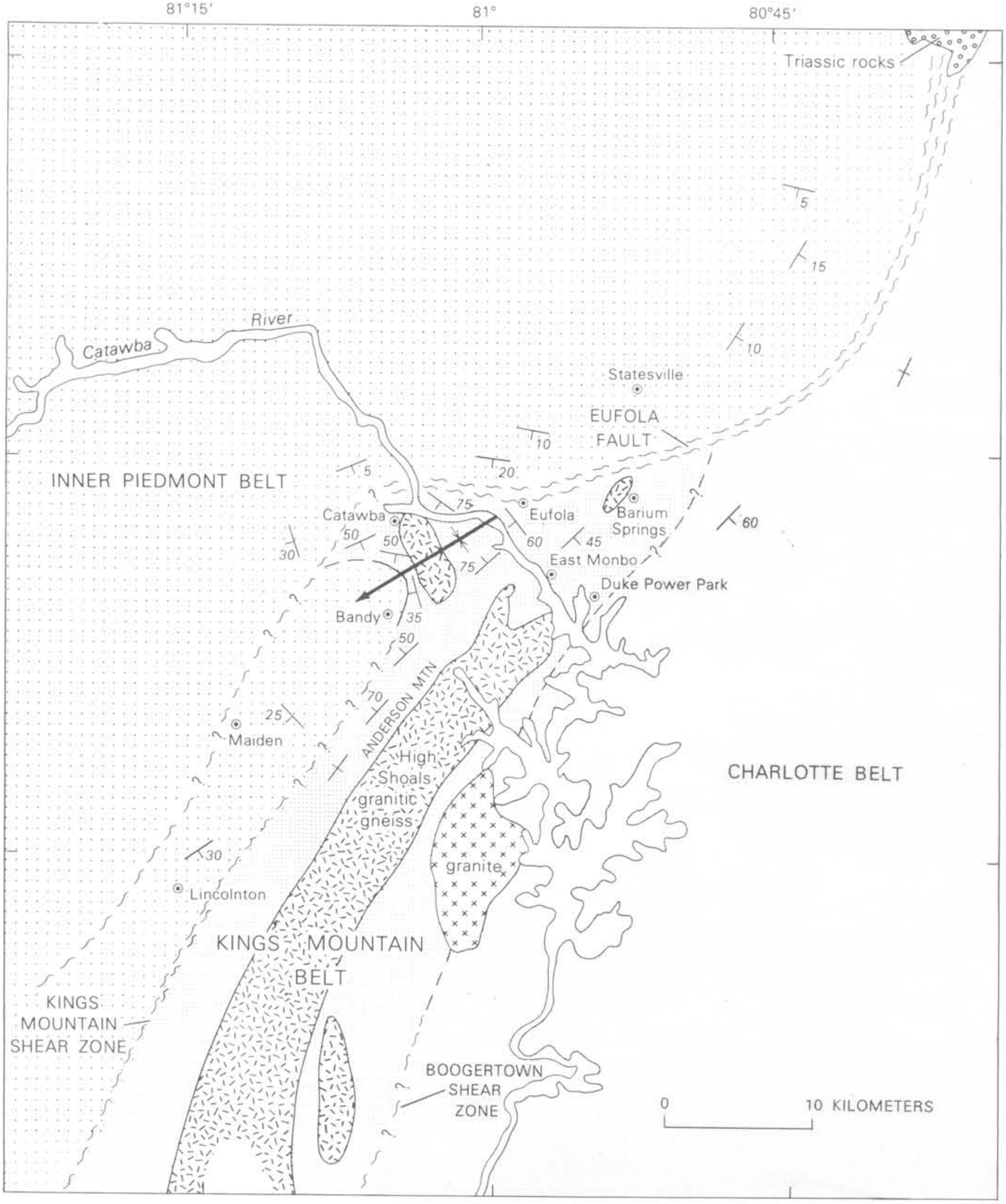

Figure 1. Regional relationships around the northern Kings Mountain belt. Representative attitudes include bedding, transposed bedding, and foliation.

To the west, the apparent structure is more complicated. Most of the Catawba 7-1/2′ quadrangle is occupied by an open southwest-plunging synform, with its axis passing close to Murrays Mill, 4 km southwest of the town of Catawba. The core of the synform is occupied by coarse-grained schist and pegmatite of the Inner Piedmont. Flanking these are schists, amphibolites, and amphibolitic metatuffs of Kings Mountain type, although without the more diagnostic Kings Mountain lithologies, in which foliation (and presumably bedding) swings from west-dipping northeast-southwest and north-south attitudes on the east limb to south-dipping east-west and finally northeast-southwest attitudes on the north limb. Northeast of these, a body of foliated porphyritic granite, apparently correlative with the High Shoals, is elongate northwest-southeast, and so roughly conforms to the open curve of the Murrays Mill synform, as do amphibolites and felsic gneisses further northeast to, and across, the Catawba River.

In last year's guidebook I described a cataclastic zone extending southward from the Davie County Triassic basin, separating the Inner Piedmont and Charlotte belts (the latter perhaps including some Kings Mountain equivalents) (Milton, 1980). Further reconnaissance brings this zone south, curving to the west to pass just south of Statesville to the Catawba River between Interstate 40 and US Rte. 64-70. Fault activity at a late stage in the regional geologic history (Mesozoic?) is indicated by unconsolidated gouge and quartz-lined vugs, and probably somewhat earlier prehnite- and laumontite-filled veinlets. Earlier phases of activity may be reflected in a complex history of polymetamorphism exhibited by Inner Piedmont schists in the fault zone, which involves solution of kyanite, staurolite, and garnet, growth of muscovite, margarite, and chlorite and probably still later postkinematic chloritoid.

Near Eufola, the fault zone separates steeply dipping Kings Mountain(?) rocks on the south from Inner Piedmont rocks with shallow southerly dips on the north. Farther west, where Kings Mountain rocks in the north limb of the Murrays Mill synform and Inner Piedmont rocks to the north have roughly parallel attitudes and both consist largely of biotite and hornblende schists, the Eufola fault (as it may be called) is evidenced only by the cataclastic effects. I have not been able to trace it west of the Catawba River, but isolated indications of faulting suggest it may turn to a southwest trend to pass near Maiden (well within the Inner Piedmont), and perhaps connect with a fault mapped by R. Goldsmith (personal commun.) running from just west of Lincolnton to the southwest. What it does not do, is connect in any simple fashion with the Kings Mountain shear zone. Likewise, I have not found any evidence in central North Carolina for a fault between the Kings Mountain and Charlotte belts, such as would correspond with the Central Piedmont suture hypothesized by Hatcher (1980).

Aeromagnetic maps (Daniels and Zietz, 1980) show a pattern of strong short-wavelength anomalies in the Charlotte and Kings Mountain belts that contrasts markedly with the magnetic quiet of the Inner Piedmont. The magnetic boundary, as determined from examination of profiles along individual flight lines, does not coincide with the geologic boundary mapped on the ground near Eufola, but lies about 6 km to the south. One possible explanation is that the Kings Mountain rocks here are in a thin plate thrust to the north. If true (and I have no more substantial evidence to offer), there is an interesting parallelism between the Eufola fault and the similarly transverse-to-structure segment of the Yadkin thrust fault 60 km to the north.

The apparent folding of Kings Mountain and Inner Piedmont rocks as a single package by the Murrays Mill synform is a complication not found in the areas of detailed mapping to the south. The Bandy-Catawba-Barium Springs area contains some complex and significant structure. It is less certain that the exposures are adequate to allow its decipherment.

Although locally there are ambiguities, the boundary between the Kings Mountain and Inner Piedmont belts is, in general, readily mapped. The opposite sides show distinct structural styles and give the impression of being different lithotectonic terranes. The Kings Mountain-Charlotte belt boundary, on the other hand, is, except perhaps along the Boogertown shear zone, less well defined and may be a somewhat arbitrary division between more sedimentary and more volcanic-plutonic facies of a single terrane. Isolated occurrences of quartzite in the Charlotte belt appear to be of Kings Mountain type, as was suggested by Privett (1973). There are more of these widely scattered through the Charlotte belt than were known to Privett and so they cannot be used to trace a direct extension of the Kings Mountain belt but rather indicate the affinity of the entire belt. Further afield, a promising area to look for Kings Mountain equivalents is the poorly known terrane around Winston-Salem and Reidsville. Marble in isolated occurrences near Winston-Salem is said to resemble marble of the Kings Mountain belt (Conrad, 1960) and there is a hint in Espenshade's (1975) reconnaissance mapping of a northeast-plunging synform around Winston-Salem.

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Geologic map of the Kings Mountain belt between Gaffney, South Carolina, and Lincolnton, North Carolina

J. Wright Horton, Jr., 928 National Center, U.S. Geological Survey, Reston, VA 22092

INTRODUCTION

The geology of the region between Gaffney, S.C., and Lincolnton, N.C., has been mapped as part of a reconnaissance mapping program in the Charlotte 2° quadrangle. All 12 stops of the 1981 Carolina Geological Society field trip (Horton and others, this volume) are within this area; their locations are shown on Plate 1.

Previous geologic maps, including those compiled and discussed by Goldsmith and others (1978) and Schaeffer (1981), provided background information and allowed fieldwork to be concentrated in the most critical and least known areas. Aeromagnetic (Daniels and Zietz, 1980) and aeroradioactivity (Daniels and Zietz, in press) maps were helpful in the field, particularly in areas of poor exposure. Plate 1 also benefited from recent detailed mapping in the Grover and Kings Mountain quadrangles (Horton, unpub. data), the Blacksburg South quadrangle (Butler, this volume), and the Kings Creek quadrangle (Godfrey, 1981; Murphy and Butler, this volume).

REGIONAL GEOLOGY

The Kings Mountain belt (Plate 1) was defined by King (1955) to include distinctive metasedimentary rocks such as quartzite, conglomerate, and marble associated with mica schists that are partly volcanic in origin. Dip angles of foliation and compositional layering are typically steep in the Kings Mountain belt (Horton and Butler, 1977), and the metamorphic grade is generally considered to be lower than that of the adjacent belts. The part of the Kings Mountain belt shown in the northern two thirds of Plate 1 is divided into two prongs (Fig. 1), eastern and western, separated by the "High Shoals" granitic gneiss of Horton and Butler (1977).

The Kings Mountain belt is bounded on the northwest by the Inner Piedmont belt and on the southeast by the Charlotte belt (Fig. 1). The geology of these belts is discussed in greater detail by Goldsmith (this volume) and Wilson (this volume). Regional relationships are discussed by Horton and Butler (this volume).

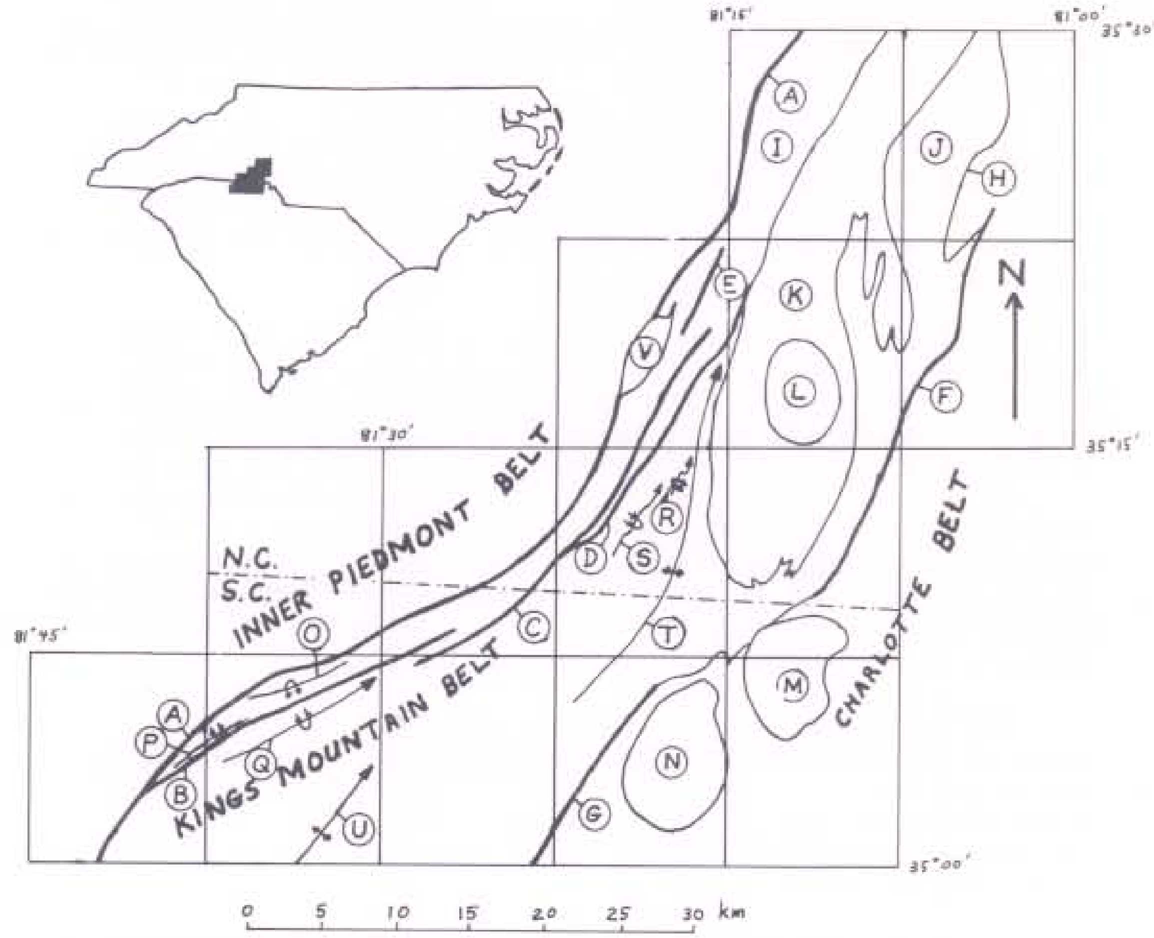

Figure 1. Tectonic map of the study area. The following features are labeled: (A) Kings Mountain shear zone; (B) Blacksburg shear zone; (C) Kings Creek shear zone; (D) unnamed shear zone; (E) Long Creek shear zone; (F) Boogertown shear zone; (G) unnamed shear zone, possibly an extension of the Boogertown zone; (H) arbitrary boundary between the Kings Mountain and Charlotte belts in Lincoln County; (I) "western prong" of the Kings Mountain belt; (J) "eastern prong" of the Kings Mountain belt; (K) "High Shoals" granitic gneiss; (L) postmetamorphic granite at Gastonia; (M) postmetamorphic granite at Clover; (N) postmetamorphic granite near York; (O) Canoe Creek antiform (F_2); (P) Limestone Springs synform (F_2); (Q) Cherokee Falls synform (F_2); (R) Crowders Mountain antiform (F_1); (S) Sherrars Gap synform (F_1); (T) South Fork antiform (F_2); (U) McKowns Creek antiform (F_2); (V) granite at Sunnyside, believed to be Cherryville Quartz Monzonite.

The Inner Piedmont belt is characterized by low undulatory dips and its complex structure is discussed by Goldsmith (this volume). In the area shown on Plate 1, the Inner Piedmont consists primarily of layered biotite gneisses, mica schists, amphibolites, and intrusive granitoids. These granitoids include the Toluca Quartz Monzonite and the Cherryville Quartz Monzonite (Griffitts and Overstreet, 1952).

The Toluca forms lenticular bodies concordant with the regional foliation (Plate 1). It is found only in the Inner Piedmont belt. The age of the Toluca is poorly known, but a Cambrian age is inferred on the basis of limited uranium-lead isotopic data (Davis and others, 1962; Odom and Fullagar, 1973).

The Cherryville occupies a large area of the Inner Piedmont in the region shown on Plate 1; a coarse-grained phase of the Cherryville can be seen at stop 3. An isolated body, believed to be Cherryville, lies partly within the Kings Mountain belt at Sunnyside, N.C. (Fig. 1; Plate 1). Contacts are mostly concordant but locally discordant with the country rock foliation. Kish (1977) reported a rubidium-strontium whole rock isochron age of 341 ± 11 m.y. for the Cherryville, 343 ± 14 m.y. for related granite pegmatite, and 352 ± 10 m.y. for spodumene pegmatite in the area. Dikes and sills of spodumene pegmatite (stop 4) are concentrated in a narrow belt along the southeastern flank of the Inner Piedmont near the Kings Mountain shear zone.

The relatively small lenticular granite bodies on the southeastern flank of the Inner Piedmont belt near Gaffney, S.C., may be outlying bodies equivalent to the "Pacolet Mills" granite of Wagener (1977), which crops out just south of the areas shown on Plate 1. The Rb-Sr whole-rock age of the "Pacolet Mills" is 415 ± 40 m.y. (Fullagar and Kish, this volume).

The Charlotte belt in the area shown on Plate 1 consists largely of premetamorphic plutonic igneous rocks such as hornblende metadiorite, biotite metatonalite, metagranodiorite, and metagranite, and lesser amounts of metavolcanic rocks that are also varied in composition. These rocks were intruded by postmetamorphic igneous rocks such as the gabbro at York, S.C., and the granite bodies northwest of York and east of Clover, S.C. (Plate 1). The gabbro is similar to that in Mecklenburg County, N.C., described by Wilson (this volume). The granite near York has a Rb-Sr age of 322 ± 6 m.y.; its contacts (Plate 1) have been refined considerably from those of Butler (1966).

STRATIGRAPHY OF THE KINGS MOUNTAIN BELT

The Kings Mountain lithotectonic belt is best characterized by the presence of distinctive metasedimentary and metavolcanic rocks, consistent with King's (1955) original definition. It can be characterized by other attributes, such as steep dip angles (Horton and Butler, 1977; Goldsmith, this volume) and lower metamorphic grade relative to adjacent belts (Hatcher, 1972), but these features vary from place to place within and across the characteristic lithologies.

A key to understanding the stratigraphy of the Kings Mountain belt is the South Fork antiform (Fig. 1), which was interpreted as a right-side-up anticline by Kesler (1955), Espenshade and Potter (1960), and Horton and Butler (1977). I support this interpretation on the basis of several observations of indistinct graded bedding on the west limb of the fold, but regard it as tentative because of reversals in the direction of apparent grading that occur along strike even within individual beds. Assuming this interpretation is correct, the stratigraphic sequence is essentially that proposed by Horton and Butler (1977).

Metavolcanic rocks, mostly dacitic to andesitic in composition, are interlayered with quartz-sericite schist in the lower part of the section. The metavolcanic facies include hornblende gneiss, feldspathic biotite gneiss, and phyllitic or schistose volcaniclastic rocks (Horton, 1977). Murphy and Butler (this volume), who describe some of these rocks in detail, interpret them as moderately reworked crystal tuffs containing local beds of coarser pyroclastic material in the form of lapillistone. The metavolcanic rocks grade laterally and vertically into quartz-sericite schist, called locally "the schist of Kings Creek" by Murphy and Butler (this volume). This schist represents a mixture of epiclastic or sedimentary material and extensively altered pyroclastic material. The schistose pyroclastic rock at stop 11 is one of the uppermost metavolcanic units, according to Murphy and Butler (this volume).

These facies grade upward into a sequence of rocks that is largely metasedimentary in origin. These rocks include quartz-sericite schist (stop 1), high-alumina quartzite (stop 7), and at least three beds of quartz-pebble metaconglomerate (stop 9; France and Brown, this volume; Hatcher and Morgan, this volume). Two of the metaconglomerate beds are separated by an intervening unit of manganiferous schist (stop 10).

Lithologies of the Kings Mountain belt west of the Kings Creek and Blacksburg shear zones (Fig. 1, Plate 1) are somewhat different from those described above, which are east of the shear zones. These rocks, informally called the "Blacksburg" lithologies by Horton (1977), include sericite schist or phyllite, marble (stop 2), micaceous quartzite, and lenses of amphibolite and calc-silicate rock. The sericite schist is commonly graphitic and generally contains more white mica and less quartz and plagioclase than the sericite schist to the east. If one assumes a conformable stratigraphic sequence and minimum structural disharmony across the shear zones, these lithologies may represent the youngest rocks of the Kings Mountain belt. These assumptions are risky, however, because stratigraphy cannot be correlated across the shear zones.

PLUTONIC ROCKS OF THE KINGS MOUNTAIN BELT

Biotite metatonalite intrusions are most abundant in the lower parts of the Kings Mountain belt section. Their age is inferred to be late Proterozoic Z on the basis of preliminary uranium-lead isotopic data from zircons (J. W. Horton and T. W. Stern, unpub. data). These sodium-rich plutonic rocks are generally more silicic but otherwise similar in major-element composition to pyroclastic rocks of the Kings Mountain belt (J. W. Horton, unpub. data). Murphy and Butler (this volume) interpret the metatonalite bodies as shallow sills and plugs that intrude their own volcanic ejecta. Sodium-rich volcanic and plutonic rocks of similar age are known in the Carolina slate belt and Charlotte belt (Butler and Ragland, 1969; Fullagar, 1971) and metatonalite bodies identical with those of the Kings Mountain belt are widespread along the western side of the Charlotte belt (Plate 1, Fig. 1).

The rocks mapped as metatrondhjemite (Plate 1) are more leucocratic than those mapped as metatonalite but are similar in composition and may be related. The metatrondhjemite, like the metatonalite, was included in the Bessemer Granite of Keith and Sterrett (1917). The largest bodies crop out near Bessemer City, N.C., and in the core of the Cherokee Falls synform near Blacksburg, S.C.

The metagabbro and metadiorite unit (Plate 1) consists of hornblende-quartz metagabbro and hornblende-quartz metadiorite. Dikes of these rocks cut the metatonalite (Espenshade and Potter, 1960; Murphy and Butler, this volume). Similar rocks occur in the Charlotte belt (Plate 1).

The "High Shoals" granitic gneiss (stop 5) is a coarse-grained, porphyritic, gneissic biotite granite or granitic gneiss that occupies an area of batholithic size within the Kings Mountain belt (Plate 1). It was mapped as Yorkville Granite by Keith and Sterrett (1931) and as Yorkville Quartz Monzonite by Espenshade and Potter (1960). Horton and Butler (1977) introduced the informal name, "High Shoals," to distinguish it from younger, postmetamorphic granites such as the one near York, S.C., from which the name Yorkville was derived. Paleomagnetic data suggest an age younger than Taconic (Brown and Barton, 1980). Previous reconnaissance maps seriously underestimated the enormous size of the "High Shoals." In addition to the area shown by Horton and Butler (1977, Fig. 3), it also occupies a major part of their unit of undivided "biotite gneiss and granitic gneiss".

The postmetamorphic porphyritic biotite granite pluton at Gastonia, N.C. (Plate 1), resembles the plutons in the Charlotte belt near York and Clover and is probably about the same age.

Mesozoic diabase dikes in this region are nearly vertical and typically strike N. 40°-50° W. Most range from a few centimeters to a few meters in thickness. The largest, which crops out near Henry Knob, is about 15 m thick and 13 km long. The Triassic-Jurassic age range is confirmed by paleomagnetic as well as isotopic data (deBoer and Snider, 1979).

STRUCTURE OF THE KINGS MOUNTAIN BELT

Mesoscopic structure and deformational sequences in the Kings Mountain belt are described elsewhere in this volume. The most detailed sequences based on overprint criteria, those sequences at stop 4 in the field guide (Horton and others, this volume) and in the area of Duke Power Company's Cherokee Nuclear Plant site (Schaeffer, this volume), are remarkably similar and both include five episodes of folding, F_1-F_5, and related deformation, D_1-D_5. The map pattern is controlled largely by folds of the two earliest episodes, F_1 and F_2. Two foliations, S_1 and S_2, are conspicuous throughout the Kings Mountain belt; S_2 appears to be the dominant foliation in most areas. D_3 structures are conspicuous in the major shear zones (Fig. 1) and sporadic elsewhere. D_4 and D_5 structures are also sporadic but they rarely affect the map pattern.

Macroscopic folding

The map pattern in the southern half of the area is dominated by the South Fork antiform and the Cherokee Falls synform (Fig. 1). The South Fork antiform was previously interpreted as an F_1 fold (Horton and Butler, 1977) but is now classified as F_2 along with the Cherokee Falls synform. An older schistosity, S_1, has been mapped around the hinge of the South Fork antiform, and this schistosity is folded by mesoscopic F_2 folds in the hinge area. The younger dominant schistosity appears to be axial planar to the South Fork antiform and is classified as S_2 in this part of the Kings Mountain belt. Other macroscopic F_2 folds (Fig. 2) include the McKowns Creek antiform, the Limestone Springs synform, and the Canoe Creek antiform. Butler (this volume) and Schaeffer (this volume) also interpret the McKowns Creek and Canoe Creek folds as F_2 antiforms.

Isoclinal F_1 folds of mappable scale have been recognized in the Kings Mountain quadrangle (Horton, unpub. data) and may be more widespread than Plate 1 suggests. The Sherrars Gap synform (Espenshade and Potter, 1960; Horton, unpub. data) and the Crowders Mountain antiform (Horton, unpub. data) are the best documented examples of macroscopic F_1 folds (Fig. 1). These folds are refolded by macroscopic F_2 folds which produce the same dextral asymmetry on opposite limbs. Furthermore, the younger dominant schistosity, S_2 in these areas, intersects the older bedding, S_o, and schistosity, S_1, with the same angular relationship across both limbs of these folds.

Fold patterns show disruption on all scales, particularly along the western side of the Kings Mountain belt, and there are many discontinuities roughly parallel to the regional schistosity. These discontinuities are interpreted as tectonic slides or ductile faults that formed locally in areas of intensified D_2 deformation. The tectonic slides are best documented in the Blacksburg South quadrangle, where they have been described by Butler (this volume).

The "High Shoals" granitic gneiss truncates the eastern limb of the South Fork antiform near Bessemer City, N.C., but units such as the manganiferous schist continue to outline the eastern limb of the fold as discontinuous screens within the "High Shoals" (Plate 1). This indicates that the "High Shoals" was emplaced during or after the D_2 deformation. Nevertheless, the foliation in the "High Shoals" is parallel to S_2 outside the pluton and is believed to be the regional S_2. (Xenoliths in the "High Shoals" have an older foliation, S_1, not present in the "High Shoals" itself.) The "High Shoals" was thus emplaced after the formation of major F_2 folds, such as the South Fork antiform, but prior to the latest flattening or shearing on S_2. Perhaps the foliation in the High Shoals was produced by synkinematic flow.

Shear zones

Figure 1 shows several ductile shear zones or zones of steeply dipping retrogressive phyllonitic and mylonitic rocks that overprint structures related to the two earliest deformational episodes, D_1 and D_2. These shear zones are found along both margins of the Kings Mountain belt as well as within it (Horton, 1980, 1981). Most of these shear zones, but not all, coincide with lithologic boundaries or contacts.

The Kings Mountain shear zone of Horton (1981), which separates the Kings Mountain and Inner Piedmont belts, is the most profound discontinuity (see stop 6 of Horton and others, this volume). It is the only one that extends across the entire length of the area shown in Figure 1. Lithologic suites are very different across the Kings Mountain shear zone and rock units of the terranes on both sides are truncated against it (Horton, 1981). The steeply dipping slip cleavage, S_3, associated with the zone is overprinted on structures produced during the first two deformational episodes, D_1 and D_2, and structural styles are notably different on opposite sides (Horton, 1981). The Inner Piedmont side is characterized by gentle to moderate dip angles and by recumbent to inclined F_2 folds. The Kings Mountain belt side is characterized by steep dip angles and by essentially upright F_2 folds. S_2 is generally the dominant foliation in the Kings Mountain belt, whereas S_1 is generally more pronounced in the Inner Piedmont.

The Boogertown shear zone marks the eastern boundary of the Kings Mountain belt near Gastonia, N.C., but it cannot be traced northward into Lincoln County (Fig. 1, Plate 1). The boundary between the Kings Mountain and Charlotte belts is somewhat arbitrary in the northern part of the area shown on Plate 1, and some of the metavolcanic rocks and metatonalites could be considered part of either belt.

Gold, pyrite, and iron deposits occur along some of the shear zones within the Kings Mountain belt (Fig. 1). The Kings Mountain mine on the Kings Creek shear zone, and the Long Creek mine on the Long Creek shear zone (Fig. 1), were among the most productive gold mines in the region (Pardee and Park, 1948). Massive pyrite is concentrated in layers parallel to the mylonitic foliation at the Oliver pyrite mine on the

Long Creek shear zone. Several old iron mines and prospects were located in oxidized gossan overlying sulfide concentrations in these shear zones.

REGIONAL METAMORPHISM

The metamorphic isograds in Figure 2 are based on a combination of thin sections, field observations, and panned stream sediments. The staurolite and sillimanite isograds were defined by the first appearance of each mineral. Control is not adequate to permit the delineation of additional isograds at this time.

The conventional characterization of the Kings Mountain belt as lower in metamorphic grade than adjacent belts is correct in the sense that the Kings Mountain belt contains an area of greenschist-facies and/or epidote-amphibolite facies metamorphism (enclosed by the staurolite isograd in Figure 2), which is lacking in nearby parts of the adjacent belts. However, the Kings Mountain belt also contains areas metamorphosed to upper amphibolite facies (sillimanite zone).

The sillimanite isograd in the Kings Mountain belt is within a few hundred meters of the "High Shoals" granitic gneiss and is essentially parallel to the "High Shoals" contact (Fig. 2). This indicates that the emplacement of the "High Shoals" was either coeval with or later than the peak of amphibolite-facies metamorphism in the north-central part of the Kings Mountain belt. The staurolite isograd deviates significantly from parallelism with the "High Shoals," but like the "High Shoals," it transects D_2 structures such as the South Fork antiform. The age of the "High Shoals," if it could be determined isotopically, would be extremely useful for determining the time of peak metamorphism and D_2 deformation in this part of the Kings Mountain belt. Whether the thermal peak of metamorphism in this area was simultaneous with the peak of metamorphism in other parts of the Kings Mountain belt, such as the area described by van Gelder and McSween (this volume), is not yet known.

Aluminum silicate minerals in the Kings Mountain belt include andalusite, kyanite, and sillimanite. Disequilibrium assemblages of all three polymorphs have been observed at several localities (Espenshade and Potter, 1960; Horton, 1977) near the "High Shoals" granitic gneiss. These assemblages suggest that the pressure at the time of peak metamorphism was close to, but slightly greater than that of the triple point in the Al_2SiO_5 system.

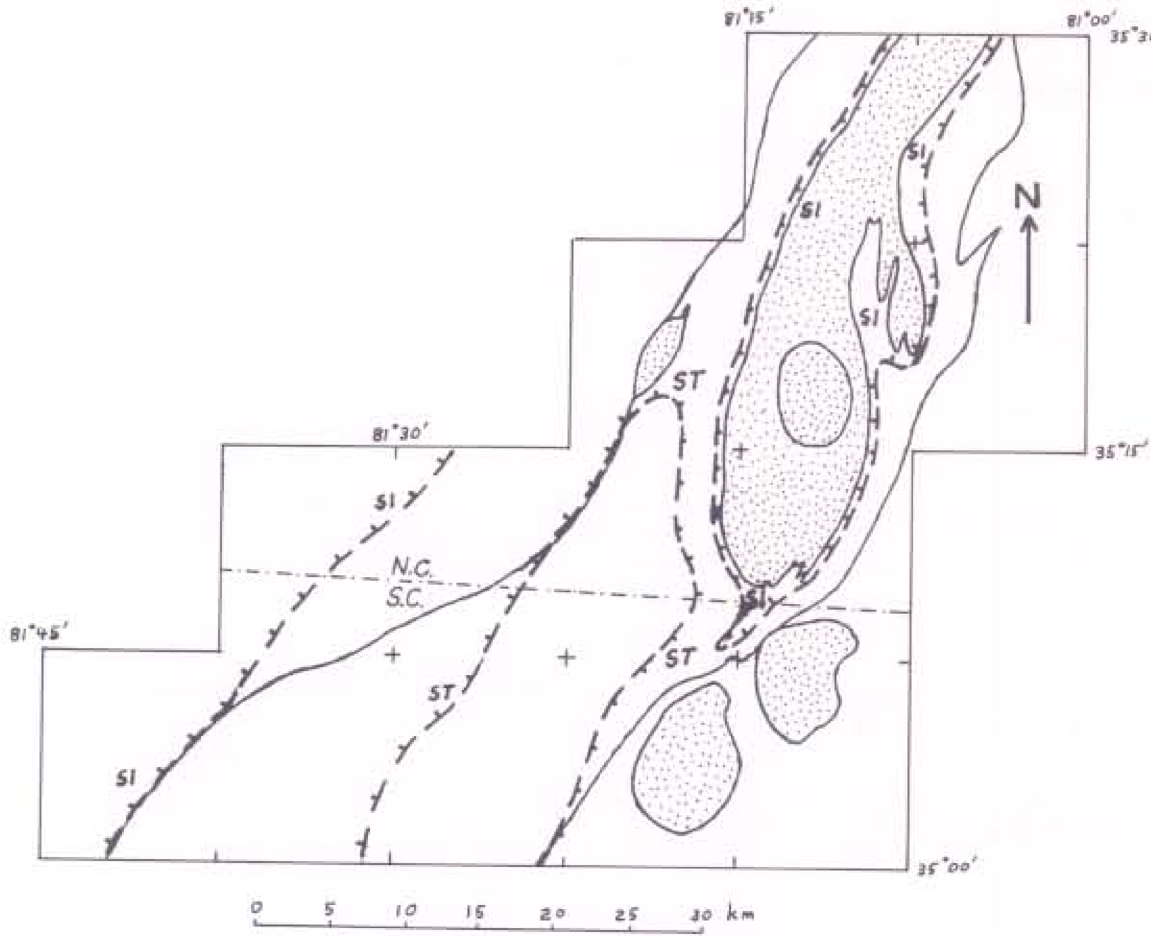

Figure 2. Metamorphic map of the study area. The staurolite (ST) and sillimanite (SI) isograds are represented by heavy dashed lines; tick marks point to higher grade. Solid lines are lithotectonic boundaries from Figure 1. Stippled areas represent synmetamorphic and postmetamorphic granitoids.

Kyanite and sillimanite occur in the Inner Piedmont belt, but in contrast to the Kings Mountain and Charlotte belts, andalusite has not been observed. The lack of andalusite suggests that the present level of exposure in the Inner Piedmont was under higher pressure and, therefore, was deeper at the time of peak metamorphism.

The Kings Mountain shear zone appears to be a metamorphic as well as a structural discontinuity (Fig. 2). The greenschist-facies and/or epidote-amphibolite facies area of the Kings Mountain belt enclosed by the staurolite isograd is bounded on the northwest by the shear zone between Grover, S.C., and Bessemer City, N.C. (Fig. 2). Similarly, the sillimanite isograd in the Inner Piedmont appears to be cut off along the shear zone near Gaffney, S.C. (Fig. 2). Whether the terranes on opposite side of the Kings Mountain shear zone were metamorphosed simultaneously or at different times is not yet known.

DISCUSSION

Metavolcanic facies are an important part of the Kings Mountain belt that may be underemphasized in some regional syntheses. The metavolcanic and metasedimentary facies appear to belong to a single terrane, and the upward transition from dominantly volcanic to dominantly sedimentary facies is gradual. This facies transition is an unlikely place for a premetamorphic suture as proposed by Hatcher and Morgan (this volume). A more likely place to look for a premetamorphic tectonic boundary or unconformity, if one exists within the Kings Mountain belt, is between the units that lie west of the Kings Creek and Blacksburg shear zones and the remainder of the Kings Mountain belt. Unfortunately, contact relationships are obscured by the retrogressive shear zones, which postdate the thermal peak of metamorphism, and by intervening plutons (Plate 1; Fig.1).

The arbitrary nature of the boundary between the Kings Mountain and Charlotte belts in some areas (Fig. 1) and the similarity of metavolcanic, metasedimentary, and plutonic rocks in the two belts, suggests that these belts are dominantly sedimentary and volcanic-plutonic parts of the same terrane. The central and eastern parts of the Kings Mountain belt, which merge with the Charlotte belt, are dominantly antiformal and probably anticlinal, but there is no evidence of a corresponding synform on the western side of the Charlotte belt. The western side of the Kings Mountain belt, which appears to contain the youngest rocks, may be dominantly synformal.

Hatcher and Zietz (1980) proposed the existence of a cryptic suture, the "central Piedmont suture," separating the eastern edge of the North American craton from a terrane to the east underlain by mafic crust. They located this suture in the Piedmont along the boundary between the Kings Mountain and Charlotte belts. Gravity and magnetic data suggest that a major crustal boundary lies near the "central Piedmont suture" of Hatcher and Zietz (1980), but there is no evidence of its expression at the surface between the Kings Mountain and Charlotte belts. The Kings Mountain and Inner Piedmont belts, on the other hand, appear to be different lithotectonic terranes, and the Kings Mountain shear zone, which separates them, appears to be a metamorphic as well as a lithologic and structural discontinuity. The Kings Mountain shear zone is the most important tectonic boundary at the surface in this area (Fig. 1). Its relationship, if any, to Hatcher and Zietz's (1980) "central Piedmont suture" is unclear. Perhaps it merges with the "central Piedmont suture" beneath the surface or truncates an older Paleozoic suture at depth.

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Structural patterns in the Inner Piedmont of the Charlotte and Winston-Salem 2° quadrangles, North Carolina and South Carolina

Richard Goldsmith, U.S. Geological Survey, Reston, VA 22092

INTRODUCTION

Structural patterns have been compiled on a small scale in the Charlotte 2° quadrangle and part of the Winston-Salem 2° quadrangle, North Carolina and South Carolina, as an aid in interpreting the tectonic setting of part of the Inner Piedmont. The patterns of foliation and lineation shown are primarily derived from measured attitudes plotted on 1:24,000 scale quadrangle maps during reconnaissance mapping in the Charlotte 2° quadrangle by myself, D.J. Milton, J.W. Horton, Jr., and the late J.B. Hadley. The remaining data were condensed from published maps by Bryant and Reed (1970), Overstreet and others (1963), Espenshade and others (1975), Rankin and others (1972), and Horton (1977).

GENERAL SETTING

The Inner Piedmont of North Carolina and South Carolina (Fig. 1) consists of layered biotite gneiss, mica schist and quartzite, migmatitic biotite and hornblende gneiss, amphibolite, widely distributed granitoid masses of different size, composition, and age, and scattered small ultramafic masses. The internal structure is complex, and polyphase folding and nappe structures are evident (Griffin, 1971, 1974; Hatcher, 1978; Hatcher and Butler, 1979; Verseput, 1980; Clarke, 1981). In North Carolina, the Inner Piedmont is bounded on the northwest by the Brevard zone and the imbricate thrusts bordering the Grandfather Mountain window, on the north by the Yadkin thrust bounding the Sauratown Mountain anticlinorium, and on the southeast and east by faults along the west edge of the Kings Mountain belt (Horton, 1981) and by faults extending southwestward from the Davie County Triassic basin (Milton, 1980; and this volume). The Inner Piedmont is considered to be allochthonous (Rankin, 1975; Hatcher, 1978; Cook and others, 1979).

Metamorphism in the Inner Piedmont is Barrovian and the grade is low to medium (garnet to kyanite zones) on the flanks and high (sillimanite-muscovite zone) in the central part of the belt. This patterns suggests an anticlinal structure. However, overall attitudes of foliation and layering indicate an asymmetrical synformal structure with the trough towards the southeast side. Possibly the metamorphism is not Barrovian and the apparent inversion of the isograds is due to post-metamorphic deformation which has brought up a higher pressure facies on the flanks of the synform as suggested by Rankin (1975), following Morgan (1972). However, the texture and mineral relationships in the rocks make this seem unlikely. Possibly the Inner Piedmont is the inverted nose of a large nappe, or, more likely, a stacked series of nappes with higher grade rocks thrust over lower grade. Le Fort (1975, p. 27-30) has a good discussion of explanations for terranes having inverted isograds. A better grasp of the stratigraphy of this part of the Inner Piedmont might help resolve this matter.

PATTERNS OF FOLIATION AND LINEATION

Compositional layering, most of which is interpreted as transposed bedding, is parallel to a pervasive primary foliation nearly everywhere in the Inner Piedmont. In a few places this foliation can be seen to be axial planar to minor folds. However, the foliation pattern in general parallels the distribution of bedrock units.

The pattern of foliation (Fig. 1) illustrates the quasi-synformal nature of the Inner Piedmont. Moderate southeastward dips and linear trends of foliation prevail southeast of the Brevard zone and the Yadkin thrust. The parallelism of the foliation southeast of the Brevard zone with thrusts bounding the Grandfather Mountain window was noted by Bryant and Reed (1970). A similar parallelism is evident along the Yadkin fault. Thrusts and sheared-off overturned folds are probably present within the Inner Piedmont southeast of the Brevard zone. Tight isoclinal westward-verging folds, in places sheared off, with moderately dipping axial planes, are present in outcrops in this general area. East of the west-facing slopes of the Brushy Mountains and South Mountains, the pattern appears less linear because of lower dip angles and these fronts may represent a tectonic boundary. In the central part of the Inner Piedmont, the many flat dip symbols and the contorted pattern reflect the overall flat attitude of the foliation and the superposition on it of later folding. Zones of linear foliation indicate steeper dips than elsewhere. Along the southeast side of the central zone, the foliation tends to dip west, but is locally reversed because of later folding. Dips steepen to near vertical in, and east of, the Kings Mountain shear zone (Horton, 1981). The change in pattern from the Inner Piedmont into the Kings Mountain belt is more abrupt and discordant than is the change into the Blue Ridge across the Brevard and Yadkin faults.

Most lineations shown on Figure 2 represent measurements of fold axes, but a few are mineral orientations, primarily of sillimanite. Bryant and Reed (1970) note that mineral lineations in their part of the Inner Piedmont are parallel to fold axes. Most fold axes that were measured during reconnaissance belong to the dominant fold system in the Inner Piedmont: these are folds (F_2) that fold foliation and are isoclinal to tight, inclined

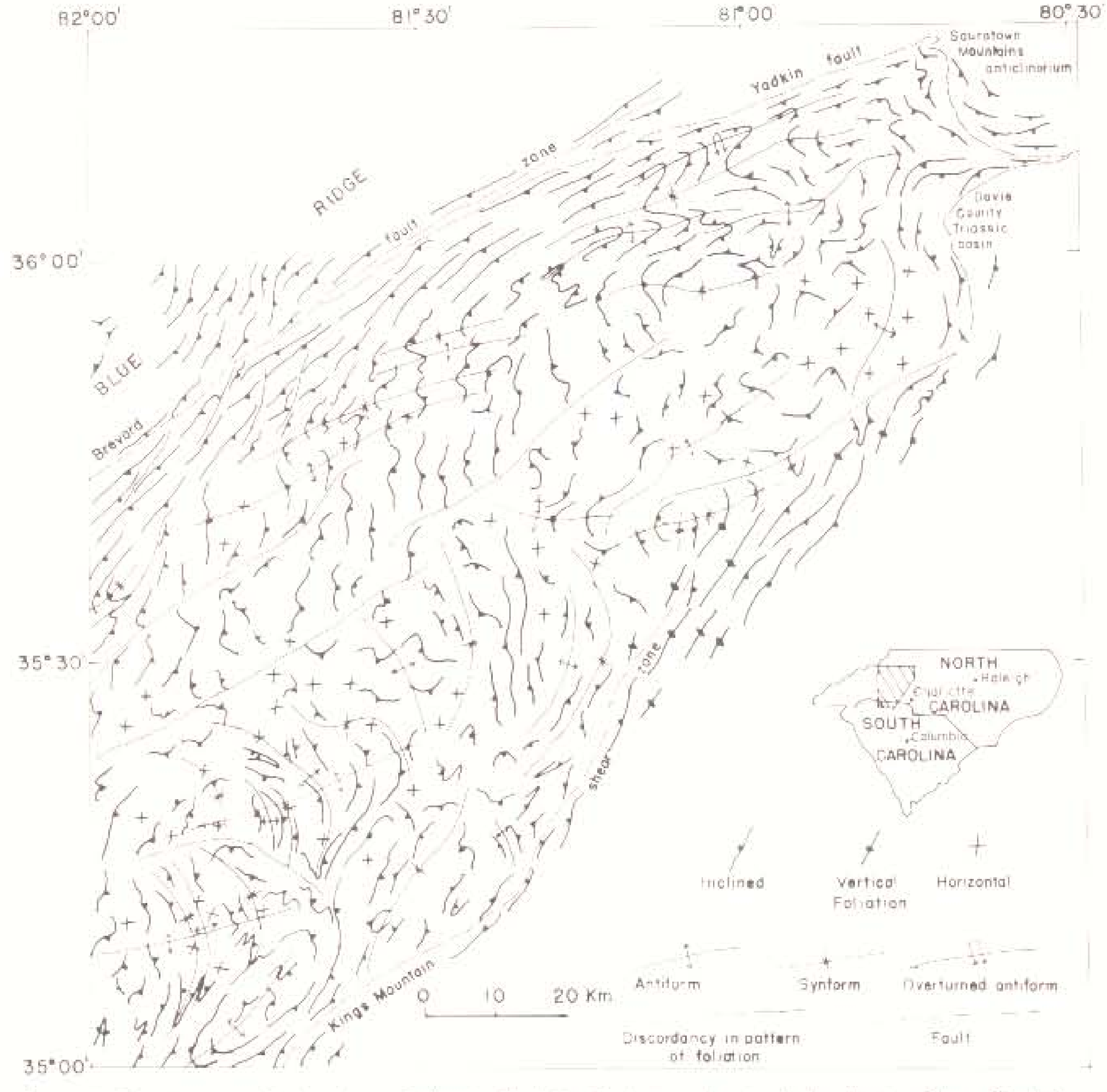

Figure 1. Form lines on foliation, Inner Piedmont, Charlotte 2° sheet and part of the Winston-Salem 2° sheet

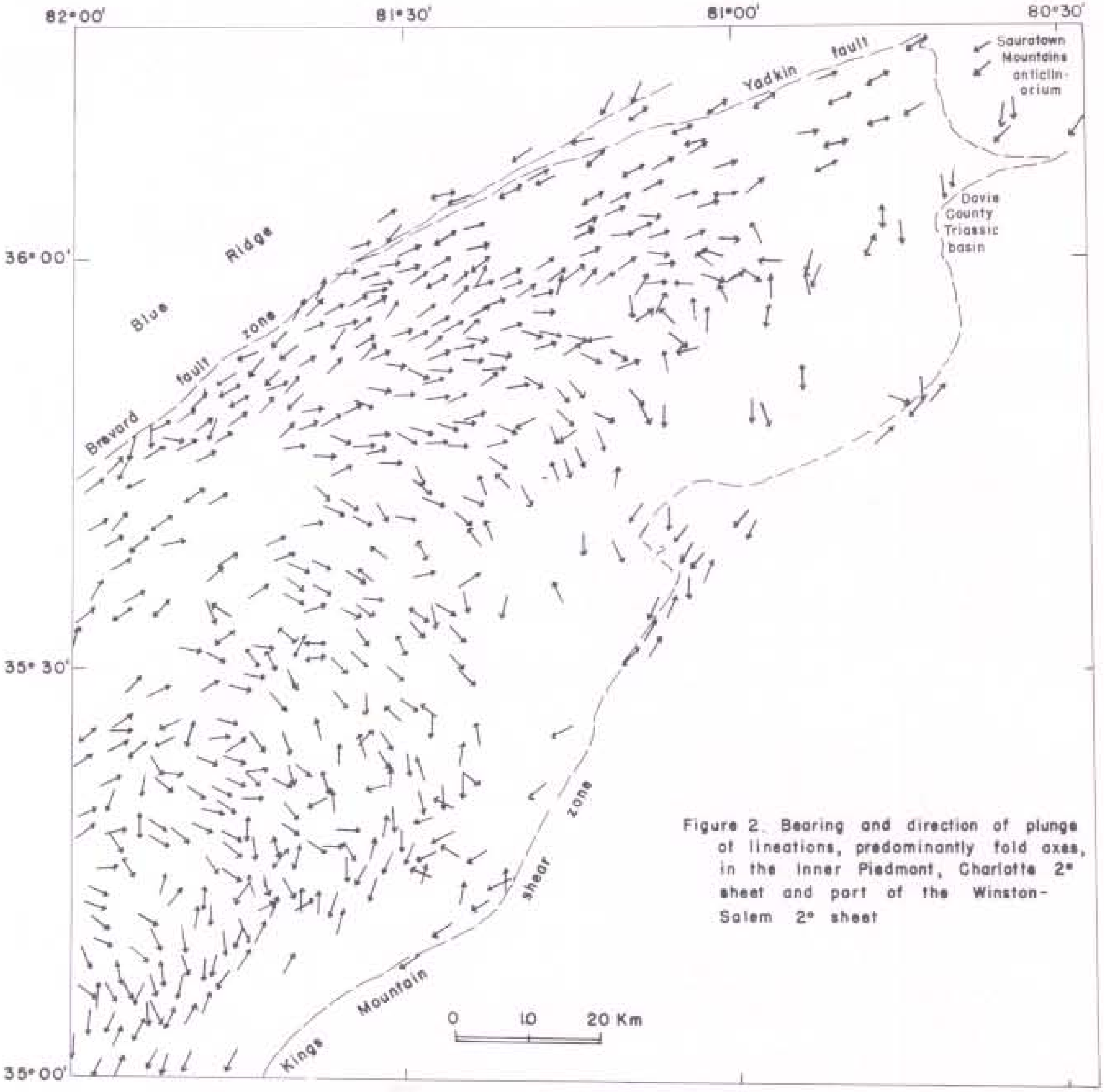

Figure 2. Bearing and direction of plunge of lineations, predominantly fold axes, in the Inner Piedmont, Charlotte 2° sheet and part of the Winston-Salem 2° sheet

and recumbent. Vergence in these folds is usually westward. Only a few folds of layering to which foliation is axial planar (F_1) were seen. Of the folds measured, a few are tight to open folds (F_{3+}) which refold F_2 folds and have axial surfaces steeper than those of F_2. In places these form crinkles, kinks, rolls, or simple flexures. These are of more than one generation. A common type of late fold is an abrupt monoclinal flexure with a northerly or northeasterly trend and with east or southeast side down. Such flexures may be present on a large scale and account for part of the pattern of foliation on Figure 1. Broad warps tend to have an easterly alignment.

Measurements of axial surfaces of the different fold generations are too few for meaningful evaluation. Where measured, however, the surfaces, mostly of F_2 folds, trend northerly and dip to the east, although dips to the west are present locally due to refolding. F_2 folds do not clearly show in the foliation pattern (Fig. 1) although their presence can be inferred from the general pattern. Post-F_2 folds are fairly clearly indicated by flexures in foliation trends. The curvilinear traces of folds shown in Figure 1 are probably drawn on crests, rather than on hinges of folds, if these folds are indeed F_2 folds. F_2 folds typically have fairly flat to gently dipping axial surfaces.

The pattern of lineations (Fig. 2) conforms fairly well to the foliation pattern. The lineations form a broad arch in plan view across the Inner Piedmont having generally northeasterly plunges on the west side, easterly and southeasterly plunges in the central zone, and southerly to southwesterly plunges near the Kings Mountain belt. The lineations on the whole have shallow plunges reflecting the overall flatness of the foliation, although steep plunges occur along with shallow plunges in the Brevard and Kings Mountain shear zones (Fig. 3). The fold axes of early minor folds (F_2) tend to follow the foliation, whereas axes of later folds lie athwart the pattern, marking the axes of post-F_2 folds and of crenulations. This can be seen in the central part of the quasi-synform where the northeast-trending lineations are axes of post-F_2 folds (Figs. 2 and 3). Without the F_2 axes, the lineation pattern would probably show a fairly uniform northeast trend.

DISCUSSION

Domains of coherent pattern of foliation bounded by zones of abrupt change are suggested in Figure 1. Obvious discontinuities are indicated by solid lines. Some of these discontinuities may be nappe boundaries. However, specific boundaries of such nappes, if present, were not detected during reconnaissance mapping. Many structural features seen in outcrop throughout the area suggest the possibility of shearing off on a larger scale. Overstreet and others (1963) show curvilinear faults on the western part of their map of the Shelby quadrangle that may be such boundaries. Small granitoid masses are frequently aligned along shear or slip planes in outcrop (Fig. 4; see also Hatcher and Butler, 1979, Fig. 60). Larger granite masses may be located along large discontinuities, although this remains to be proven.

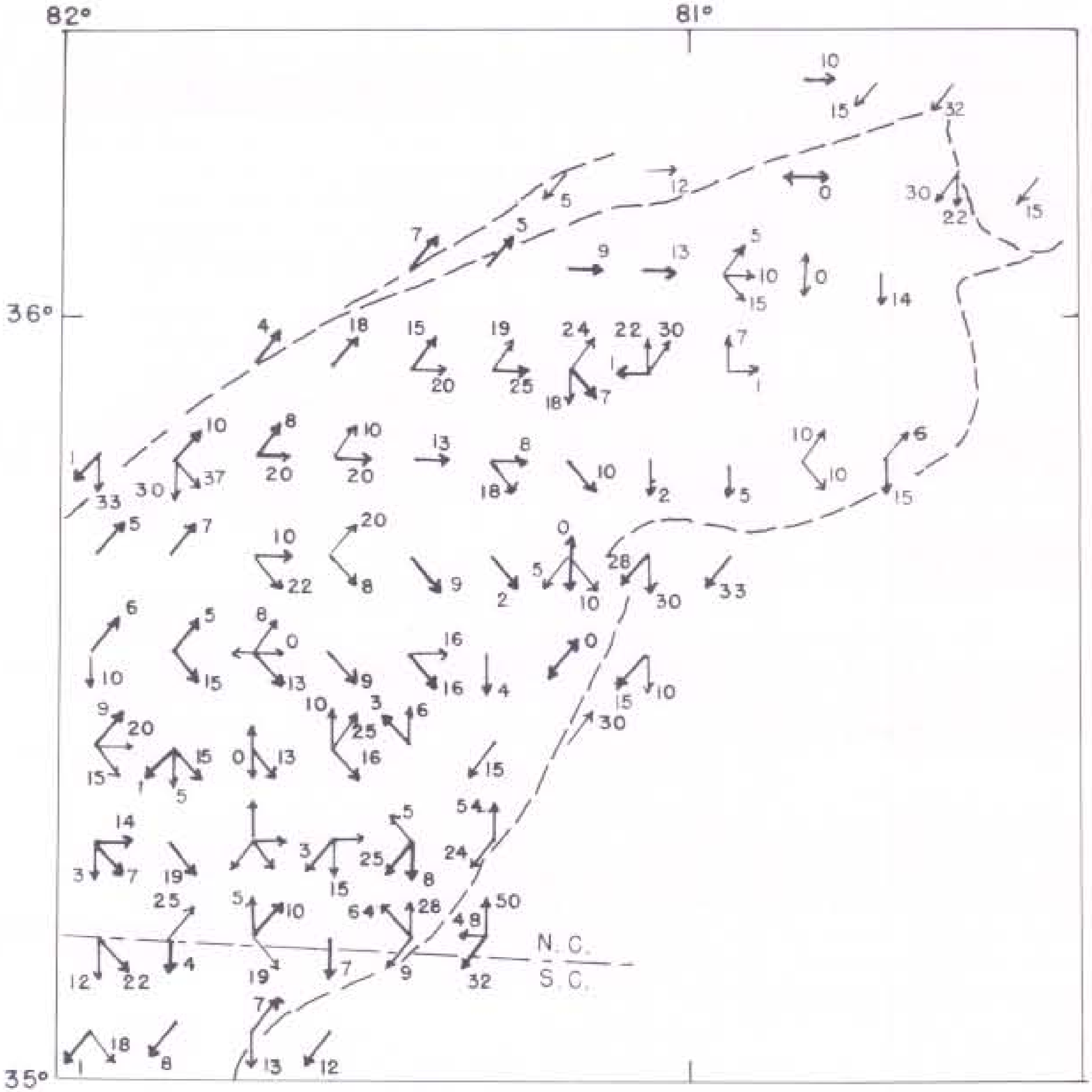

Figure 3. Direction and average plunge of lineations by semi-quadrants in each 7 1/2' quadrangle in the Inner Piedmont, Charlotte 2° sheet and part of the Winston-Salem 2° sheet. Preponderant lineations are shown by thick lines. Dashed lines are bounding faults. Lineations without numbers indicate direction only.

Most of the boundaries of the Inner Piedmont are marked discordancies. Along and southeast of the Brevard zone, and along and south of the Yadkin fault, the foliation and lineation seem to be parallel to the thrusts bounding the Grandfather Mountain window and to the Yadkin fault, but the pattern is discordant across them. The plunge of lineations and dip of foliation in the Inner Piedmont is in general northeast almost to the Yadkin fault where foliation and lineations reverse direction and dip and plunge to the south off the Sauratown Mountain anticlinorium. Yet basement rocks of the Blue Ridge and Sauratown Mountains plunge continuously southeast and south under the Inner Piedmont as indicated by the south and southeast-sloping aeromagnetic gradient (Daniels and Zeitz, 1980). This is further argument for an allochthonous Inner Piedmont. The boundary of the Inner Piedmont with the Kings Mountain belt is clearly one of structural discordance, much more so than the Inner Piedmont boundary to northwest and north. North of the Statesville area, the Inner Piedmont is adjacent to the Charlotte belt and the boundary is apparently a fault. A southeast-trending zone of discordance (Fig. 1) is close to the location of a fault discussed by Milton (this volume) that extends southeast into the Inner Piedmont. The northeast-trending foliation prominent on the flanks of the Inner Piedmont is possibly a result of F_3 folding which has completely transposed the F_2 folds, whereas in the central zone, F_3 folds have not concealed the F_2 folds.

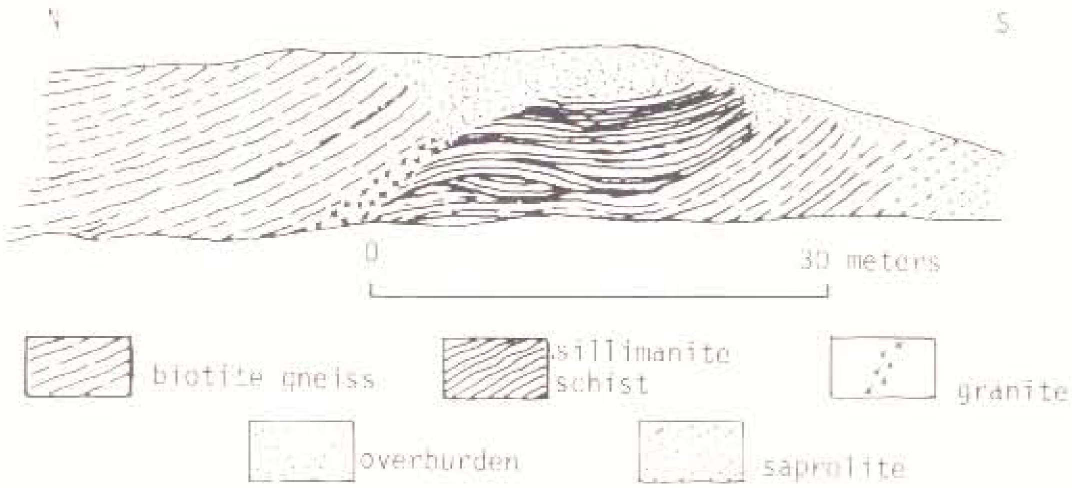

Figure 4. Cut in biotite gneiss thrust over sillimanite schist. Granite occupies discordant zone. Exposed at shopping center off U.S. 64 and 70, Hickory, North Carolina.

Although the northeast trend of the Inner Piedmont is determined by its boundaries, the foliation pattern within the Inner Piedmont is S-shaped in map view and has an overall northerly trend. Clearly an earlier fold system or systems (F_1?-F_2) has been refolded (F_{3+}) and the earlier axes rotated. The later folding, disregarding broad warps, appears to have a northeast trend. The pattern indicates right-lateral movement on the flanks.

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Geologic interpretation of geophysical data from the "Mecklenburg-Weddington" gabbro complex, southern Mecklenburg County, North Carolina

Frederick A. Wilson, U.S. Geological Survey, National Center,
Reston, Va. 22092

INTRODUCTION

The "Mecklenburg-Weddington" gabbro complex is made up of three major gabbro plutons, associated mafic metavolcanic rocks, and smaller granitoid intrusive rocks. The complex is located in the Charlotte belt south of the city of Charlotte in southern Mecklenburg County, N.C., and extends into part of York County, S.C. (Fig. 1). Hermes (1968) interpreted his Mecklenburg gabbro-metagabbro complex as two gabbro plutons, an early pluton (Pzmgbm, Pzmgbo, mvmc; Fig. 2) that was metamorphosed during regional metamorphism and a later post-metamorphic gabbro pluton (Pzgbm). His gravity survey of the younger pluton suggested a thickness of 2.5-6 km. Later geophysical maps of the Charlotte 2° sheet (gravity, Wilson and Daniels, 1980a; aeroradioactivity, Daniels and Zietz, in press; aeromagnetism, Daniels and Zietz, 1980) and reconnaissance geologic maps (Goldsmith and others, 1978; Butler, 1978; Wilson, 1981) defined more accurately the "Mecklenburg" gabbros and the exposure of gabbro near Weddington. Recent petrologic and chemical analysis of Weddington rock samples (Wilson and Daniels, 1981; Wilson, 1981) indicates that this pluton and the other gabbro plutons described by Hermes (1968) are all part of a differentiated gabbro complex.

This paper presents interpretations of the subsurface structure of this gabbro complex based upon the aeroradioactivity, aeromagnetic, and gravity data and structural models.

GEOLOGY

The "Mecklenburg-Weddington" gabbro complex (Fig. 2) contains hornblende gabbro (Pzmgbm, Pzmgbo), pyroxene-hornblende gabbronorite, olivine gabbronorite (Pzgbm, Pzgbp, Pzgbw) troctolite (Pzgbw) and related smaller bodies of diorite, syenite (Pzsy), monzonite (Pzmz), and mafic (mvmc) (Geotimes, 1973) metavolcanic rocks. Small bodies of contemporaneous(?) granodiorite (Pzgdi) and hornfels around the periphery of the gabbros are related to the emplacement of the gabbro complex in an older plutonic complex of quartz diorite (mqdi), tonalite, granodiorite (mgdi), and intermediate (mvi) to felsic metavolcanic (mvf) rocks.

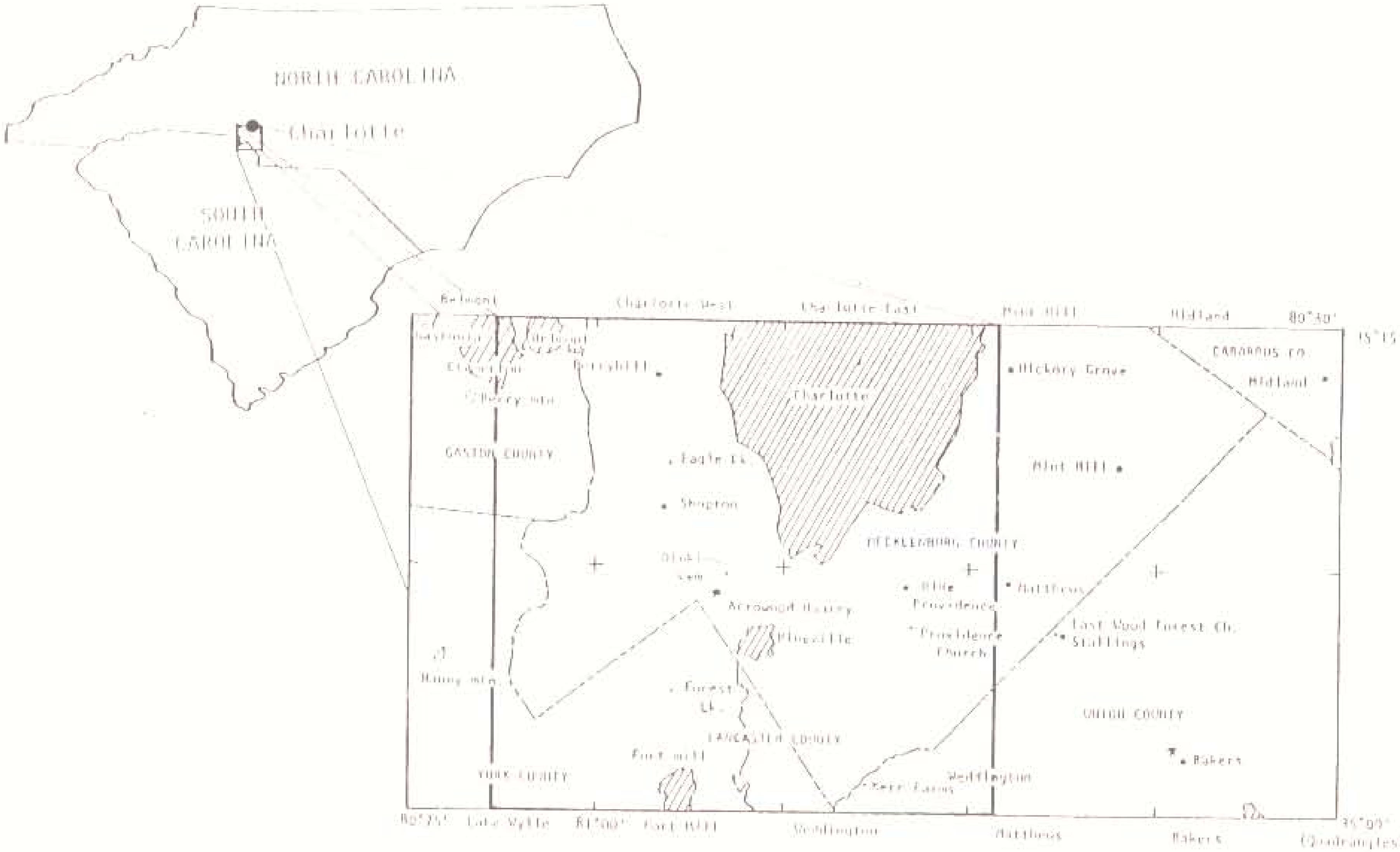
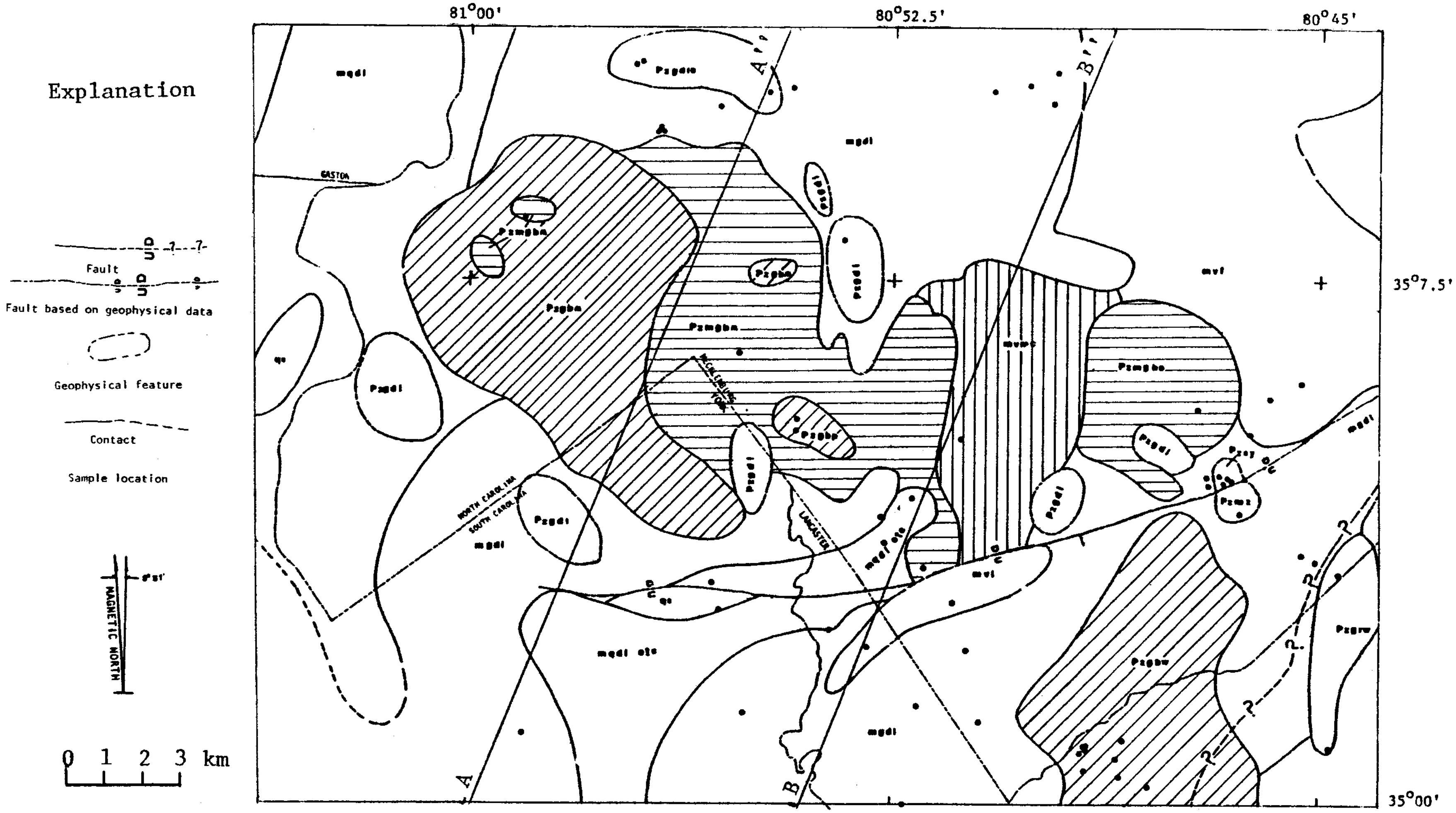


FIGURE 1. Location and cultural map of the "Mecklenburg-Weddington" gabbro complex area.



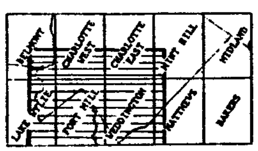


Figure 2. Geologic map of southern Mecklenburg County, N.C. and part of York County, S.C.

Plutonic rocks

units	descriptions
Pzgrw	Granite near Weddington: coarse-grained to porphyritic brown rock
Pzgdi, Pzgdle	Granodiorite, at Eagle Lake (Pzgdle): fine-grained to medium-grained, allotriomorphic to microporphyritic, gray granodiorite
Pzsy	Syenite near Providence Church: medium-grained, light-brown rock
Pzmz	Monzonite at Providence Church: medium-grained pinkish-brown rock
Pzgb, Pzgbm, Pzgbp, Pzgbw	"Mecklenburg" (Pzgbm), "Weddington" (Pzgbw) and "Pineville" (Pzgbp) gabbro: medium-grained, poikilitic, hypidiomorphic granular to cumulate-textured black to gray rock.
Pzmgb, Pzmgbm, Pzmgbo	"Mecklenburg" (Pzmgbm) and "Olde Providence" (Pzmgbo) hornblende gabbro: medium- to coarse-grained gray to black rock.

"Mecklenburg-Weddington" gabbro complex

units	descriptions
mqdi etc.	Metaquartz diorite etc.: medium-grained quartz diorite, biotite gneiss, garnetiferous muscovite biotite gneiss.
mgdi	Metagranodiorite: medium-grained tonalite and granodiorite containing altered plagioclase.
mqdi	Metaquartz diorite: medium-grained to coarse-grained quartz diorite containing zoned and altered plagioclase.

Old plutonic complex

Stratified rocks

units	descriptions
mvmc	Mafic metavolcanic rocks near Chaffin Lake: medium to fine-grained gray to black rock containing abundant epidote
[illegible]	Quartz schist, quartzite to mica schist

Metavolcanic rocks

units	descriptions
mv, mvf, mvm, mvi	Felsic metavolcanics (mvf): white to bluegray aphanitic rock; mafic metavolcanics (mvm): fine-grained greenstones; intermediate metavolcanic rocks (mvi): gray to blue-gray aphanitic rocks.

The shape of the gravity anomaly associated with these gabbroic rocks (Fig. 3) suggest that they were formed in three or more interconnecting magma chambers (Wilson and Daniels, 1980b; Wilson, 1981, p. 84). The rock exposed near Olde Providence, mafic metavolcanic rocks (mvmc), hornblende gabbro (Pzmgbo), diorite syenite (Pzsy), and monzonite (Pzmz), suggest the upper levels of a differented magma system. The cupolas of olivine gabbronorite (Pzgbm) in hornblende gabbro (Pzmgbm), and roof pendents of hornblende gabbro (Pzmgbm) in olivine gabbronorite suggest lower levels. The gabbro near Weddington which contains olivine gabbronorite and troctolite suggest the most mafic magmas and possibly the lowest exposed levels of the system (Wilson and Daniels, 1981).

GEOPHYSICAL INTERPRETATION

Contacts

Because exposures of bedrock are rare and contacts are seldom seen in the Piedmont, it is useful to compare the mapped geologic and soil contacts of the "Mecklenburg-Weddington" gabbro complex with the contacts indicated by aeroradioactivity, aeromagnetic, and gravity data. The geophysical contacts of the "Mecklenburg-Weddington" gabbro complex (Figs. 4, 5) were constructed by connecting the midpoints of the steepest gradients between high and low anomalies around the periphery of the complex. Soil contacts are from Hearn and Brinkley (1912), and geologic contacts and geophysical gradients are from Wilson (1981).

Aeroradioactivity methods measure gamma radiation which originates mainly in potassium-40 in surface rocks and soils (U.S. Department of Energy, 1979). This radiation represents conditions at the surface to only a few centimeters of depth. Radioactive gradients of contacts, therefore, should correlate closely with surface geologic contacts as illustrated by Fig. 4. The interpreted radioactivity contacts enclose most of the mapped soils derived from mafic rocks indicating how effective the radioactive method can be in locating the contact of rocks that have sharply differing potassium contents.

Structure

The gravity and magnetic fields provide information on the subsurface structure of the gabbro bodies. The shape of the gravity anomaly over the complex closely conforms to surface boundaries of the gabbros suggested by the soil and geologic maps and indicates that the main mass of mafic rock is confined within these boundaries; but the magnetic gradients, especially south of the western part of the complex (Fig. 5), extend far beyond the surface outcrop pattern.

The western complex is circled by two magnetic gradients. One gradient, at about 5000 gammas, often coincides with radioactivity

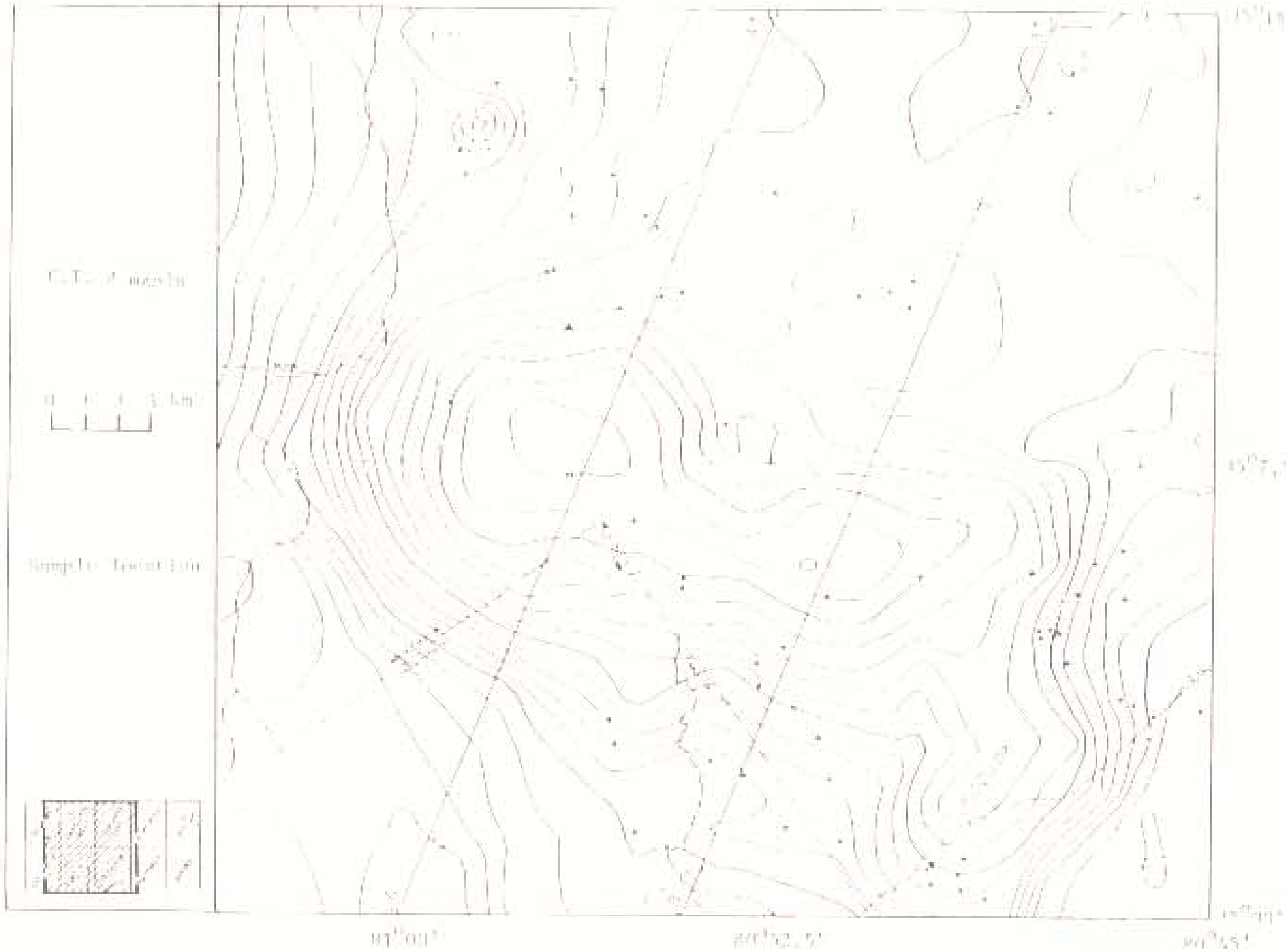


Figure 3. Simple Bouguer gravity map of the study area.

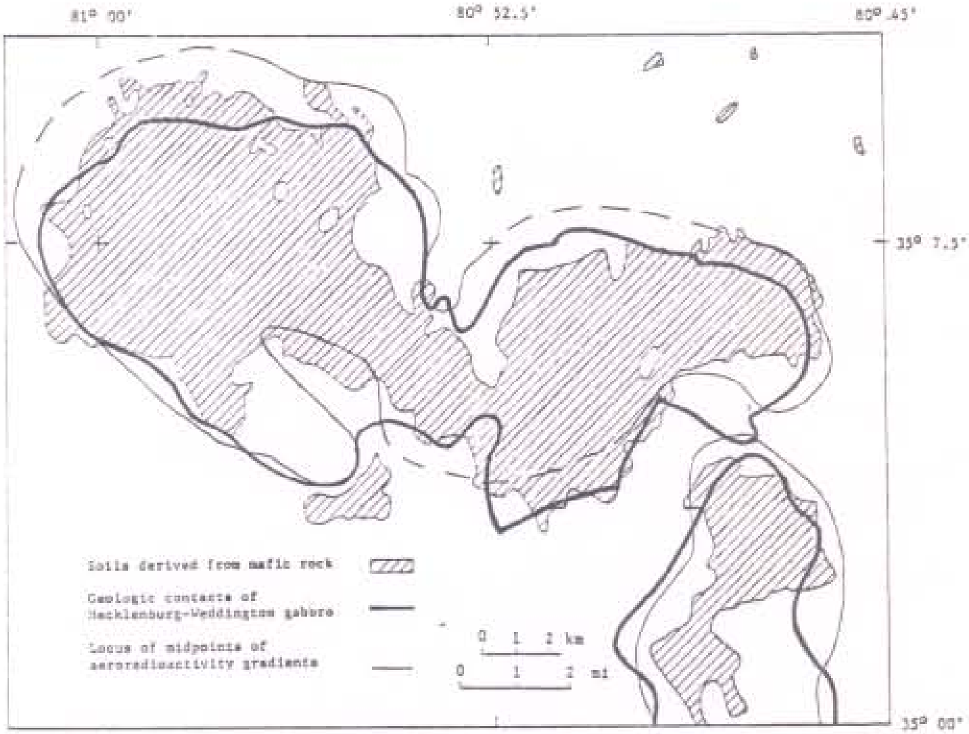


FIGURE 4. Aeroradioactivity gradients show close correlation with soil and geologic contacts.

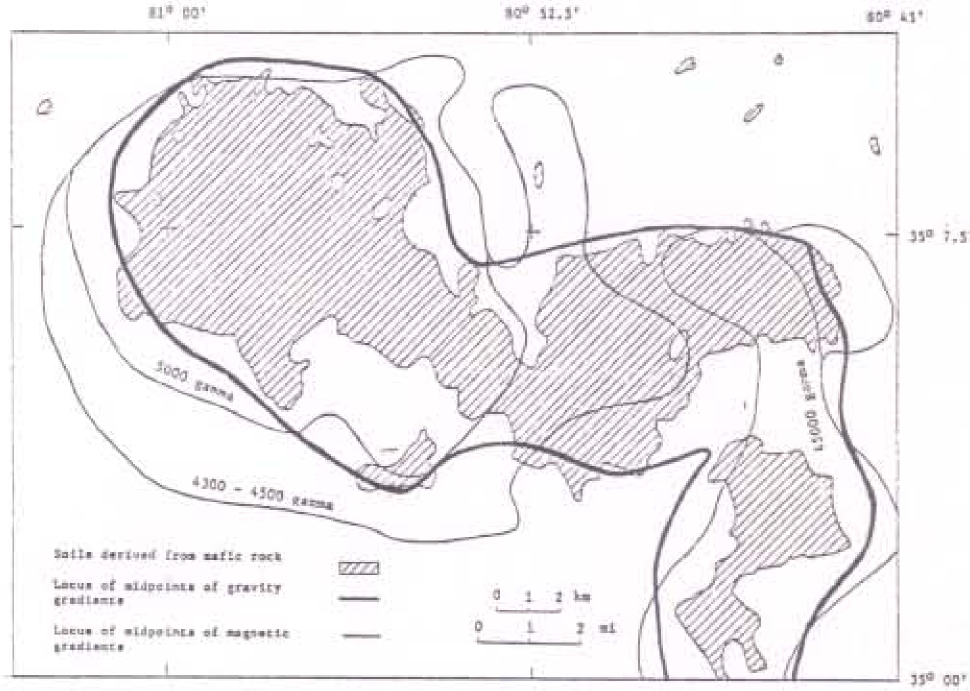


FIGURE 5. Gravity and magnetic gradients indicate subsurface structures.

gradients and geologic contacts. The 5000 gamma gradient, therefore, approximates the surface contact of the gabbro. Another gradient, at about 4300 to 4500 gammas extends much farther south than the gravity gradient and 5000 gamma magnetic gradient and may be caused by a thin subsurface sill-like structure which does not have enough mass to influence the shape of the gravity anomaly. This second magnetic gradient may also be related to subsurface hornfels in the country rock produced by metamorphic or metasomatic processes.

The magnetic gradients on the east side of the complex near Olde Providence and Weddington extend beyond the gravity gradient midpoint, soils, and geologic contacts, suggesting that these magnetic gradients may also indicate thin sills or contact phenomena.

The magnetic anomaly over the gabbro near Weddington has a very steep gradient along its southeastern edge which coincides with steep radioactivity and gravity gradients. These steep geophysical gradients suggest a sharp contact extending to considerable depth which might be a southern extension of the Gold Hill fault (Butler, 1977). The gravity anomaly over the gabbro near Weddington suggests that the body is a sill-like structure about 1.5 km thick which dips to the north.

The gravity anomaly over the "Mecklenburg" gabbro indicates bodies with steeply dipping sides (Fig. 3). The western and southern sides of the combined anomaly have gradients that range from 0 to +24 milligals indicating contacts with low-density granitic rock. But the northern side of the anomaly merges with the 12 milligal high north of the complex, probably caused by dense mafic rock connected with the gabbro complex.

Gravity models

The model of the "Mecklenburg" gabbro was constructed to match gravity profiles, A-A' and B-B', (Figs. 1 and 6) using the Talwani 2 dimensional computer program (Talwani and others, 1959) to calculate gravitational attraction. The observed profiles are parallel to the strike of the regional gravity gradient near the 0 isogal. In this area, hornblende gabbro samples have an average density of 2.94 g/cc, olivine gabbronorite has an average density of 2.89 g/cc, and granodiorite north and south of the gabbro has an average density of 2.66 g/cc. These density contrasts of 0.28 g/cc and 0.23 g/cc yield a theoretical thickness for the body of 3.5-4.5 km. The model assumes that the gabbro and metagabbro of Hermes (1968) are parts of the same plutonic complex. Additional geochemical and isotopic data are needed to test this assumption.

The model indicates that the "Mecklenburg-Weddington" gabbro complex is a lopolith-like structure and that the north side is a sill-like structure about 2 km thick which extends northward causing the broad 12 milligal gravity high in the northern Charlotte belt. This sill-like mass of mafic rock could be in the form of sheets, dikes, or multiple sills and

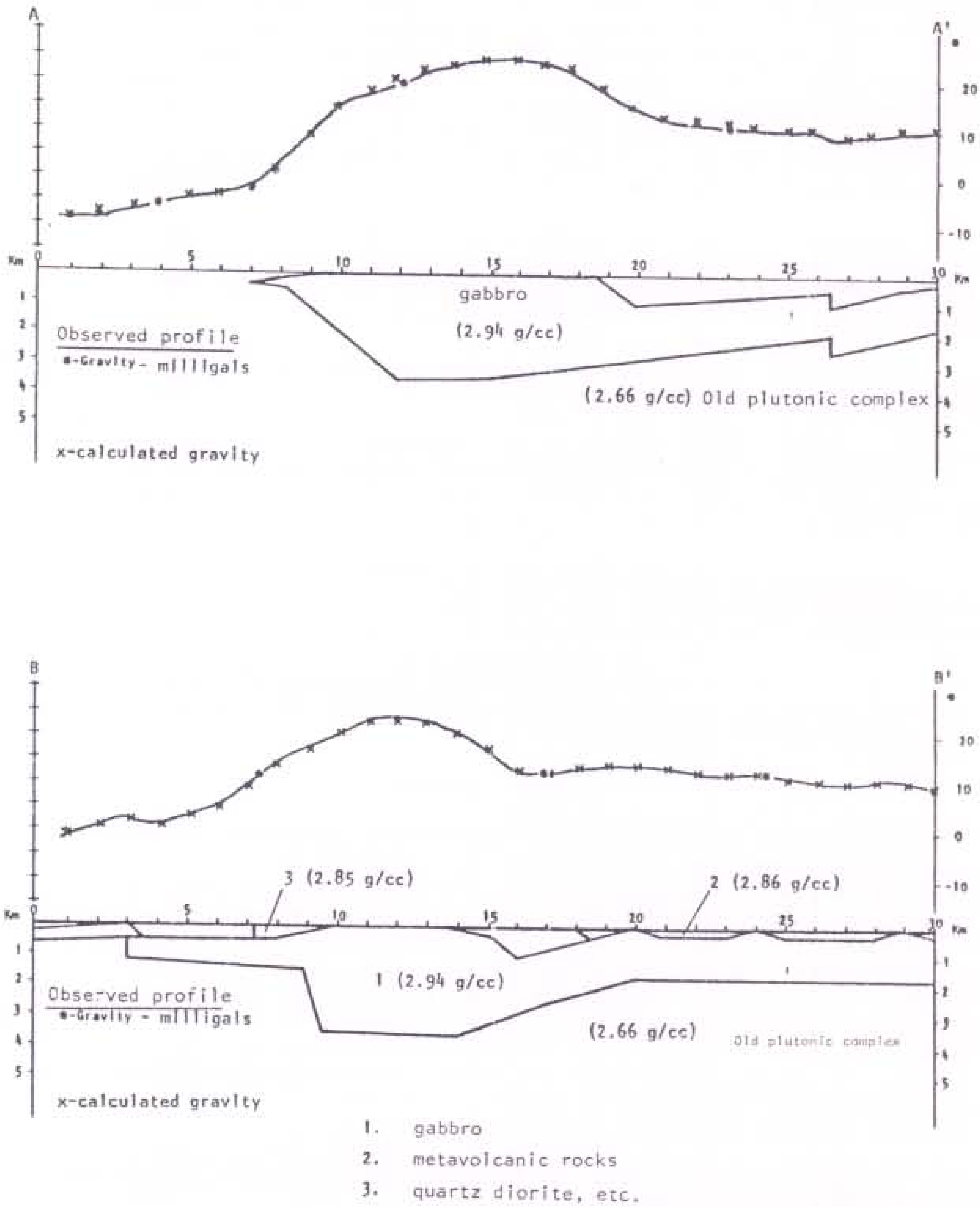


FIGURE 6. Structure models matched to gravity profiles A-A'; B-B' (Fig. 3); A-A"; B-B"; (Fig. 2) indicate the "Mecklenburg" gabbros are lopolith-like structures.

not necessarily in the form of a single sill as shown. Thinner sheets and sills may be metamorphosed more readily and form some of the metagabbroic rocks which crop out in the Charlotte West quadrangle (Wilson, 1981). On figure 6, the sill is projected toward the surface wherever positive gravity and magnetic anomalies, soils derived from mafic rock, and mapped geology indicate mafic rocks at or near the surface.

CONCLUSIONS

1. The "Mecklenburg-Weddington" gabbro complex is a differentiated complex containing hornblende gabbro, olivine gabbronorite, troctolite, pyroxene-hornblende gabbronorite; smaller related bodies of diorite, syenite, and monzonite; and mafic metavolcanic rocks.
2. The area of mafic-rock outcrop is expressed by close correlation of aeroradioactivity gradients and soils and geologic contacts.
3. Gravity anomalies, which closely agree with the shape of mafic-rock outcrops, indicate three interconnected gabbro plutons.
4. The "Mecklenburg" gabbro plutons have a lopolith-like structure 3.5-4.5 km thick which have a sill 1-2 km thick extending north.

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Mineralogy of the Foote mine, Kings Mountain, North Carolina

John Sampson White, Department of Mineral Sciences, Smithsonian Institution, Washington, D.C. 20560

INTRODUCTION

The tin-spodumene belt of North Carolina is about 48 km (30 miles) long and less than 1 km (0.6 miles) wide. It strikes approximately N15°E, extending from near Gaffney, S.C. to Lincolnton, N.C. The belt consists, in part, of pegmatite bodies of late Devonian or early Mississippian age (Kish, 1977) intruded into amphibolites and schists, parallel to the strike of the foliation and both along and across its dip. To the northwest is the Cherryville Quartz Monzonite, of similar age, which is likely genetically related to the pegmatites.

The spodumene-quartz-microcline pegmatite is remarkable in that it contains an estimated 20% spodumene, more or less evenly distributed throughout. A concentration of pegmatite bodies near Kings Mountain led to the operation of an open pit mine for lithium by the Foote Mineral Company, commencing in 1952 (Kesler, 1961).

Examination of thousands of mineral specimens from the Foote mine, gathered over many years, has led to the recognition of four sharply distinct stages of mineral crystallization within the pegmatite, each stage having formed under its own unique set of conditions. Each of the nearly 100 different species recognized thus far may be readily assigned to one of these stages (Table 1).

While the number of species is relatively high for a pegmatite, the number of elements comprising these phases is modest and it will be shown that nearly all of the elements required for the crystallization of the secondary, tertiary and quaternary suites of minerals could have been and probably were provided by the minerals of the primary suite. The wallrock contributed only a few components which were incorporated into a narrow band of minerals concentrated along portions of the contact.

THE PRIMARY STAGE

Apart from the unusually high spodumene content, the Foote mine pegmatite is atypical in several other respects. It is unzoned; there is no quartz core and the spodumene is rather uniformly distributed throughout. The pegmatite appears to have been exceptionally dry, as evidenced by the nearly total absence of hydrous phases. Muscovite is rare and even when encountered it is only in very small, isolated and highly sheared clots, usually in feldspar. Hydrous lithium-rich phases such as lepidolite, elbaite and amblygonite, commonly found in other lithium pegmatites, are

Table I. Selected species from the Foote mine paragenesis. Part A shows the elements provided by the primary suite and the wallrock.
Part B lists the principal elements required for each of the later states of crystallization.

(A)

PRIMARY	Contribution to System*				
Pegmatite					
Spodumene	Li	Cs(?)			
Beryl	Be	Cs(?)			
Manganapatite	Mn	P			
Microcline	K	Na	Rb(?)		
Cassiterite	U(?)				
Zircon					
Wallrock					
Minerals not identified	Fe	Ca	S	B	CO_2

(B)

SECONDARY	Critical Elements*				
Holmquistite	Li				
Biotite	Fe	Cs	Rb		
Schorl	Na	Fe	B		
Ferroaxinite	Ca	Fe	B		
Spessartine-grossular	Mn	Ca			
Pyrrhotite	Fe	S			
Clinozoisite-epidote	Ca	Fe			
Albite	Na				
Quartz					
TERTIARY					
Apatite	Ca	Mn			phosphate
Fairfieldite	Ca	Mn	Fe		"
+ Swizterite (1)	Mn	Fe			"
+ Roscherite (triclinic analog)	Ca	Mn	Fe	Be	"
Lithiophilite	Li	Mn	Fe		"
Lithiophosphate	Li				"
Eosphorite	Mn	Fe			"
Vivianite	Fe				"
+ Tetrawickmanite	Mn	Sn			hydroxide
Rhodochrosite-siderite	Mn	Fe			carbonate
Bikitaite	Li				silicate
Eucryptite	Li				"
Bertrandite	Be				"

	Milarite	K	Ca	Be	silicate
	Bavenite	Ca	Be		"
	Tin Titanite	Ca	Ti	Sn	"
+	Eakerite	Ca	Sn		"
+	Brannockite	K	Li	Sn	"
+	Swinefordite	Li	Ca	Na	"
QUATERNARY					
	Beraunite	Fe			phosphate
	Frondelite	Mn	Fe		"
	Hureaulite	Mn			"
	Mitridatite	Fe			"
	Paravauxite	Fe			"
	Phosphosiderite	Fe			"
+	Kingsmountite	Ca	Mn	Fe	"
	Strengite	Fe			"
	Strunzite	Mn	Fe		"
	Xanthoxenite	Ca	Fe		"
	Laueite	Mn	Fe		"
	Rockbridgeite	Fe			"
	Birnessite	Na	Mn		oxide
	Cryptomelane	K	Mn		"
	Gypsum	Ca			sulfate

* Al and Si are assumed to be extravagantly abundant in both pegmatite and wallrock so are not included in this table

\+ Denotes new species, first found at the Foote mine

(1) See discussion at end of paper

absent.

The primary suite of minerals, then, seems to have formed under uncharacteristic conditions which led to a homogeneous pegmatite mass consisting of microcline, quartz and spodumene as the dominant phases. Primary albite was not identified by the author but others report that it is abundant (Griffitts, 1954; Kesler, 1961). The most abundant of the minor phases is manganapatite, always a dull forest green in color. The remaining primary minerals are zircon, beryl, cassiterite, ferrocolumbite and fersmite.

Following the crystallization of the primary minerals, the pegmatite was squeezed into the amphibolite and schist, along and across the foliation (Fig. 1, from Kesler, 1961). Substantial evidence of intrusion in a nearly, or even completely, crystallized state, rather than _in situ_ crystallization from pegmatitic solutions, is provided by: 1) absence of hydrous phases; 2) sugary granulated texture of the quartz; 3) shearing of much of the spodumene along its prominent cleavage and shearing of the rare clots of muscovite; 4) the absence of a frozen contact or a reaction zone where pegmatite and schist/amphibolite meet; 5) evidence of drag folding of the schist; in particular, at the contact.

THE SECONDARY STAGE

At some time after its emplacement, the pegmatite responded to the existing stress field by developing nearly vertical longitudinal fractures and faults striking about N85°W. This joint system provided conduits for hydrothermal solutions from below, solutions which attacked portions of the pegmatite, dissolving most of the spodumene, manganapatite, beryl and cassiterite in these areas as well as some microcline. Today these areas are vuggy and devoid of spodumene, thus of no value as ore. The vugs commonly contain micro quartz and albite crystals.

The important elements released by the primary minerals for subsequent crystallization of later phases are: spodumene (Li), microcline (K,Na,Rb?), beryl (Be,Cs?), manganapatite (Mn,P), cassiterite (Sn), and possibly (U) from zircon (to account for rare tertiary autunite).

The result of this action is that the solutions became enriched in Li, Be, K, Na, Mn, P and Sn, but especially Li due to the vast amount of spodumene in the pegmatite. When solutions encountered wallrock at the contacts, iron-rich amphibole was replaced by the lithium amphibole holmquistite, and biotite was enriched in cesium and rubidium (Hess and Stevens, 1937). Calcium, boron, iron and sulfur were released from the wallrock through reaction with the hydrothermal solutions. These became important constitutents of a group of minerals formed at the contact, dominated by schorl, pyrrhotite, grossular, spessartine, ferroaxinite, and epidote-clinozoisite. It is essential to assume that the wallrock provided boron because there are no boron minerals in the primary pegmatite, particularly the typical pegmatitic tourmaline elbaite.

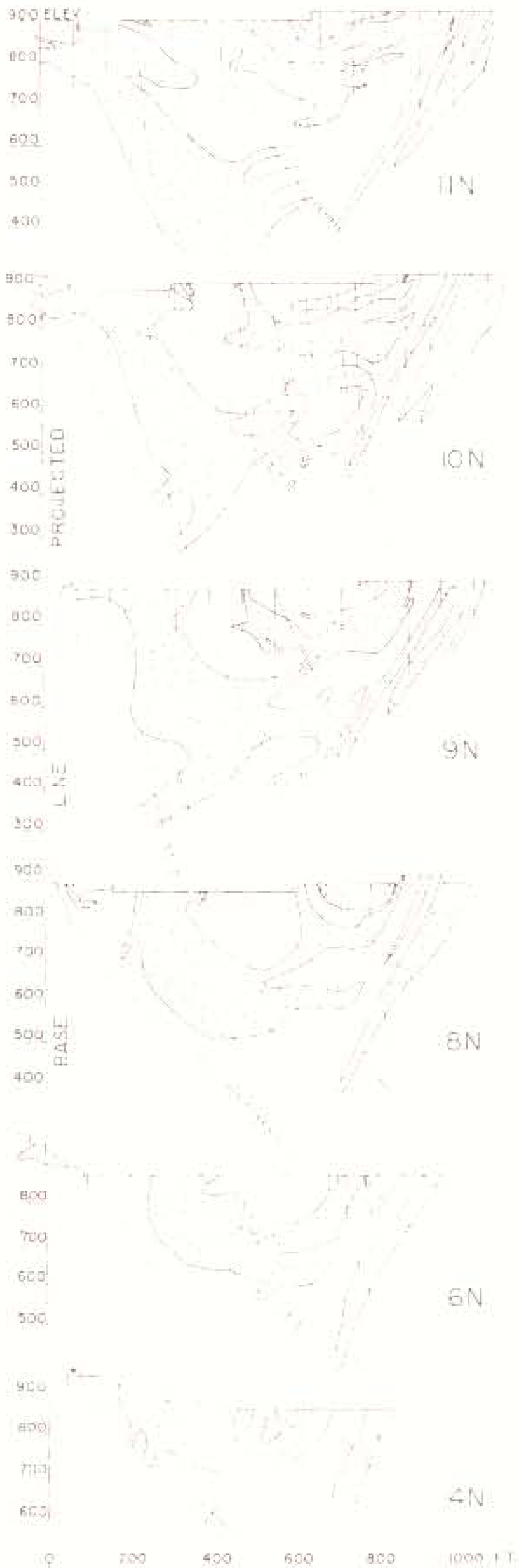

Figure 1. Cross sections in the open pit area, looking north. Stippled areas are pegmatite (from Kesler, 1961).

The ultimate result of the wallrock alteration is that the pegmatite became sealed off; the remaining metal-rich solutions within the pegmatite could not exit because the blanket of holmquistite and biotite formed an impermeable barrier.

THE TERTIARY STAGE

Metal-laden hydrothermal waters were trapped within the pegmatite along joints and in brecciated areas. Upon cooling, they precipitated a complex group of minerals consisting primarily of anhydrous or slightly hydrated phosphates and a diverse assemblage of silicates, including many lithium and/or tin species, and several members each of the zeolite and clay-serpentine groups of minerals.

The most ubiquitous of the phosphates is apatite, now no longer green in color, having less manganese and almost no iron. The apatite of this paragenesis occurs in a dazzling variety of habits, from long prismatic, to flat tabular, to barrel shapes, to fuzzy druses, and more. The colors are most commonly a shade of pink but flesh, beige, burgundy, purple, blue and white have been observed.

Nearly as common and as diverse in habit is fairfieldite. Perhaps its two most common habit/color forms are transparent, honey-colored single crystals of squat habit, and rounded dense clusters (Fig. 2) of white to pale grey randomly intergrown crystals. These represent what might be considered extremes, and every intermediate variation is known.

Another very abundant phosphate is switzerite, the first new species described from this mine (Leavens and White, 1967). Two other new phosphate species have been described as well, kingsmountite (Dunn, et. al., 1979) and a yet to be named triclinic analog of roscherite. Thus far 31 different phosphate minerals have been recognized, most belonging to the tertiary paragenesis. Attesting to the unusual conditions of crystallization that prevailed, beautiful sharp and transparent deep orange micro crystals of lithiophilite (Thomssen and Anthony, 1977) have been found. Heretofore, lithiophilite has been known only as a primary mineral in pegmatites, always in very large, deeply oxidized rough crystals. The Foote mine crystals permitted precise goniometry and a new twin law for the species was reported.

The silicate minerals are equally interesting. The lithium silicates bikitaite and eucryptite are widely found, with the former frequently encountered in excellent crystals coating large flat joint surfaces and the latter in brecciated pipelike zones. The most important beryllium minerals are bertrandite, bavenite and milarite. Tin species include two new ones first discovered at the Foote mine, brannockite (White, et. al., 1973) and eakerite (Leavens, et. al., 1970) (Fig. 3), as well as an unusual pale blue tin-bearing titanite. Still another new tin species from this mine is the manganese tin hydroxide tetrawickmanite (White and Nelen, 1973).

The carbonates rhodochrosite and siderite are very common and every proportion of Mn/Fe appears to occur.

Figure 2. Fairfieldite from the Foote mine. The spheres are about 1 cm in diameter. Photograph by Ben Kincaid.

Figure 3. Eakerite from the Foote mine. The largest crystal is about 3 mm long. Photograph by Ben Kincaid.

THE QUATERNARY STAGE

Along the rim of the quarry one can readily observe an oxidized zone extending perhaps twenty feet below the surface. It is particularly obvious because it has been stained brown by ferric iron. Most of the tertiary carbonates and phosphates in this zone have been attacked and dissolved by supergene solutions, thereby generating a new suite of minerals characterized by highly hydrated phosphate species and a variety of manganese and iron oxides.

It is not unusual to find six or more of these phosphate species in a tiny cavity in the altered pegmatite. Typical assemblages in such cavities include beraunite, frondelite, hureaulite, kingsmountite, mitridatite, paravauxite, phosphosiderite, strengite, strunzite, and xanthoxenite. The nonphosphate phases include birnessite, cryptomelane and gypsum.

SWITZERITE, A SPECIAL PROBLEM

The placement of switzerite, $(Mn,Fe)_3(PO_4)_2 \cdot 7H_2O$, in the sequence of crystallization is ambiguous. While its water content of $7H_2O$ (when fully hydrated) is high for a tertiary stage mineral, both the Mn and Fe are divalent. Most quaternary stage Mn and Fe is oxidized to the trivalent state. For this reason and because switzerite occurs throughout the quarry <u>except</u> in the supergene zone, it has been included with the tertiary minerals. Vivianite is another mineral which occurs in fresh pegmatite, but has a high number of waters (8) in its formula and has divalent iron. Switzerite and vivianite could both be quaternary, but this would require that they formed below the water table under reducing conditions.

When switzerite was first discovered and described (Leavens and White, 1967) analysis revealed only four waters. Later, in a deep and wet part of the mine, very fresh transparent switzerite was found which contained seven waters. Upon drying at room temperature the mineral readily loses three of the waters and the structure changes enough that x-ray diffraction patterns of the 7- and 4-hydrates are radically different. A proposal has been submitted (to the New Minerals and New Mineral Names Commission of the International Mineralogical Association) asking that the 7-hydrate be named switzerite and the 4-hydrate be renamed metaswitzerite.

The author greatly appreciates the valuable review comments of Daniel J. Milton and J. Wright Horton, Jr., which have been incorporated, thereby significantly improving this paper.

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Geology of the northern half of the Kings Creek quandrangle, South Carolina

Murphy, Cynthia Folsom*, and Butler, J. Robert, Department of Geology, University of North Carolina, Chapel Hill, North Carolina 27514

*Present address: Department of Geology, University of Georgia, Athens, Georgia 30602

INTRODUCTION

The northern half of the Kings Creek 7 1/2 minute quadrangle lies entirely within the Kings Mountain belt in eastern Cherokee and western York counties, South Carolina (Fig. 1). Metamorphosed subvolcanic and volcaniclastic lithologies dominate the area (Plate 1). The latter can be further divided into both pyroclastic and epiclastic material, based on Fisher's classification (1966). Chemical compositions of volcaniclastic units are mainly dacitic to andesitic; intrusions range from gabbroic to tonalitic. Metasedimentary rocks which appear to be related, in part, to volcanic activity are present in lesser amounts. Horton (in prep.) has given the units a tentative late Proterozoic Z age (approx. 600 m.y.) based on preliminary uranium-lead data from zircons. Triassic-Jurassic (?) diabase dikes cut through most units in the area. All units except these dikes have been multiply deformed and metamorphosed to at least greenschist grade.

The map units mainly strike northeast and dip steeply. The axial surface of the Cherokee Falls synform lies northwest of the Kings Creek area and that of the South Fork antiform to the southeast (Horton and Butler, this volume), therefore the rock units are essentially a homoclinal sequence younging to the northwest. Regional stratigraphy is discussed by Horton and Butler (1977, this volume). Neither repetition of marker beds nor fold hinges could be mapped at 1:24,000 scale. Mesoscopic isoclinal F_2 and possibly F_1 folds, along with a variety of later structures, can be seen in some of the best outcrops.

Recently, there has been increased interest in syngenetic submarine exhalative and volcanogenic deposits. The Kings Creek quadrangle contains rocks similar to those found in areas of known massive sulfide mineralization of this type (cf. Sangster, 1972; Sawkins, 1976). These lithologies, combined with the presence of known manganese, barite, iron, and gold deposits in the area, suggest that this quadrangle may have considerable economic significance.

The Kings Creek quadrangle was originally mapped as part of the Kings Mountain 15-minute quadrangle by Keith and Sterrett (1931). The York County portion was remapped during reconaissance work done by Butler (1966).

This work was supported in part by the South Carolina Geological Survey and the National Science Foundation, under Grant EAR-7826127 to J. R. Butler.

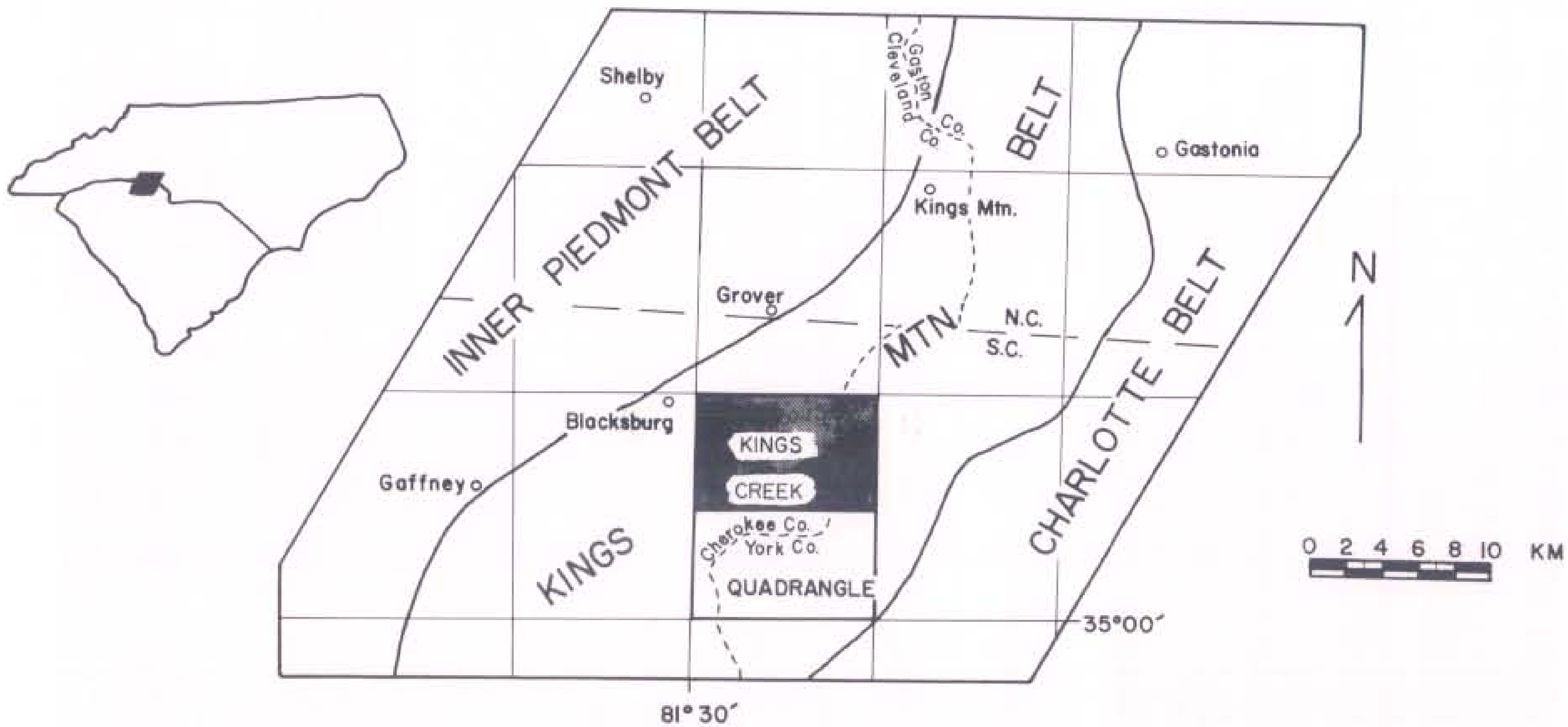

Figure 1. Map showing the location of the northern half of the Kings Creek 7½ minute quadrangle. Regional map modified from Horton and Butler (1977).

X-ray diffraction and microprobe analyses were done at the Department of Geology, University of Georgia. Vernon Hurst, Robert Kaufman, and Diane Wagner helped in running and interpreting the X-ray patterns. Discussions with Gilles Allard, Steve Nagel, Jay Stormer, and Jim Whitney were very helpful. Gilles Allard, Sean Murphy, Karen Obenshain and Jim Whitney reviewed the manuscript. Sean Murphy assisted the senior author at all stages in the project.

STRATIGRAPHY

Metatonalite-dacitic metatuff complex

The oldest unit in the area is a metatonalite-dacitic metatuff complex. The complex is dominated by fine- to medium-grained shallow intrusions which occur as both concordant and disconcordant bodies. These are interpreted as sills and plugs, respectively. Based on changes in textures within a compositionally uniform area, it appears that the majority of these bodies intrude their own volcanic ejecta. Some, however, do intrude the overlying schist of Kings Creek, primarily at or near the contact between the two units. The metatonalite may be either equigranular or porphyritic; textures within both types are very uniform. These rocks are composed of plagioclase and quartz with accessory biotite and white mica of undetermined composition. Epidote and microcline are present locally. Both epidote and white mica occur as alteration products of the plagioclase.

The extrusive rocks are volumetrically less important within the study area, although they appear to increase to the south (Godfrey, 1981). Most are located stratigraphically above the intrusions in the western part of the complex. They occur primarily as moderately reworked (?) crystal tuffs which grade laterally as well as vertically into the schist of Kings Creek to the northwest. Coarser grained pyroclastic units may also be present in the form of lapillistone, but are very difficult to distinguish from other rocks in the complex because the lithic clasts appear to be composed of fragmented hypabyssal material and grain boundaries are obscure. The crystal tuffs are composed of slightly rounded plagioclase grains in a fine-grained matrix of quartz, biotite, white mica and untwinned plagioclase (?). No pronounced compositional banding is visible; plagioclase grains, which have a fairly wide size range, occur randomly throughout the heterogeneous ground mass.

The schist of Kings Creek

The metatonalite-dacitic tuff complex is overlain by fine-grained sericite schist and quartz-sericite schist, informally named the schist of Kings Creek. In most instances, the contact between the two units is gradational over several hundred meters. However, when hypabyssal rocks are involved, the contact is a sharp intrusive one.

The undifferentiated schist of Kings Creek represents a mixture of epiclastic, reworked pyroclastic, and unreworked (?) pyroclastic material, much of which has undergone extensive alteration. [Note: Where "epiclasts are crystals, crystal fragments, glass fragments, and rock fragments that have been liberated from any type of pre-existing rock (volcanic or nonvolcanic) by weathering or erosion and transported from their place of origin by gravity, air, water, or ice"(Schmid, 1981; see also Fisher, 1966)]. All of the rocks contain a large

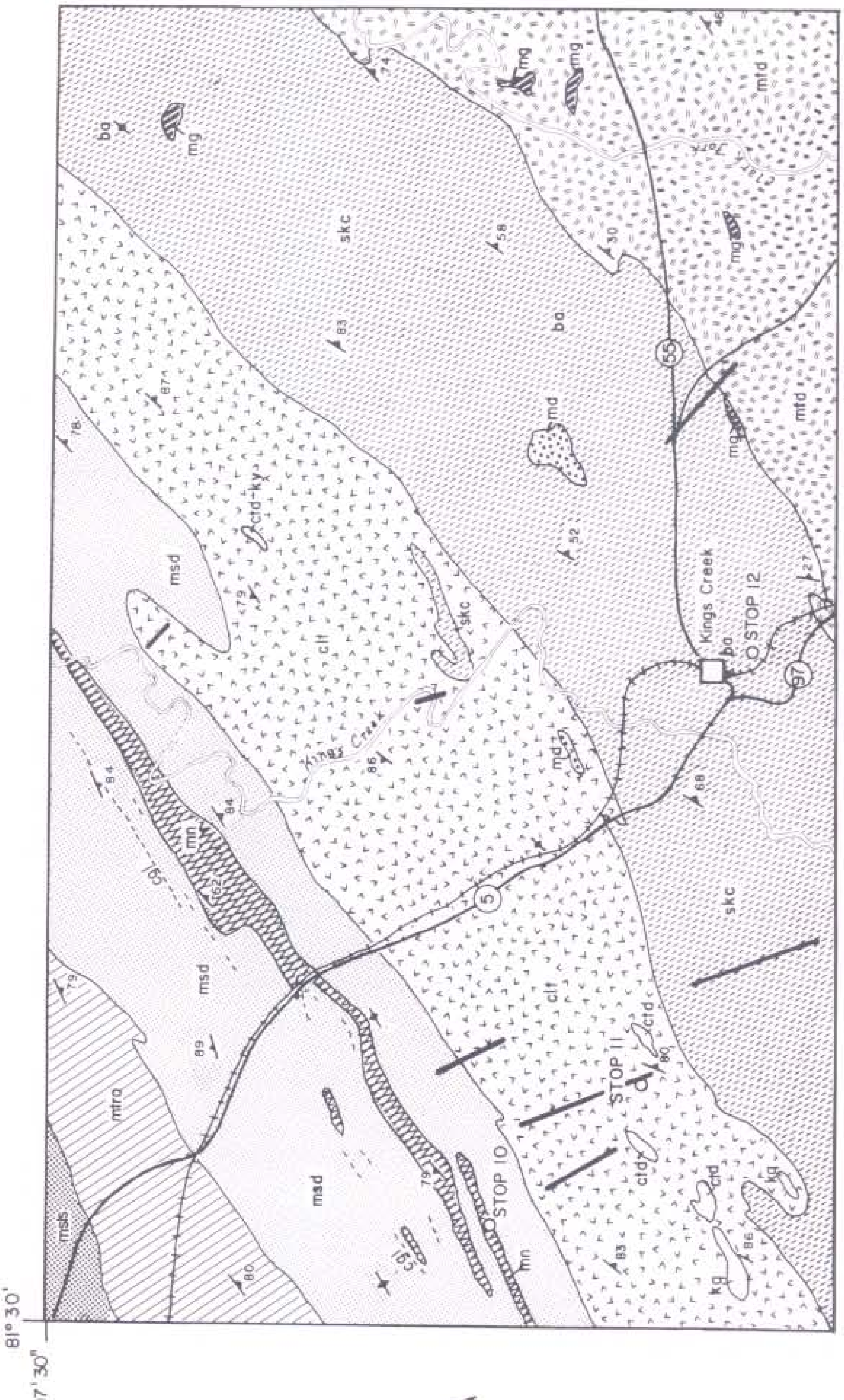
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Plate 1. Preliminary geologic map of the northern half of the Kings Creek 7 1/2-minute quadrangle.

EXPLANATION

Metasiltstone: grey phyllite interlayered with quartz-rich micaceous schist.

Metatrondhjemite-amphibolite: intermixed felsic gneiss and amphibolite with minor felsic dikes, laminated quartzites, and chlorite schists.

Metasedimentary rocks: plagioclase-quartz-muscovite schists; chlorite schists; calcareous metasedimentary rocks; quartz-muscovite schists; bluish-grey phyllites.


Quartzite pebble metaconglomerate: grain supported quartzite pebble metaconglomerate and quartzites; thickness not to scale.

Manganiferous schist: sericite schist with high Mn-oxide content; quartz muscovite schists with variable amounts of Mn-rich garnets.

Crystal-lapilli metatuff: undifferentiated crystal-lapilli tuffs, lapilli tuffs, and crystal tuffs and flows; all rich in Fe-Ti oxides and therefore bluish-grey in color.

Chloritoid schists: chloritoid-rich crystal-lapilli metatuff; chloritoid schist; chloritoid-kyanite schists.

Kyanite quartzite: kyanite-rich quartzites with local pyrite enrichment.

Metadiorite (?): massive to schistose olive-green rock composed of plagioclase, epidote and chlorite in a groundmass of the same plus quartz and sericite.

Schist of Kings Creek: white sericite schist, commonly stained by iron oxides; local areas of chlorite schist, pyritiferous schist, and barite enrichment.

Barite: indicates locations within the schist of Kings Creek where barite is concentrated.

Metagabbro: massive amphibole, plagioclase and epidote rock.

Metatonalite-dacitic metatuff: massive to schistose biotite-quartz-plagioclase rock.


Triassic-Jurassic diabase dikes.


Approximate lithologic contact.


Strike and dip of the main foliation.

amount of fine-grained white mica which is referred to as sericite. The use of this word is meant to indicate grain size, not composition. At the present time, no chemical or X-ray analyses have been done on micas from this unit to determine their composition.

The rocks interpreted to be epiclastic contain significant amounts of quartz (approx. 50%); the remainder is sericite. Plagioclase crystals and other volcanic materials are not observed. The nearly pure sericite schists are more problematic. They could represent one or more different protoliths. In some of these rocks, no volcanic textures or remnants of volcanic mineralogy were noted; therefore, they may be epiclastic in origin. However, other sericite schists have fairly obvious to obscure outlines of altered plagioclase laths which have apparently undergone complete alteration (Fig. 2). They are interpreted as derived from hydrothermally altered volcanic ejecta (flows and/or pyroclastics) which may or may not have been reworked. The presence of tourmaline, pyrite and other minerals typical of hydrothermal alteration suggests that the alteration is not due to metamorphism. Locally, chlorite schists and pods of unaltered dacitic pyroclastic materials are found within the schist of Kings Creek; neither of these rock types occurs on a mappable scale.

The schist of Kings Creek contains several areas of barite enrichment. At most localities, the barite occurs as thin (less than 1 cm thick) concordant layers or as disseminated grains within the sericite schist. In the mining pits immediately south of the community of Kings Creek, however, the barite forms nearly pure veins (less than 1% quartz) which are over half a meter thick (Stop 12).

Metagabbro

Both the metatonalite-dacitic metatuff complex and the schist of Kings Creek are intruded by gabbroic rocks, now composed primarily of hornblende, actinolite, and plagioclase partially to completely altered to epidote. Outctop patterns indicate that both dikes and sills exist. The textures in some of the rocks suggest that minor metabasalts may also be present. True thickness of these bodies cannot usually be determined, due to the obliteration of the contacts by weathering; most appear to be less than 50 meters thick.

Metadiorite(?)

Both the schist of Kings Creek and its transition zone with the overlying crystal-lapilli metatuff contain small pods (less than 500 m in maximum dimension) of a massive to schistose plagioclase-epidote rock. Most of the textures are those of a shallow intrusion, with larger grains of plagioclase, epidote, and chlorite in a fine-grained matrix of the same plus quartz and white mica. Locally, however, some clastic textures are present. These rocks are most likely the product of minor subvolcanic and volcanic activity which produced material of intermediate to mafic composition. The bodies usually have discordant contacts, suggesting that the rocks are dominantly intrusive in origin.

Although no whole-rock analyses of this unit have been completed at this time, modal analyses and the average compositions of the major components can be used to estimate the chemical composition and thereby classify the rock. The only magnesium-bearing mineral is chlorite, present in amounts ranging

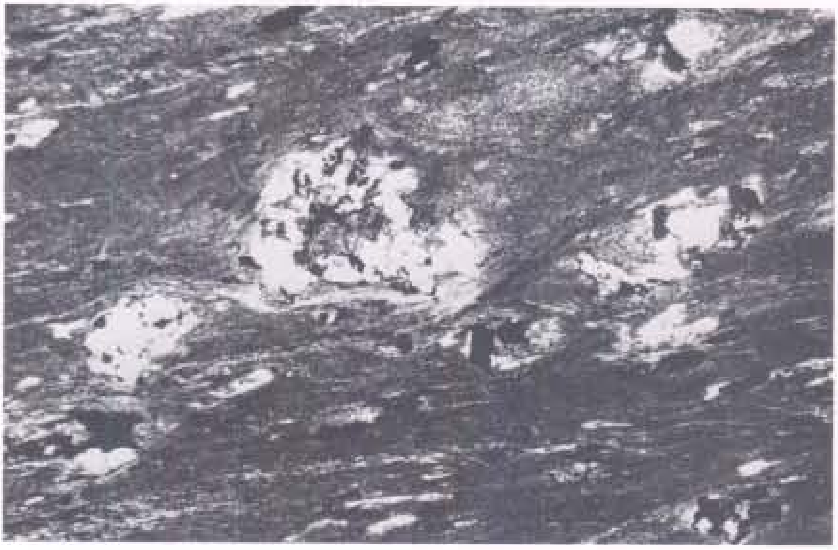

Figure 2. Photomicrograph of sericite schist from the schist of Kings Creek. Note alteration of the plagioclase grains. This is an example of some of the least altered grains in the unit. The longest dimension is approximately 7.5 mm.

Figure 3. Photomicrograph of a crystal-rich flow from the crystal-lapilli metatuff unit. Note the nearly euhedral plagioclase phenocrysts and very fine-grained, evenly distributed ground mass. The longest dimension is approximately 7.5 mm.

from 18 to 20%. Assuming 20 wt. % MgO in the chlorite, the rock contains 3.6 to 4.0 wt. % MgO. This corresponds well to the average 3.71 wt. % MgO in diorites (Cox, Bell, and Pankhurst, 1979). In comparison, gabbros average 7.59 and tonalites average 2.80 wt. % MgO. SiO_2, CaO, and FeO (as total Fe) can be compared in a similar manner with the same results.

Crystal-lapilli metatuff

The contact between the schist of Kings Creek and the overlying metatuff can best be described as a transition zone. Most of the zone shows interlayering of the two distinct lithologies; parts of the zone, however, are composed of a unique rock type which probably represents a thorough mixing of the materials found in each unit. This "mixed" rock type lacks the iron-titanium oxide enrichment characteristic of the crystal-lapilli metatuff; clasts and crystals are typically present but the former are usually smaller in size and less distinct. The rocks are commonly rich in epidote. The apparent thickness of this zone ranges from approximately 100 m to almost 2 km. It is presumed that the true thickness is considerably less than this, as small-scale isoclinal folding may have thickened most of the units in the study area.

The crystal-lapilli metatuff unit is composed of undifferentiated crystal-lapilli tuffs, lapilli tuffs, and crystal tuffs and flows (Fig. 3). Local occurrence of flow banding, in addition to clastic textures, suggests that parts of this unit are the result of pyroclastic flows rather than falls.

All of the rocks within the unit can be easily distinguished from the underlying units by their distinctive bluish-gray color; this color is the result of finely disseminated iron-titanium oxides in the matrix. The crystal-lapilli tuffs typically contain dark gray to almost white clasts, although locally the former may be absent. These clasts, especially the darker ones, closely resemble flattened pumice fragments, or fiamme, seen in fresh ignimbrites and related volcanic rocks (Ross and Smith, 1960).

The matrix of the crystal-lapilli metatuffs is typically a fine-grained white mica. Preliminary electron microprobe and X-ray diffraction data from three different locations indicate that at least four different micas are present. Two of the locations sampled contained intimately intermixed (interlayered?) muscovite and paragonite in a ratio of three to two, respectively. Microprobe analyses of a sample from Stop 11 gave alkali ratios of 6:3:1 for calcium, sodium, and potassium respectively. X-ray diffraction data, however, indicate only two micas are present. One is margarite; the other has a basal spacing of 9.947 A and will require further investigation before a positive identification can be made.

Areas rich in chloritoid occur within the metatuff. Chloritoid schist, chloritoid-kyanite schist and kyanite quartzite are also present in minor amounts. These rocks, plus a small body of magnetite-hematite iron ore which is associated with the kyanite quartzite, all lie roughly on strike with one another. Possibly this represents a horizon characterized by hydrothermal alteration.

Metasedimentary rocks

Above the metatuff is a heterogeneous suite of rocks which appear to be largely sedimentary in origin. The quartz and/or mica content is relatively high throughout and most of the rocks show compositional layering, although some layering is obscure. An overall stratigraphy can be developed within the group, but in general, lithologies are not strictly confined to a specific horizon.

Bluish-gray phyllites. At the base of the sedimentary sequence, in the northeastern part, are finely laminated bluish-gray phyllites. These are interpreted to be reworked crystal-lapilli metatuffs and/or very fine-grained metatuffs, based on the lack of crystals and clasts and the similarity between the composition of this rock as a whole and the groundmass of the underlying crystal-lapilli metatuff. The rocks are predominantly composed of very fine-grained white mica of undetermined composition with up to 2% finely disseminated iron-titanium oxides. Foliations are extremely well developed due to the high mica content.

Quartz-muscovite schists. Quartz-muscovite schists also occur at the base of the sedimentary sequence, but are more common to the southwest. These rocks appear to be derived from relatively mature sediments. Compositional layering, defined by quartz to mica ratios, is generally well developed.

Manganiferous schist. Fairly continuous horizons of manganiferous schist occur within the bluish-gray phyllites and the quartz-muscovite schists. Most of the rocks are extremely weathered and are composed of manganese oxides and sericite (Stop 10). Rare occurrences of fresh rock consist of quartz-muscovite schists with variable amounts of garnets concentrated in the micaceous layers. Seven microprobe analyses indicate the garnet is almandine-spessartite, with Fe content greater than Mn. This unit may be the product of volcanic exhalative activity.

Calcareous metasedimentary rocks. Pods of metasedimentary rocks too small to show at map scale occur in contact with and above the manganiferous schist. Mineralogy is variable, but the major constituents commonly include quartz, calcite, muscovite, and chlorite. These rocks indicate that the sedimentary sequence, at least in part, was deposited in or near a marine environment.

Quartzite-pebble metaconglomerate. Above the manganiferous schist are quartzite pebble metaconglomerates and quartzites which grade laterally into one another as the proportion of pebble to sand-size material varies. The conglomerates from this area have very little clay-to-silt-sized matrix material and are nearly orthoquartzitic. In thin section (especially visible in plane light) these rocks appear to be largely grain supported. The grains are commonly rounded. Calcareous metasedimentary rocks and impure marble, located above and below this unit, indicate a marine environment of deposition. Overall, the characteristics of the unit suggest that deposition took place under high energy conditions such as in the surf zone of a beach environment. The pebbles themselves are composed of finer grains of quartz (Figs. 4 and 5) and could be derived from quartzite, recrystallized vein quartz, recrystallized chert, or any combination thereof (Pettijohn, 1975, p. 166). Well-laminated, fine-grained quartzites (metacherts?) occur at several horizons above the conglomerates; the source material for the pebbles may have been similar beds.

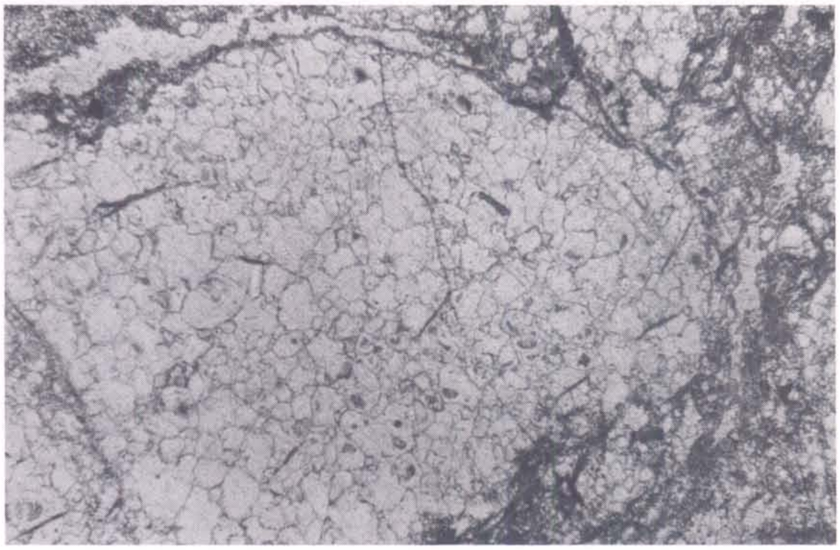

Figure 4. Photomicrograph of a quartzite pebble from the quartzite pebble metaconglomerate; plane-polarized light. The longest dimension is approximately 7.5 mm.

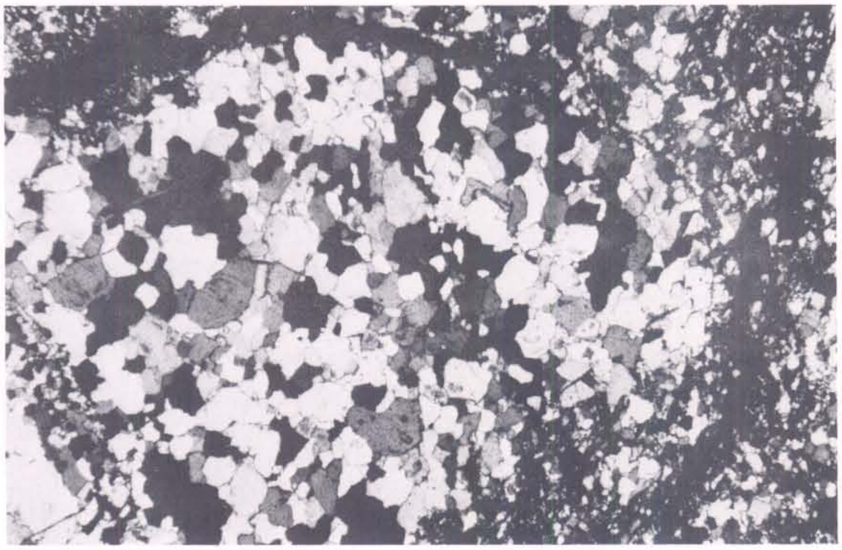

Figure 5. Photomicrograph of the metaconglomerate, same pebble as in Figure 4; crossed polarizers. Note the fine interlocking grains of quartz which make up the pebble.

Chlorite schists. Chlorite-rich schists with a variety of textures generally lie above the quartzite pebble conglomerate. The majority of the rocks occur as either very chlorite-rich schists with little or no compositional layering or as plagioclase-quartz-chlorite rocks with distinct compositional layering between light and dark minerals. The outcrop patterns of some nonlayered chlorite schists and their higher plagioclase contents suggest that they may be metamorphosed mafic dikes. Horton (in prep) has attributed the high chlorite content of these rocks to retrograde metamorphism associated with ductile shearing along the proposed Kings Creek shear zone.

Plagioclase-rich schists. Plagioclase-muscovite-quartz schists occur throughout the sedimentary sequence, but are volumetrically most significant above the chlorite rocks. The relative amount of the three main constituents varies from one location to another, but on the average are present in roughly equal amounts. The large number of well-rounded plagioclase grains and the layering of the micas suggests that the bodies are reworked metavolcanic deposits.

Metatrondhjemite-amphibolite complex

Above the metasedimentary units is a complex composed of amphibolite and felsic gneisses with minor laminated quartzites, felsic dikes, and chlorite schists; impure marble was noted at one location. A single outcrop usually contains both felsic gneiss and amphibolite, plus or minus the other lithologies; therefore, separate lithologies are not mapped.

The actual contact between the metatrondhjemite-amphibolite complex and the underlying metasedimentary rocks is obscured in most locations by lack of outcrop. Horton (in prep.) has suggested that the contact is marked by ductile shearing along the Kings Creek shear zone. However, Horton (personal communication, 1981) has not been able to trace this shear zone for more than 400 m into the Kings Creek quadrangle; therefore it may be a discontinuous feature.

In general, the relationship between the various lithologies is not clear. Most of the complex was mapped on the basis of float. Where outcrop is present, the amphibolite and metatrondhjemite are commonly interfingered on the centimeter to meter scale. The interfingering is highly irregular and no consistent patterns were noted. Felsic dikes cross-cut both units.

The metatrondhjemites occur as fine-grained to medium-grained moderately well foliated to massive felsic gneisses. They are characterized by plagioclase phenocrysts in a matrix of plagioclase and quartz with accessory white mica, biotite, and chlorite. Textures indicate that the rocks are shallow intrusions. Horton (in prep.) calls these rocks metatrondhjemites, based on chemical analyses from the Grover quadrangle. The term metatrondhjemite is therefore applied to the felsic gneisses of the complex in this quadrangle as well, as there are no chemical analyses from the Kings Creek quadrangle upon which a rock classification could be based.

Amphibolites of the complex are typically medium grained and contain plagioclase, actinolite, and hornblende. Locally, the chlorite content may also be significant. The textures observed are not definitive enough to indicate a definite origin for these rocks; they could be metabasalts or metasediments or a combination of the two.

Metasiltstone

Uppermost in the stratigraphic section of the study area is a gray phyllite interlayered with a quartz-rich micaceous schist. Only two outcrops of this unit were found within the quadrangle; both were highly weathered. Consequently, contact relationships with the underlying metatrondhjemite-amphibolite complex and exact lithologies are unknown. Based on work done by Horton (in prep.) to the north and Butler (this volume) to the west, the unit is believed to be phyllitic metasiltstone with local variation in quartz content.

Triassic-Jurassic(?) dikes

The only post-metamorphic intrusions are diabase dikes (plagioclase, pyroxene, and olivine) which cross-cut most of the metavolcanic and metasedimentary rocks in the study area. Based on their mode of occurrence, mineralogy, lack of foliation and metamorphism, and typical north-northwest strike, they are presumed to be equivalent to the Triassic-Jurassic dikes found throughout the Appalachians.

METAMORPHISM

All of the rocks in the northern half of the Kings Creek quadrangle, with the exception of the Triassic-Jurassic (?) dikes, were metamorphosed to upper greenschist-lower amphibolite grade under medium to low pressure type of metamorphism. Based on the criteria outlined below, a temperature range of 490°C to 535°C and a pressure range of 3.6 kb to 4.0 kb can be established for prograde metamorphism in the southeastern two-thirds of the map area. Stream sediment sampling indicates that in the northwestern third, temperature and pressure conditions may have exceeded these limits (Gregory, this volume). The geothermal gradient associated with this metamorphic event was probably around 35°C km^{-1}.

The lower limit for the temperature conditions is determined by the presence of two assemblages: kyanite plus quartz plus hydrous minerals and hornblende plus actinolite. (Amphibole compositions were ascertained by electron microprobe.) Pyrophyllite breaks down to kyanite plus quartz plus water at approximately 400°C (Hemley and others, 1980). At 4 kb, the first appearance of hornblende with actinolite is estimated to occur at 490°C (Winkler, 1979, p. 243). The upper temperature limit for the southeastern two-thirds of the map area was determined by the assemblage of Fe-chloritoid plus kyanite (located in the crystal-lapilli metatuff unit). This assemblage breaks down to form Fe-staurolite plus quartz plus water at 535°C and 4 kb (Richardson, 1968, p. 478). Northwest of the chloritoid-kyanite locations, temperatures greater than 535°C are indicated by the presence of staurolite in stream sediment samples (Gregory, this volume). Assuming a relatively constant geothermal gradient, pressure conditions would also be increased. Plagioclases in the amphibolites of the northwestern corner have an average composition of An_{28}, based on preliminary microprobe analyses; this also indicates lower amphibolite-grade metamorphism.

Using the temperatures established above, the assemblage of margarite plus quartz can be used to establish a lower pressure limit of approximately 3.5 kb. At 500°C and pressures less than 3.5 kb the assemblage goes to anorthite plus kyanite-andalusite plus water (for systems free of CO_2) (Storre and Nitsch, 1974). Using the alumino-silicate curves of Holdaway (1971), the presence of kyanite gives a similar low pressure limit of 3.6 kb at 490°C.

The upper pressure limit can be derived only by making certain assumptions. First, it is assumed that there was only one prograde metamorphic event and that this event was associated with a regional geothermal gradient which affected rocks of the Kings Creek as well as the surrounding quadrangles. Second, Horton (1978) found the assemblage of kyanite plus andalusite plus sillimanite, although at slight disequilibrium, in the Kings Mountain quadrangle immediately northeast of the study area. This strongly suggests that the conditions of metamorphism were very near those of the alumino-silicate triple point in that quadrangle. Using Holdaway's curves, the geothermal gradient which passes directly through the triple point is approximately 350°C km^{-1}. At this gradient and 535°C, the upper pressure limit is about 4 kb for the southeastern two-thirds of the study area. In the northwestern third, pressures may have exceeded 4 kb, but probably not significantly.

In addition to the major prograde metamorphic event, a retrograde event is indicated by alteration of biotite to chlorite. Chlorite is commonly seen without biotite, which may be due either to the retrograde metamorphism or to the characteristically low potassium content of these rocks.

STRUCTURE

A minimum of four planar structural elements occur within the map area. The first three are defined by the presence of foliations which are axial planar to F_1 - F_3 folds (Horton and Butler, 1977). The last fabrics to develop are kink bands which affect all three earlier foliations.

At most locations there are two steeply dipping, subparallel, northeast-trending foliations. Although locally both may be equally well developed, one is usually dominant. The intersection of these foliations creates platelettes that give the rocks a shredded appearance, especially the more micaceous ones. Horton and Butler (1977, this volume) give relative ages of S_1 and S_2 to these foliations; Horton (in prep.) describes S_2 as the dominant cleavage north of the map area. Compositional layering (S_0), when visible, has an attitude normally differing from S_2(?) by only a few degrees.

The third foliation (S_3) is less prevalent, but when present is commonly dominant. This foliation strikes east-northeast and dips shallowly to the southeast. S_0 was not observed at any of the locations where S_3 is measurable.

A plot of the poles to 217 measurements of the main foliation (including both S_1 and S_2) indicates that the main foliations predominantly strike N 50° E and dip between 80° NW and 80° SE (Fig. 6). The attitude of the kink banding associated with the latest deformations event(s) varies greatly; no regular pattern was determined, but the kinks commonly strike northwest.

All folds observed within the area occur either on the mesoscopic or microscopic scale. The folding is isoclinal with axial planes parallel to the main schistosity (S_1 or S_2); fold axes plunge less than five degrees to the northeast. Some isoclines deform an earlier cleavage and are therefore F_2 folds.

Outcrop patterns give some indications of large-scale F_1 folding within the study area, but none with sufficient certainty to warrant mapping as such.

Faulting observed within the map area was dominantly brittle and on a small scale (displacement of less than 10 centimeters). Horton (in prep.) has located a ductile shear zone in the Grover quadrangle and traced it for 400 m into the Kings Creek quadrangle. No evidence of ductile shearing was noted farther southwest; however, this may be due to the scarcity of outcrops along the projection of the zone.

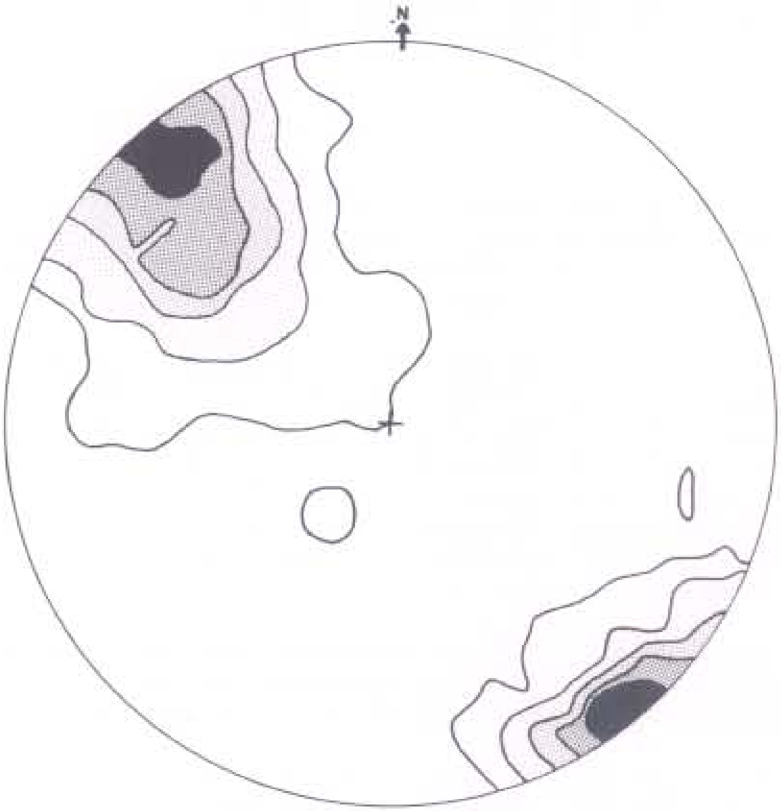

Figure 6. Plot of the poles to the planes of 217 main foliation measurements (includes both S_1 and S_2). Lower hemisphere projection. Contours equal 1,8,16,24, and 32%.

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Geology of the Blacksburg South quadrangle, South Carolina

J. Robert Butler, Department of Geology, University of North Carolina, Chapel Hill, North Carolina 27514

INTRODUCTION

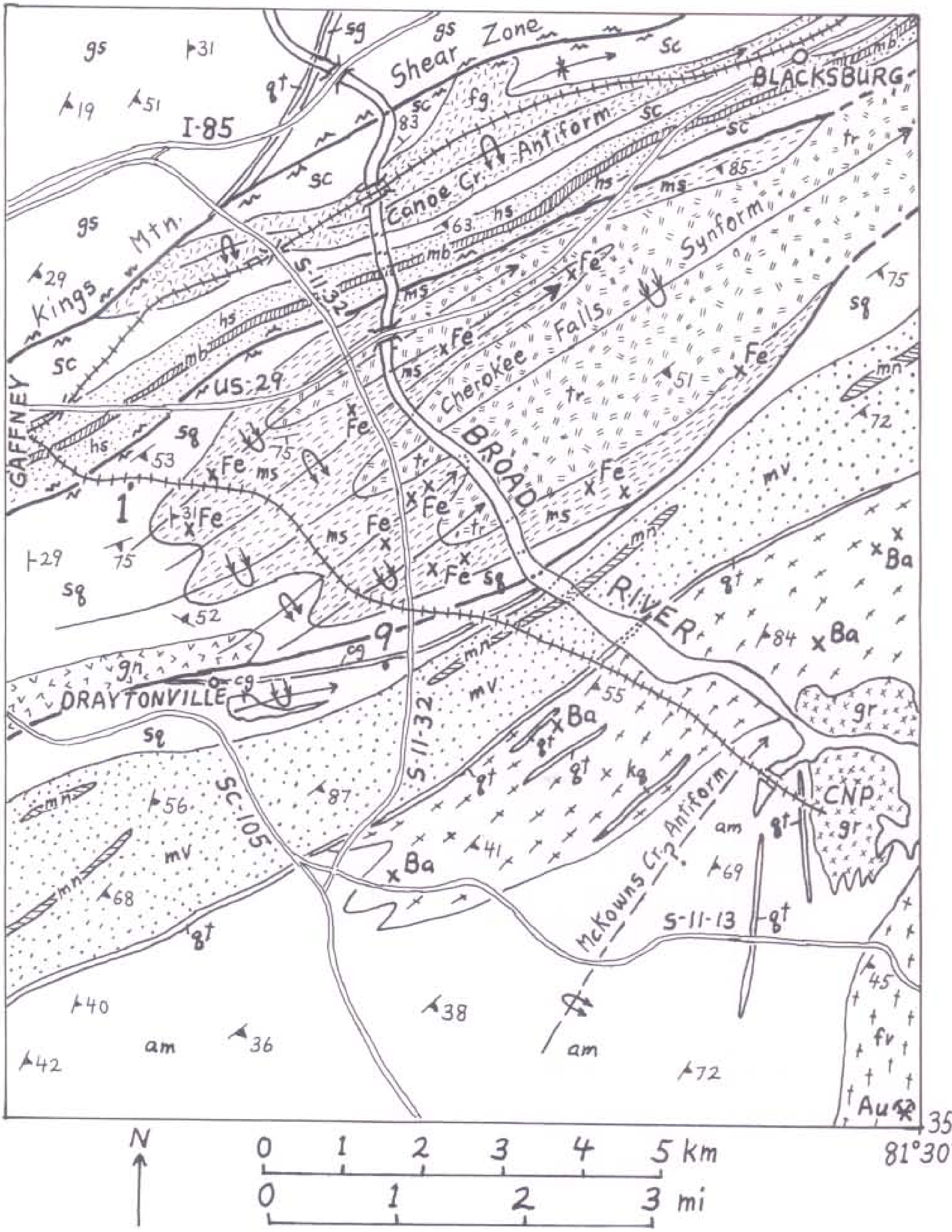
The Blacksburg South quadrangle is situated mostly in the Kings Mountain belt, but the northwestern part extends across the Kings Mountain shear zone into the Inner Piedmont belt (Fig. 1). The Broad River nearly bisects the quadrangle and has cut a fairly steep-walled valley about 65 m below the general Piedmont surface. Outcrops are much more common than in most of the Piedmont, because tributary streams cutting down to river level have exposed bedrock in many places.

The quadrangle has a remarkable variety of rocks, structures, and mineral deposits. The rocks include nearly all of the distinctive types that characterize the Kings Mountain belt. The most prominent fold, the complex, northeast-plunging Cherokee Falls synform, is a key structure in this part of the belt (Horton and Butler, 1977, this volume). The quadrangle includes some of the clearest evidence that the Kings Mountain shear zone truncates structures in the Inner Piedmont belt (Horton, 1981). The shear zone also truncates the Canoe Creek antiform, a large fold in the Kings Mountain belt.

The site of the Cherokee Nuclear Plant, under construction by Duke Power Company, is in the southeastern part of the quadrangle. The excavations have been mapped and studied in great detail and this research has helped elucidate geologic history of the Kings Mountain belt (Fullagar and Kish, Schaeffer; this volume). Also, a railroad spur and several roads built for access to the site afforded excellent new exposures (Stop 1).

This paper summarizes the geology and mineral resources of the Blacksburg South quadrangle. Aspects of the geology are discussed in several parts of this volume (Horton and Butler, Hatcher and Morgan, Posey, Schaeffer, Stop 1, Stop 9), including rock units and structures that extend northeastward into the adjacent Kings Creek quadrangle (Murphy and Butler).

The South Carolina Geological Survey supported most of the field work. The National Science Foundation supported much laboratory research and some mapping, under Grant Nos. GA-37039 and EAR-7826127. I have benefitted from numerous discussions with Wright Horton, Cindy Murphy and Malcolm Schaeffer. Harry Posey helped track down some elusive old mine locations.


Kings Mtn. Shear Zone
I-85
BLACKSBURG
Canoe Cr. Antiform
Cherokee Falls Synform
GAFFNEY
US 29
S-11-32
BROAD RIVER
DRAYTONVILLE
SC-105
McKowns Cr.? Antiform
S-11-13
CNP
gs
sg
gt
sc
fg
mb
hs
ms
tr
Fe
mn
mv
Ba
gn
cg
kg
gr
am
fv
Au
35°
81°30'
N
0 1 2 3 4 5 km
0 1 2 3 mi

EXPLANATION

Kings Mountain belt

sc sericite and chlorite schist with thin quartzite layers

fg foliated granitic gneiss

tr metatrondhjemite with numerous mafic dikes

ms mafic schist and impure quartzite, with lenticular and layered iron deposits

sq sericite schist, chlorite schist and quartzite; partly metavolcanic

mb Gaffney marble, calc-silicate rocks, quartzite and schist

hs hornblende and mica schists, calc-silicate rocks, thin quartzite

gn fine-grained, foliated biotite felsic gneiss

cg metaconglomerate and quartzite

qt quartzite, with sericite schist

kq kyanite quartzite

mv metasiltstone and metatuff, metasedimentary with metavolcanic interlayers

mn manganiferous schist

gr felsic intrusive rocks

fv felsic metavolcanic and volcaniclastic rocks

am amphibolite and mafic schist; mainly volcanic rocks and shallow intrusions

Inner Piedmont belt

qt quartzite

sg schist with large garnets

gs schist, gneiss and granite, undivided

Symbols

45 strike and dip of layering, including bedding

67 strike and dip of schistosity

antiform: upright, overturned

synform: upright, overturned

mine or prospect

Fe - iron

Ba - barite

Au - gold

CNP Cherokee Nuclear Plant site

1 field trip stop

Units are not necessarily in stratigraphic order. Age of rocks is uncertain; they are probably late Proterozoic and/or early Paleozoic, with some middle Paleozoic Cherryville Quartz Monzonite in Inner Piedmont.

Figure 1. Preliminary geologic map of the Blacksburg South quadrangle, Cherokee County, South Carolina.

STRATIGRAPHY

The Blacksburg South quadrangle includes most of the distinctive lithologic types in the Kings Mountain belt (Fig. 1). The structurally lowest, and probably oldest, part of the sequence is the complex of mafic-to-felsic volcanic rocks and related intrusions in the southeastern part. This complex is succeeded northwestward by units that contain volcaniclastic rocks as well as obviously sedimentary ones such as metaconglomerate, quartzite and marble. Marbles and fine-grained metasedimentary rocks are more abundant to the northwest, suggesting a decrease in volcanic activity upward in the section and northwestward within a given unit. Posey (this volume) presents a model for some of these changes. Felsic gneiss in the cores of the Canoe Creek antiform and an unnamed antiform west of Draytonville Mountain (Fig. 1) may be derived from volcanic and subvolcanic rocks correlative in part with the predominantly volcanic sequence farther southeast.

Stratigraphy and deformational history of the Inner Piedmont in this region are poorly known. The older rocks are high-grade garnet-mica schist, sillimanite-bearing schist, biotite gneiss, amphibolite, and biotite-hornblende gneiss, with some thin quartzites. These are intruded by numerous small pegmatite bodies and plutons of various sizes that are similar to the Cherryville Quartz Monzonite farther north, which has a Rb-Sr whole-rock age of about 350 m.y. (Kish, 1977).

STRUCTURE

Structure in the Kings Mountain belt within the quadrangle is dominated by isoclinal folds with relatively short wavelength but large amplitude, that mostly plunge gently northeastward and continue for many kilometers along strike. The clearest example is the Cherokee Falls synform, which has several subsidiary folds that produce finger-like outcrop patterns (Fig. 1). The Canoe Creek antiform is cored mainly by fine-grained granitic gneiss and is truncated by the Kings Mountain shear zone. The McKowns Creek antiform is less well defined, partly because of fewer good marker beds in that part of the area and partly because of the effects of intrusive bodies.

The fold patterns show disruption on all scales. There are numerous discontinuities that generally parallel the regional strike. For example, one large discontinuity truncates map units that define the Cherokee Falls synform on the north, but a quartzite-metaconglomerate unit just to the south is continuous entirely across the quadrangle. Isolated fold hinges and disrupted fold limbs, also on all scales from microscopic to the largest shown on the map, attest to the extreme amount of deformation. Partly because of these disrupted folds, Keith and Sterrett (1931) showed numerous faults parallel to strike. The discontinuities generally occur along zones of well-developed schistosity, with fabric elements of similar sequence and style to those in adjacent rocks. There is generally no evidence of brittle deformation. The discontinuities are probably tectonic slides, a type of ductile fault defined by Hutton (1979, p. 165) as a fault which forms in metamorphic rocks prior to or during a metamorphic event, occurs within a zone of coeval penetrative deformation that is an intensification of a more widespread deformation phase, and may lie along and be sub-parallel to the boundaries of lithological units. For example, Draytonville Mountain is held up by thick metaconglomerate forming the hinge of a complex fold plunging east (Stop 9); compositional layering and at least one older S-surface are folded into a synform. The metaconglomerate is similar to, but does not connect with, the unit seen at Stop 9 that can be traced for 5 km. The Draytonville structure is interpreted to be an isoclinal synform with limbs that are disrupted by tectonic slides.

The Kings Mountain shear zone truncates early structures (probably both D_1 and D_2 folds) in the Inner Piedmont as well as the Kings Mountain belt. The clearest example is the D_2 Canoe Creek antiform, in which the entire northwestern limb and core are cut out along the shear zone. Horton (1981) noted that a distinctive garnet-mica schist unit and adjacent quartzite in the Inner Piedmont can be traced for 13.5 km southward into the Blacksburg South quadrangle, where they are truncated by the shear zone. The southern end of the units and the truncation are shown in Figure 1. The Kings Mountain shear zone is marked by a variety of deformed rocks, including phyllonite (fish-scale schist), mylonite, protomylonite, breccia, and silicified breccia, that occur in a belt generally 50 to 200 m thick. The variety suggests a long and complex history of deformation along the zone, but main movement was probably middle Paleozoic (Horton and Butler, this volume).

The mesoscopic structure and deformational sequences in the quadrangle southeast of the shear zone are discussed elsewhere in this volume, as listed above. One or two prominent steep cleavages (S_1 and S_2) are visible in almost every outcrop. They are normally subparallel except in fold hinges, where clear overprinting relationships can be seen. Post-S_2 mesoscopic structures are widespread, but sporadically developed, and they rarely represent enough strain to affect the map pattern. Deciphering the later phases of deformational history and correlating them regionally will require more work, although a good start has been made (Schaeffer, this volume).

METAMORPHISM

The Kings Mountain shear zone is a metamorphic discontinuity as well as a structural one. Sillimanite-grade schist and gneiss northwest of the zone are significantly coarser than rocks just southeast of the zone and pegmatite bodies are present in most outcrops. Sillimanite occurs in thin section and is present in all five of the sediment samples from small streams draining Inner Piedmont rocks (Gregory, this volume). Southeast of the shear zone, no sillimanite was found either in thin sections or sediment samples, and pegmatite bodies are absent, except near or within some shallow intrusions in the southern part of the quadrangle. Staurolite and kyanite sporadically occur in thin sections from most of the quadrangle, but rarely occur together. In stream-sediment samples, staurolite is ubiquitous, kyanite is widespread, and small amounts of andalusite are present at several localities (Gregory, 1981). Metamorphic grade may diminish to greenschist facies in the southeastern part of the quadrangle, but data are insufficient at present. Gregory (this volume) projected the staurolite isograd through the southeastern part, but his control points are sparse and many rocks have inappropriate chemical compositions for developing the pertinent index minerals. Position of the staurolite isograd probably is generally (if not precisely) correct, as much of the Kings Creek quadrangle has assemblages of upper greenschist facies (Murphy and Butler, this volume). Metamorphic rocks in the Blacksburg South quadrangle are therefore at sillimanite grade northwest of the shear zone, at staurolite-kyanite grade over most of the quadrangle and perhaps at upper greenschist grade in the southeasternmost parts. The age of metamorphism and timing relative to structural events are discussed by Horton and Butler (this volume).

MINERAL RESOURCES

The Blacksburg South quadrangle was the heart of the old Iron District, which played such a major role in the economic life of the region from the 1760's until the 1880's (Moss, this volume). Old iron-ore pits are abundant, following strata-bound deposits along the flanks and around the complex hinge of the Cherokee Falls synform (Fig. 1). Several partly-collapsed furnaces remain, but little else can be seen at the iron-manufacturing centers. The furnaces were constructed of huge blocks of local stone, making them more resistant to the depredations of time.

The only significant gold production in the quadrangle was the Flint Hill (also called Darwin) mine in the southeastern corner. The mine is in the western edge of the Smyrna gold district, which included about 50 old gold mines and prospects that are mostly situated east of the Broad River in eastern Cherokee and western York Counties (Butler, 1980, 1981). The mine was in operation when visited by Lieber (1858), but apparently closed within a few years. There is no record of later activity, but some of the workings appear to be much younger, possibly dug in the 1930's. The total production is unknown, but the old reports cite figures indicating the mine produced at least 2,000 ounces of gold and perhaps much more. The workings include 3 main shafts, one said to have been 26 m deep (Sloan, 1908), and several other shallow shafts and pits. Production was from a quartz vein that averaged 1 to 1.2 m thick and contained auriferous pyrite with some massive chalcopyrite (Sloan, 1908). Keith and Sterrett (1931) showed 3 areas of gold placers about 2 km northeast of Draytonville, but production was apparently insignificant. An exploratory adit about 60 m long was dug in that area in the 1930's, but apparently produced no gold. Some of the local people have small gold nuggets panned in the vicinity.

The quadrangle includes the southwestern end of the Carolina barite belt, which extends for 40 km in a narrow belt (Van Horn and others, 1949; Horton and Butler, this volume). The barite deposits are within a unit composed mainly of metamorphosed felsic volcanic rocks and related epiclastic rocks (called the schist of Kings Creek by Murphy and Butler, this volume). The felsic unit grades southwestward into more mafic metavolcanic rocks, in which no barite is known. Barite was produced at five localities (Fig. 1), with total production on the order of several hundred tons. Keith and Sterrett (1931) showed only one barite prospect in the quadrangle, therefore the main activity was after their survey, probably in the 1950's and early 1960's.

A belt of marble crosses the northern part of the quadrangle and was quarried for use as a flux in iron manufacturing (Horton and Butler, this volume). Quarries on both sides of the Broad River were important sources of flux before the Civil War (Lieber, 1858), but later marble production was from areas outside the quadrangle (Horton and Butler, this volume). All of the quarries within the quadrangle were relatively small and none has been worked in approximately the past hundred years, therefore little evidence remains.

Zones of manganese-rich schist extend discontinuously across the southern part of the quadrangle (Fig. 1), and lumps of manganese oxides-hydroxides in weathered schist are very abundant. There are a few shallow prospect pits, but apparently no production of manganese. Graphite-rich schist occurring along and near the Kings Mountain shear zone was prospected, but the percentage of graphite was low and no production is known (Keith and Sterrett, 1931).

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Polyphase folding in a portion of the Kings Mountain belt, north-central South Carolina

Malcolm F. Schaeffer, Duke Power Company, P. O. Box 33189, Charlotte, North Carolina 28242

INTRODUCTION

The Kings Mountain belt is a distinctive sequence of metasedimentary rocks including quartzite, metaconglomerate and marble interlayered within mica schists and phyllites that are partly volcanic in origin (King, 1955). Nearly all the units in the belt have a well-developed foliation or schistosity with compositional layering generally parallel to the oldest schistosity, but in many areas not parallel to the dominant schistosity (Horton, 1977). The foliation generally strikes northeast. Dips vary from steeply southeastward along the eastern boundary to northwestward along the western boundary of the belt. The Charlotte belt, located southeast of the Kings Mountain belt, consists mainly of schists and gneisses of the amphibolite facies intruded by a complex sequence of plutonic rocks (Butler, 1966). Northwest of the Kings Mountain belt are gneisses and schists interspersed with granitoid and scattered mafic rocks of the Inner Piedmont belt (Griffin, 1971).

The geology of the Kings Mountain belt along the North Carolina - South Carolina state line has been studied by several geologists (Keith and Sterrett, 1931; Kesler, 1944, 1955; Griffitts, 1958; Espenshade and Potter, 1960; Overstreet and Bell, 1965a, 1965b; Butler, 1966, 1971; Horton, 1977). Only recently has detailed structural analysis been conducted at certain locations within the belt (Horton, 1977; Horton and Butler, 1977; Horton and Simpson, 1978; Schaeffer, 1979). This paper will present a structural synthesis of a portion of the Kings Mountain belt based on an analysis of mesoscopic structures in the Blacksburg South and portions of the Gaffney and Kings Creek 7.5 minute quadrangles. Implications related to the macroscopic structure and regional structural history of the belt will be considered.

The study area is shown in Figure 1 and a geologic map of this area is in Schaeffer (1981).

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MESOSCOPIC STRUCTURES

The various mesoscopic structural elements and their relationships to one

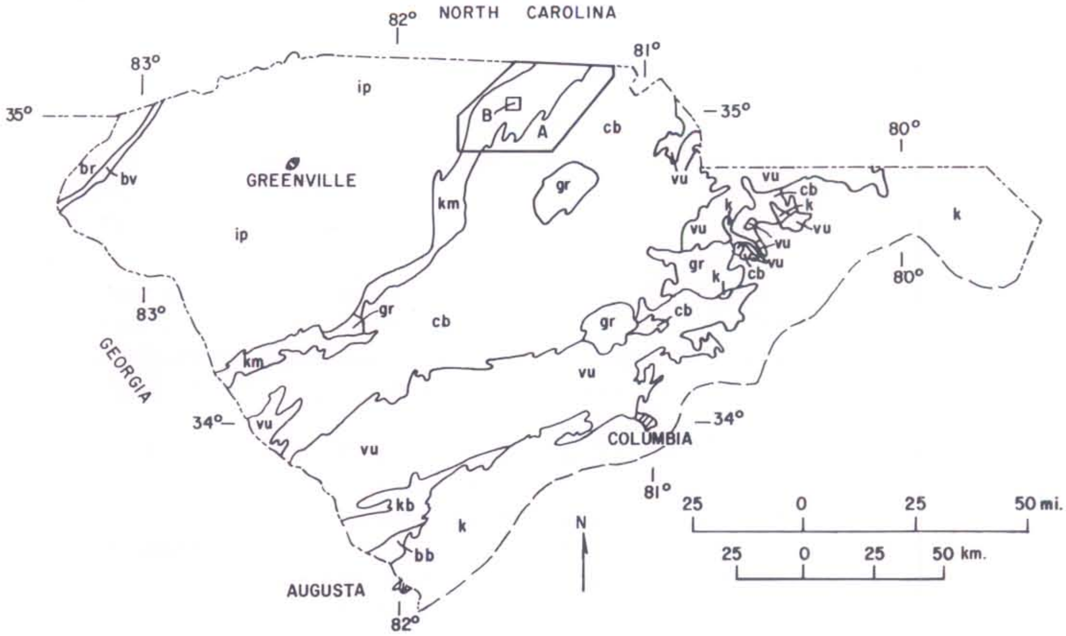


Figure 1: Index map of geologic belts in South Carolina, location of Figure 11 (A, area enclosed by heavy lines) and location of Figure 12 (B). Geologic belt legend: br- Blue Ridge, bv- Brevard zone, ip- Inner Piedmont belt, km- Kings Mountain belt, cb- Charlotte belt, vu- Carolina slate belt, kb- Kiokee belt, bb- Belair belt, gr- granite, k- Coastal plain (modified from Overstreet and Bell, 1965a).

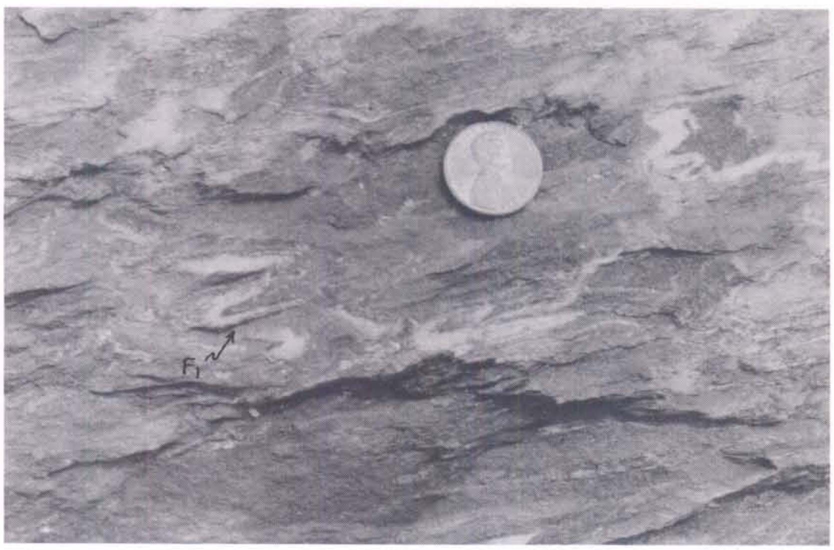


Figure 2: F_1 fold fragment ("Z" - shaped) in bluish-gray phyllite. Outcrop is located on the southeast corner of the intersection of County Road 50 and U.S. Highway 29 in the Blacksburg South quadrangle.

another are summarized and described in Table 1.

D_1 phase

The D_1 deformation phase is characterized by a variably developed S_1 axial planar foliation and minor small-scale F_1 isoclinal folds. The S_1 surface probably developed parallel to S_0 (compositional layering and/or bedding). In the central portion of the belt the S_1 foliation has been transposed by the later S_2 foliation and can be conclusively recognized only in the hinge areas of mesoscopic and macroscopic F_2 isoclinal folds.

F_1 folds are generally small-scale (wavelength 1 - 3 cm) and preserved as isoclinal "S"-, "Z"- or crescent-shaped fragments (Figure 2). These fold closures were isolated by the translation of the S_1 foliation by the later (almost coplanar) S_2 foliation, causing attenuation and shearing out of the F_1 fold limbs. The F_1 fold closures now lie within the S_2 foliation. In the nose of the Cherokee Falls synform (location 1 on Figure 11), the F_1 fold axes have been rotated in the plane of the S_2 foliation. A point-plot of F_1 fold axes indicates rotation in a plane oriented approximately N46E; 40SE, or very close to the orientation of the dominant axial planar S_2 foliation of the Cherokee Falls synform (Figure 3). The fold axes have been rotated by movement parallel to S_2. On the northwest flank of the synform in the Gaffney marble (location 2 on Figure 11), the F_1 fold axes are subparallel to the

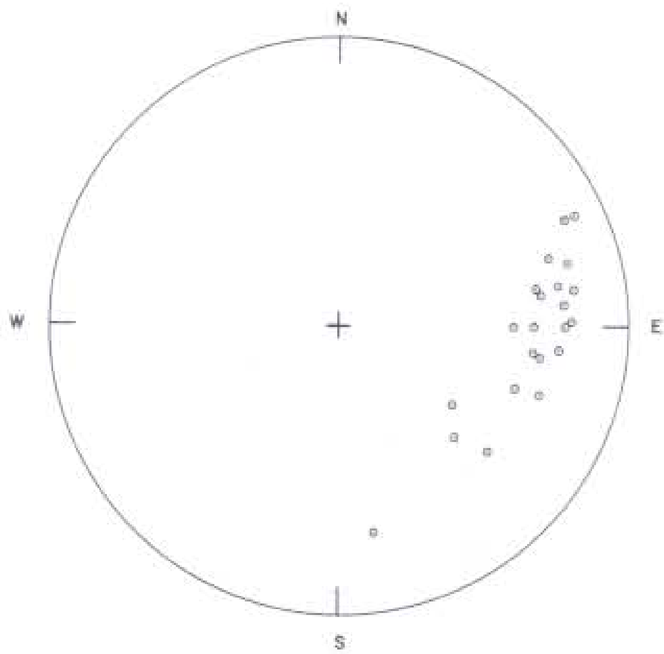


Figure 3: Lower hemisphere equal area projection of 22 F_1 fold axes in the hinge area of the Cherokee Falls synform in the Blacksburg South quadrangle. The fold axes have been rotated in a plane oriented N46E; 40SE which is close to the orientation of the S_2 foliation in the synform. (Note: The S_2 foliation elsewhere in the study area generally has a steeper dip. See Figure 4B.)

Table 1: Deformation Phases and Structural Elements in the Study Area

Deformation Phase	D_1	D_2	D_3	D_4	D_5
Folds	F_1, isoclinal, upright	F_2, isoclinal to tight, upright	F_3, open, upright (crenulations)	F_4, close to tight	F_5, gentle to open warps, kink folds
Surface Folded	S_o, bedding and/or compositional layering	S_o and S_1 foliation	S_o, S_1, S_2	S_o, S_1, S_2, S_3	S_o, S_1, S_2, S_3, S_4
Planar Structures	S_1, generally presen: only in hinge area of F_2 folds, transposed by later D_2 deformation, axial planar to F_1	S_2, dominant metamorphic schistosity, axial planar to F_2	S_3, crenulation clevage, axial planar to F_3	S_4, crenulation (weak)	S_5, kink planes
Linear Structures	L_1, locally intersection of S_o with S_1	L_2, intersection of S_1 and S_2, boudinage of thin biotite schist layers and quartz veins, mineral elongation lineation	L_3, crenulation axes, intersection S_3 with S_2	L_4, crenulation axes (?), intersection S_4 with S_2	L_5, axes of kink folds, intersection S_5 with S_2
Attitude	F_1 -NE to SE axes rotated in plane of S_2, S_1 dips to SE	F_2 -N to NE axes, S to SW axes, S_2 predominantly dips steeply SE, in areas dips NW	F_3 -NE axes, S_3 strikes NE, dips steeply NW	F_4 -NE axes, plunge at low angles, axial planar S_4 cleavage subhorizontal	F_5 -NE and SE axes, axial planes and kink planes subvertical, strike NE and NW, intersection of S_5 and S_2 plunges steeply down dip on S_2
Shearing and Faulting	Ductile, N to NE strike, parallel to limbs of F_2 folds, possibly due to attenuation of limbs during F_2 fold event		Brittle, brecciation, NE and NW strikes reactivation of earlier ductile shear zones		
Metamorphism	M_1, progressive regional metamorphism to amphibolite grade, central portion of belt to upper greenschist grade, M_1, D_1 and D_2 closely related in time, thermal peak of regional metamorphism after major D_1 deformation and during or after D_2 deformation		Lower greenschist conditions present, shear and breccia zones healed by quartz, epidote, mica, and K-feldspar, near end M_1		M_z, hydrothermal zeolite event, probably occurs after D_5

strike of the S_2 foliation. The limbs of the F_1 folds have been sheared out.

D_2 phase

The D_2 deformation phase is characterized by mesoscopic and macroscopic F_2 isoclinal to close folds with a well-developed S_2 axial planar foliation. The mesoscopic F_2 folds tend to be isoclinal in schist and phyllite and close to tight in quartzite, metaconglomerate and gneiss with the fold axes plunging northeast and southwest (Figure 4A). Ductile shearing and minor mylonization parallel to the F_2 axial planes occurred during the D_2 (and possibly the D_1) deformation phase due to attenuation in the limbs of isoclinal folds.

The S_2 foliation strikes northeast and dips predominantly southeast at steep to moderate angles in the study area (Figure 4B). The major observations supporting S_2 as the dominant foliation are the relationships between structural elements in mesoscopic F_2 folds and in the hinge area of the Cherokee Falls synform (locations 1 and 2 on Figure 11) and McKowns Creek antiform (location 3 on Figure 11). In mesoscopic F_2 folds an earlier foliation (S_1) is folded in the hinge area and a dominant axial planar foliation (S_2) is present (Figure 5). This same relationship has been observed by Horton and Simpson (1978) in the Foote mine at Kings Mountain, North Carolina. In the Cherokee Falls synform (Horton, 1977) and McKowns Creek antiform an earlier foliation (S_1) is present with the later S_2 foliation cutting it at an oblique angle. It is possible that in certain lithologies in the belt S_1 is the dominant foliation. However, the majority of field evidence in the study area indicates that the S_1 foliation was transposed by the development of the S_2 foliation.

Several linear elements are related to the D_2 deformation phase. The intersection of S_1 with S_2 defines a strong lineation that generally trends northeast. A "fish-scale", "button" or "blade-like" texture (previously described by Keith and Sterrett, 1931; Griffin, 1972; Horton and Butler, 1977) is developed in phyllites near the western boundary of the belt and is due to the intersection of S_1 and S_2. Boudins were formed in thin biotite schist layers, quartz veins and marble (Figure 6). The boudin lines in the biotite schist and quartz veins are perpendicular ("a" direction) to the F_2 fold axes. The orientation of the boudin lines may be the result of extension parallel to the F_2 fold axes. In marble the boudin lines are both perpendicular ("a" direction) and parallel ("b" direction) to the F_2 fold axes resulting in "pillow-like" structures at some locations. A mineral elongation lineation parallel ("b" direction) to the F_2 fold axes is present in some schists and phyllites in the belt.

The similar nature of the D_1 and D_2 deformational events suggests they are closely related in time and possibly to a single orogenic event. Further evidence is that the D_1 and D_2 events are overlapped by a single progressive metamorphic event that is as low as greenschist facies in the central portion of the belt, but is in the amphibolite facies in the majority of rocks in the belt (Horton, 1978). Butler (1972) and Dallmeyer (1975) have shown that this single metamorphic event took place in the crystalline southern Appalachians during the Ordovician Taconic orogeny. Horton's (1978) estimate of 440 to 407 m.y. ago (Ordovician - Silurian) for this metamorphism agrees well with

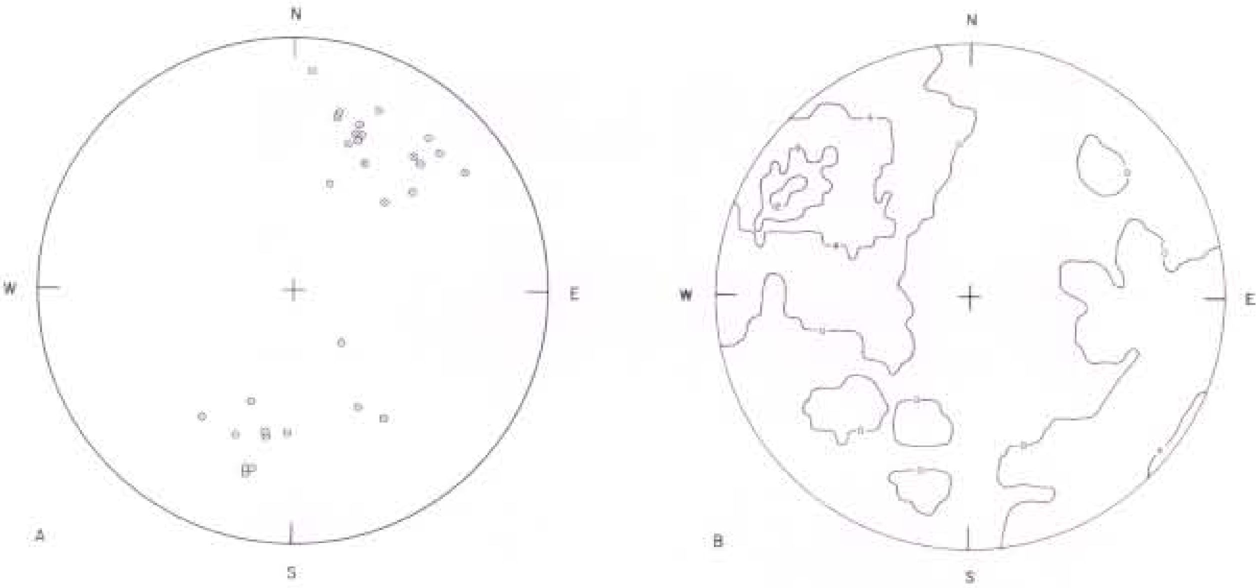


Figure 4: Lower hemisphere equal area projection of: [A]. 30 F_2 fold axes, [B]. 305 poles to S_2 foliation. Contours are 0,4,8 and 12% per 1% unit area. Data from the Blacksburg South and portions of the Gaffney and Kings Creek quadrangles.

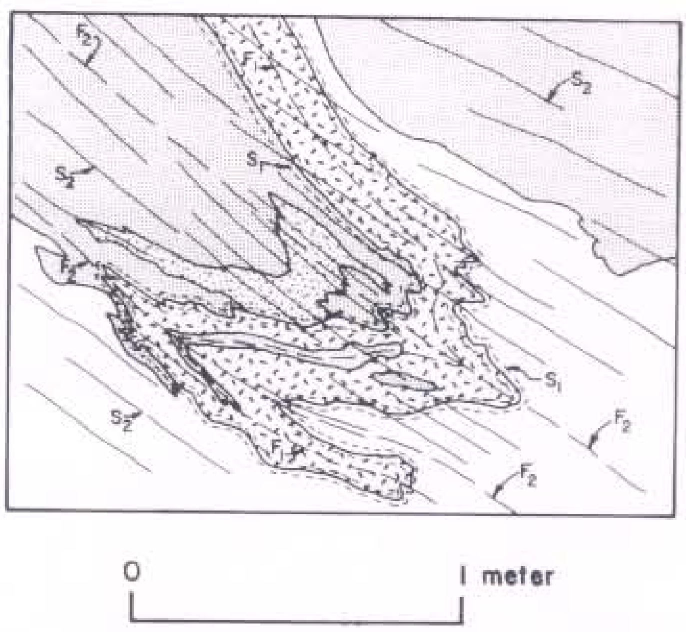


Figure 5: Sketch of F_1 fold refolded by F_2 folds. Short dashes- S_1 foliation, long dashes- S_2 foliation, intermediate dashes- trace of F_1 or F_2 axial plane. Dotted pattern- biotite and mica schist, dashed pattern- very light gray phyllite, dots and small circle pattern- quartz-mica schist, blank- gray phyllite. The saprolite outcrop is located at the intersection of County Road 132 and the Duke Power access railroad in the Blacksburg South quadrangle.

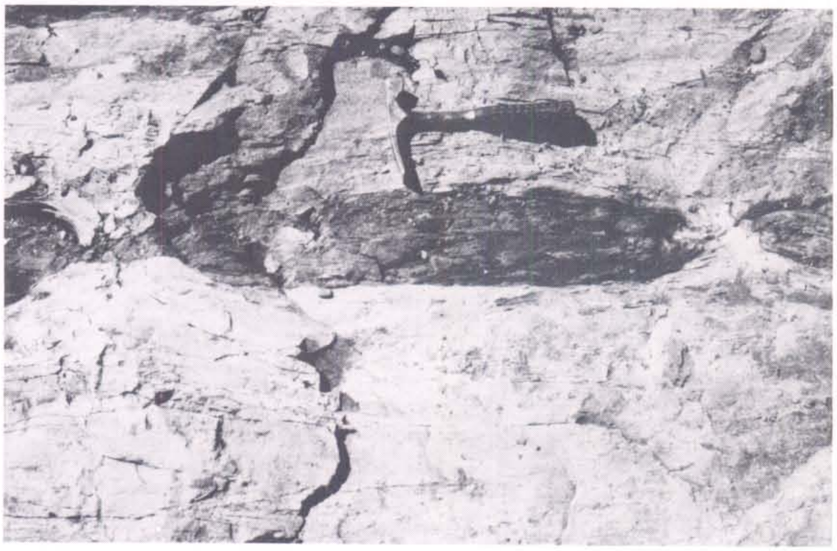


Figure 6: Boudinage in a thin biotite schist layer related to the D_2 deformation. The boudin lines are perpendicular to F_2 fold axes (not shown). Note quartz mineralization in necks of boudins. Outcrop is located north of County Road 13 near McKowns Mountain in the Blacksburg South quadrangle.

Figure 7: F_3 fold in phyllite. Note folding of S_2 foliation with development of an axial planar crenulation cleavage (S_3) in the hinge area. Same location as Figure 6.

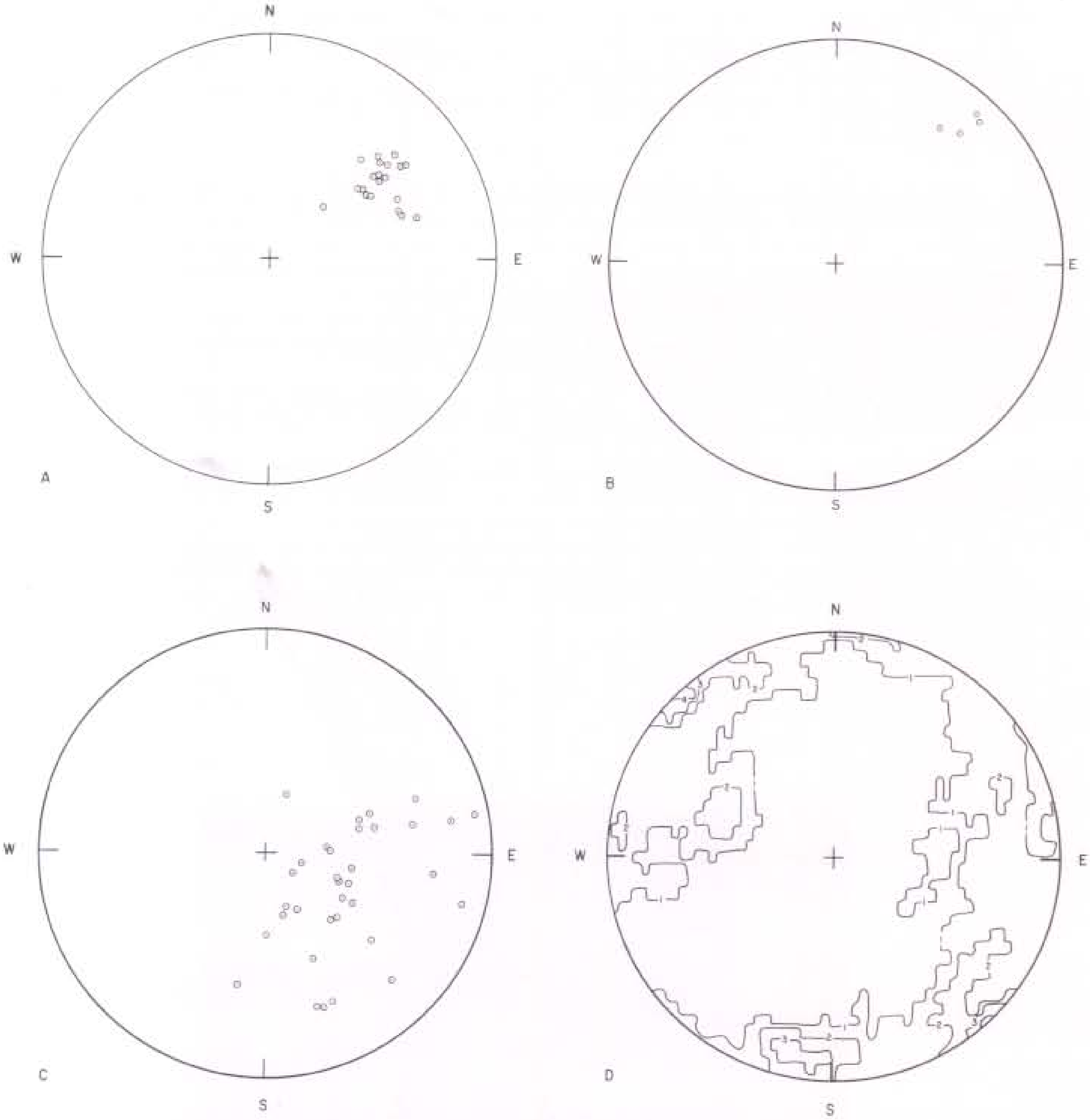


Figure 8: Lower hemisphere equal area projections of: [A]. 20 F_3 fold axes, axial planes strike northeast and dip steeply northwest, [B]. 4 F_4 fold axes, axial planes strike northeast and northwest and have shallow northerly dips, [C]. 33 F_5 fold axes, axial planes strike northwest and kink planes strike northwest and northeast, both have near vertical dips, [D]. 568 poles to joint planes, contours are 1,2,3 and 4% per 1% unit area. Data for A, B and C from the Blacksburg South and Gaffney quadrangles; for D from the southeast corner of the Blacksburg South quadrangle.

their conclusion. The D_1 and D_2 deformational events are therefore probably middle to late Taconic events with the M_1 metamorphic event being late Ordovician to early Silurian in age.

D_3 phase

The D_3 deformation phase is characterized by asymmetrical flexural-slip folds in which the S_2 foliation has been folded (Figure 7). The southeast limbs of F_3 folds are distinctly longer than the northwest limbs producing an appearance similar to drag folds. The F_3 folds trend northeast (Figure 8A) and have a well-developed axial planar crenulation cleavage that strikes northeast and dips steeply northwest. The F_3 folds are distinguished from earlier folds by the difference in mechanism and style of folding and the steep northwest dip of the axial planar crenulation cleavage. At several outcrops F_3 folds refold F_2 folds. Lineations associated with the D_3 phase include the intersection of S_3 with S_2 and the axes of small crenulations.

Reactivation of earlier D_2 shear zones occurred during the D_3 deformation phase as reflected by semibrittle to brittle deformation and in some instances brecciation of earlier shear zones. Lower greenschist metamorphic conditions were present during this deformation resulting in the shear-breccia zones being healed by quartz, epidote, mica, chlorite and potassium feldspar. The occurrence of late greenschist minerals in fractures and shear zones of the

Figure 9: F_4 fold in phyllite. The S_2 foliation is folded with a weak, subhorizontal axial planar crenulation cleavage (S_4) in the hinge area. Same location as Figure 6.

study area is similar to that described for other areas of the Piedmont (Fullagar, 1971; Butler, 1972; Bobyarchick and Glover, 1979; Gilbert and others, in review). The greenschist metamorphism probably represents a slow thermal decline from the peak of regional metamorphism although it has been speculated that this metamorphism may be a separate event related to the Acadian orogeny (Hatcher, 1978). The D_3 phase may be related to the Devonian Acadian orogeny.

D_4 phase

The D_4 deformation phase is characterized by open to tight flexural-slip folds with a poorly developed axial planar crenulation cleavage (Figure 9). The F_4 folds plunge northeast (Figure 8B) with the S_4 crenulation cleavage dipping gently northeast and northwest (almost horizontal). Lineations associated with the D_4 phase include the intersection of S_4 with S_2 and the axes of small crenulations.

D_5 phase

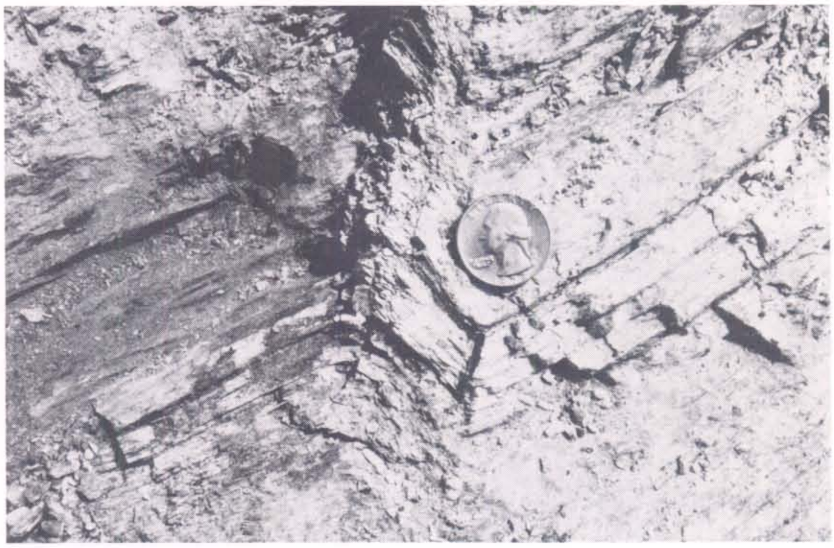
The D_5 deformation phase is characterized by gentle to open warps and kink folding of the S_2 foliation (Figure 10). The F_5 fold axes plunge primarily northeast and southeast (Figure 8C) with subvertical axial and kink planes that strike northeast and northwest. Some kink folds occur in conjugate sets (Figure 10B). The intersection of S_5 with S_2 plunges steeply down dip on S_2.

The relative timing of F_4 and F_5 folds is poorly established in the study area. Cross-cutting relationships at certain outcrops indicate both are younger than F_3 folds, but no direct relationship between them was observed. In the Grover and Kings Mountain quadrangles to the north, Horton and Butler (1977) described similar folds (their F_3 and F_4 folds, Table 2, p. 106). In the Vulcan Materials Quarry near Blacksburg, South Carolina, they observed the F_4 folds (F_5 this paper) refolding F_3 folds (F_4 this paper).

Other mesoscopic structures

Joints and other fractures are present in the rocks of the study area. A study of joints in the southeast corner of the Blacksburg South quadrangle reveals a major northeast-trending set, a major east-west-trending set, and several minor sets (Figure 8D). Some of these joints are healed by greenschist minerals while others are partially filled by prehnite-calcite and laumontite-calcite. Occurrences of zeolites and related minerals are widespread in the Piedmont (Privett, 1974a) and have been reported in the Kings Mountain belt (Privett, 1974b). They generally occur as fracture fillings and in hydrothermally altered zones adjacent to fractures. The association of zeolites with Mesozoic diabase dikes (Furbish, 1965; Toewe, 1966) suggests that the hydrothermal mineralization is related to the early to middle Mesozoic development of fractures along which the diabase was introduced (Butler, 1977). Several S_5 kink planes are healed by laumontite-calcite, possibly bracketing the age of the D_4 and D_5 deformation phases between late Devonian and middle Mesozoic (possibly Alleghanian?).

A.



B.

Figure 10: [A]. F_5 kink fold in phyllite. Note distinct kink planes left of quarter. [B]. F_5 kink folds developed in phyllite along a conjugate set of kink planes oriented N21W and N84W. Quarter for scale. Same location as Figure 6.

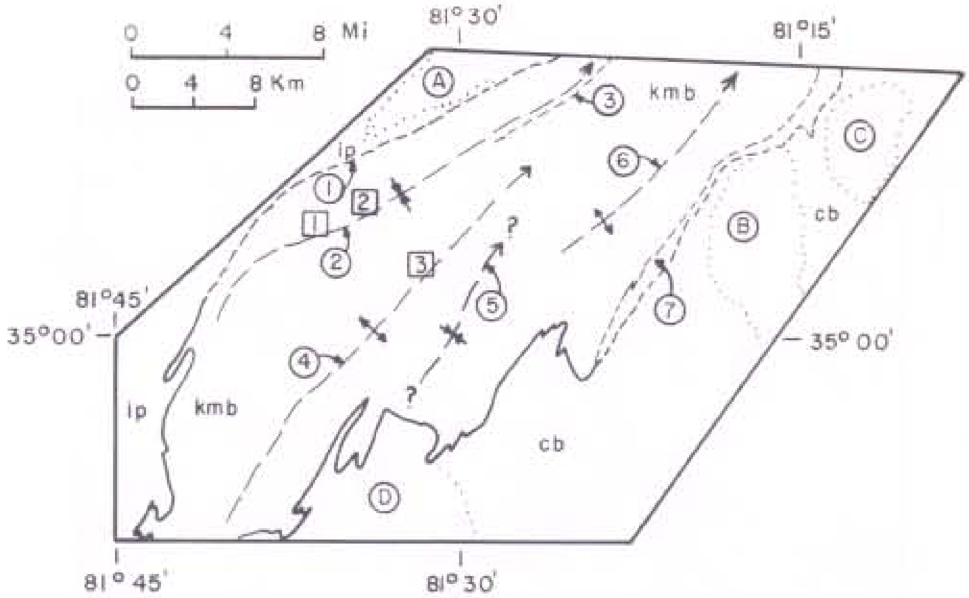


Figure 11: Map of macroscopic structures and major plutons in north-central South Carolina. Contacts of plutons shown by dots, shear zones shown by short dashes, folds shown by long dashes. Legend: ip- Inner Piedmont belt, kmb- Kings Mountain belt, cb- Charlotte belt, A- Cherryville Quartz Monzonite, B- York pluton, C- Clover pluton, D- Bald Rock pluton, 1- Kings Mountain shear zone, 2- Cherokee Falls synform, 3- Kings Creek shear zone, 4- McKowns Creek antiform, 5- inferred synform, 6- South Fork antiform, 7- transition zone of Butler (1966), possible extension of the Boogertown shear zone. Numbers in squares are localities mentioned in text.

MACROSCOPIC STRUCTURES

The macroscopic folds and shear zones in the Kings Mountain belt and major plutons of the surrounding belts in north-central South Carolina are shown on Figure 11.

Folds

Previous investigators have generalized the structure of the Kings Mountain belt as a complex fold system (Keith and Sterrett, 1931; Kesler, 1955; Griffitts, 1958; Espenshade and Potter, 1960; Horton and Butler, 1977). The major structural feature of the belt in the vicinity of the North Carolina-South Carolina state line is a large tightly-folded, north- to northeast plunging antiform (South Fork antiform, Figure 11, #6) located near the eastern edge of the belt (Kesler, 1955; Espenshade and Potter, 1960; Horton and Butler, 1977). Subsidiary folds have been recognized by several workers on the west flank of this structure (Kesler, 1955; Griffitts, 1958; Horton and Butler, 1977; Schaeffer, 1980, 1981). Southeast of the Inner Piedmont - Kings Mountain belt boundary is the Cherokee Falls synform (Griffitts, 1958; Horton and Butler, 1977; Figure 11, #2). In the central portion of the belt the writer has mapped an antiform, informally named the McKowns Creek antiform (Figure 11, #4). A synformal structure is inferred between the South

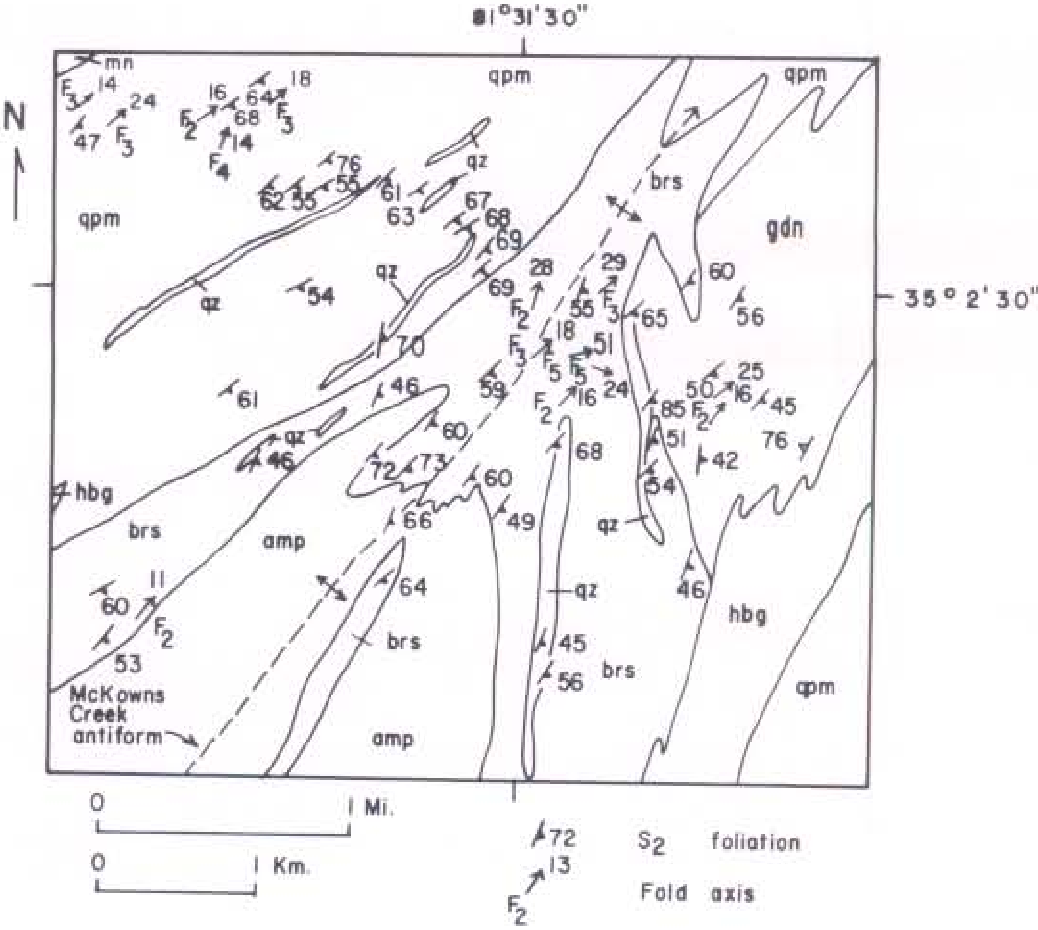


Figure 12: Geologic map of the McKowns Creek area (location B on Figure 1). Legend: mn- manganese schist, qpm- quartz-mica schist and phyllite, qz- quartzite, brs- intermediate to mafic metavolcanic rocks with interlayered felsic rocks and metasediments, amp- amphibolite, hbg- hornblende gneiss and schist with biotite schist and amphibolite layers, gdn- foliated to massive gneiss of granitic to dioritic composition.

Fork and McKowns Creek antiforms on Figure 11 (#5). However, this structure has not been recognized in the field. All of the major macroscopic folds plunge northeast with generally steeply dipping axial planes.

Examination of the mesoscopic structures in the nose of the Cherokee Falls synform (discussed in sections on the D_1 and D_2 phases) indicates that it is a macroscopic F_2 fold (also Horton, 1977). The South Fork antiform was originally interpreted by Horton and Butler (1977) as an F_1 fold. Recent work by Horton (1981, personal communication) in the hinge area of the South Fork antiform near Bessemer City, North Carolina revealed an older foliation (S_1) in quartzite that has been folded around the nose with a well-developed axial planar foliation (S_2) present. Horton (1981, personal communication) now interprets the South Fork antiform as an F_2 fold.

The nose of the McKowns Creek antiform is in the southeast corner of the Blacksburg South 7.5' quadrangle (location B on Figure 1). It is cored by amphibolite and intermediate to mafic metavolcanic rocks that wrap around the amphibolite to the northeast (Figure 12). On the east flank of the fold are two prominent quartzite ridges oriented north-south. Quartzite ridges on the west flank are oriented northeast. The dominant foliation (S_2) in the north-south quartzites is at an oblique angle to the contacts and is parallel to the axial planes of mesoscopic F_2 folds in the map area (Figure 12). An earlier foliation (S_1) can be observed in the nose of the fold and in mesoscopic F_2 folds. The orientation of mesoscopic F_2 folds (northeast plunge) in the map area, the presence of the dominant S_2 foliation and the outcrop pattern indicates the structure is an F_2 antiform.

In the area covered by Figure 11 (and at that scale) the outcrop pattern is controlled by the northeast-trending F_2 folds. Farther to the north, mapping at a larger scale indicates sone F_1 folds are present on a map scale (Horton, 1981, personal communication). The warping of the belt on a macroscopic scale around northwest-trending, nearly vertical axial planes may be related to the D_5 phase during which warping occurred on a mesoscopic scale with northwest-trending axial planes. The dominant folding of the belt (F_1 and F_2) probably occurred during the Taconic orogeny and may have been subsequently modified during the Acadian and Alleghanian orogenies.

Shear zones

Three zones of mylonitic deformation with superimposed semibrittle faulting in the Kings Mountain belt have been described by Horton (1980, 1981). The Boogertown shear zone reportedly marks the boundary between the Kings Mountain and Charlotte belts. Horton (1980, personal communication) has not traced the zone into South Carolina, but believes it may occur along the transition zone (Figure 11, #7) mapped by Butler (1966). The Kings Creek shear zone truncates the southeast limb of the Cherokee Falls synform (Horton, 1980) and has been traced by Horton (1981) into the northern part of the Kings Creek quadrangle (Figure 11, #3). Recent mapping southwest of the location, in the Blacksburg South quadrangle, has not revealed the zone (Butler, 1980, personal communication; Horton, 1980, personal communication; Schaeffer, unpublished data). The Kings Mountain shear zone lies along the boundary of the Inner Piedmont-Kings Mountain belts (Figure 11, #1) and extends at least from Lincolnton, North Carolina to south of Gaffney, South Carolina (Horton, 1981). Horton (1981) has speculated the Kings Mountain shear zone may be part of a regional fault system, including the Lowndesville and Towaliga zones, that extends from Alabama to Virginia, possibly as a single zone as much as 550 km long.

The minimum age of semibrittle deformation in the shear zones associated with the Kings Mountain belt is interpreted to be middle to late Devonian (Horton, 1981). However, the age of ductile shearing and mylonization is not firmly established. It is probable the shear zones record one or more pre- or syn-metamorphic episodes of ductile movement followed by episodes of post-metamorphic ductile movement similar to the movement histories of other faults in the southern Appalachians (Hatcher and Odom, 1980). Initial ductile movement on the shear zones may be related to the mesoscopic ductile shearing and minor mylonization that occurred during the D_2 deformation phase and therefore a middle to late Taconic event with possible superimposed post-Taconic ductile movement. Additional work is needed to accurately determine the age (or ages) of ductile movement and mylonization along the shear zones.

SUMMARY AND DISCUSSION

The Kings Mountain belt rocks have been subjected to five deformation phases resulting in polyphase folding and faulting. Tentative correlations have been made with the major tectonic events in the southern crystalline Appalachians and are summarized in Figure 13. The basis for the correlations have been discussed in the previous section. The earliest deformations (D_1 and D_2) developed isoclinal folding, mesoscopic ductile shearing and mylonization. This was overlapped by regional metamorphism (M_1). Some of the ductile deformation along the Kings Mountain and other shear zones may have occurred during this event although evidence is inconclusive. The macroscopic folds of the belt are the results of these deformations which are tentatively correlated with the middle to late stages of the Taconic orogeny. The next deformation (D_3) developed flexural-slip folds, crenulation cleavage and semi-brittle to brittle deformation along earlier shear zones. Lower greenschist metamorphic conditions were present during and after this deformation and heal the mesoscopic shear-breccia zones. This event is correlated with the Devonian (Acadian?) deformation. The latest deformations (D_4 and D_5) resulted in flexural-slip folds and kink folds. The timing of this deformation has been bracketed between the late Devonian and middle Mesozoic and may be related to the Alleghanian orogeny. A hydrothermal zeolite event (M_z) affected rocks in portions of the belt and has been associated with the early to middle Mesozoic intrusion of diabase dikes (Butler, 1977). The sequence of deformational events, faulting and metamorphism in the Kings Mountain belt correlates well (with minor variations) with the sequence of events affecting the southern crystalline Appalachian orogen compiled by Hatcher (1978, Figure 6).

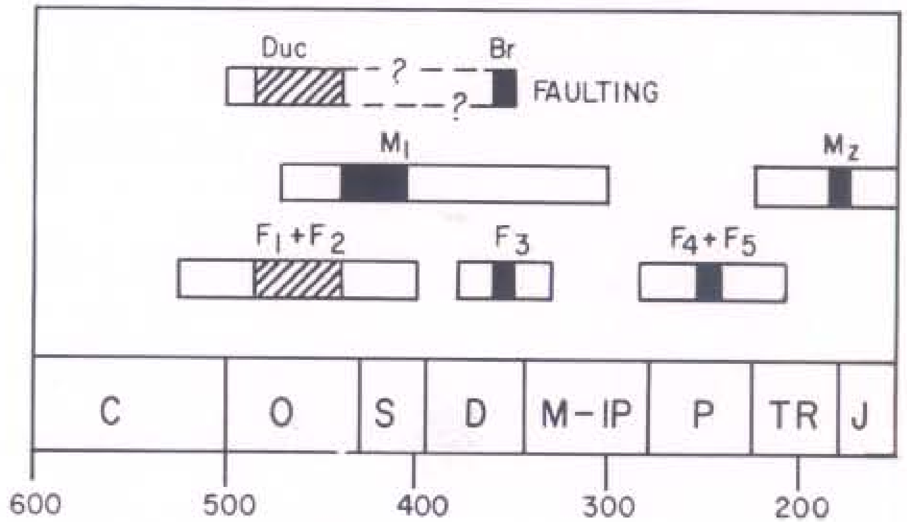


Figure 13: Tentative timing of deformation phases (folding, F), faulting and metamorphism (M, M_z- hydrothermal zeolite event) in the Kings Mountain belt.

The role of the Kings Mountain belt in the geologic history of the Appalachian orogen has been discussed in several papers in recent years (Hatcher, 1972, 1978; Glover and Sinha, 1973: Odom and Fullagar, 1973: Cook and others, 1979; Hatcher and Odom, 1980; Hatcher and Zietz, 1980). Cook and others (1979), based on the COCORP seismic-reflection profiling in Georgia, North Carolina and Tennessee, believe the crystalline rocks of the Blue Ridge, Inner Piedmont, Kings Mountain, Charlotte, and Carolina slate belts constitute a thin crystalline allochthonous sheet overlying nearly horizontal Paleozoic sedimentary rocks. In their tectonic model the Kings Mountain belt is interpreted as the back-arc basin between the continent and island arc that collided during the Acadian orogeny with probable westward transport on a sole thrust during later deformation phases. Their model allows for major deformation and metamorphism in the belt during the Acadian orogeny. This study and others (Horton, 1977, 1978, 1981) indicates the major deformation and metamorphism were produced by an older orogenic event (Taconic?).

The theory that the entire Piedmont is an allochthonous sheet is not fully accepted. Hatcher and Zietz (1980) concluded from magnetic and gravity data that the Blue Ridge-Inner Piedmont block is allochthonous and has been transported westward on a sole thrust rooted beneath the Kings Mountain belt. They view the eastern edge of the belt as a suture between an allochthonous Blue Ridge-Inner Piedmont block (underlain by continental crust) to the west and a parautochthonous Charlotte belt-Carolina slate belt block (underlain by mafic and mixed crust) to the east. Hatcher and Zietz (1980) believe the joining of the Blue Ridge-Inner Piedmont meganappe to the rest of the Piedmont along the Kings Mountain belt occurred as a late Taconic or early Acadian event. Horton's (1981) mapping of the Kings Mountain shear zone supports tectonic models that recognize a detachment near the southeastern boundary of the Inner Piedmont belt. The Inner Piedmont nappes are truncated by the shear zone and are probably detached from their root zone (Horton, 1981).

The deformational events described in this paper and others (Horton, 1977, 1978, 1981; Horton and Butler, 1977; Horton and Simpson, 1978) need to be considered when testing models of the southern Appalachian orogen. A better understanding of the timing of events (particularly ductile shearing and mylonization) in the Kings Mountain belt is necessary before a reliable evaluation of tectonic models can be made.

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A petrographic study of Kings Mountain belt metaconglomerates

Noelle A. France and Henry S. Brown, Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina 27650

INTRODUCTION

The Kings Mountain belt, a sequence of metamorphosed volcanic and sedimentary units, extends from the Catawba River in North Carolina to south of Gaffney, South Carolina (King, 1955) and may extend across South Carolina to the South Carolina-Georgia border (Overstreet and Bell), 1965a,b). It is widest and best developed around Kings Mountain, North Carolina. The eastern part of the belt is dominated by foliated granitic intrusives such as the Bessemer granite and the High Shoals granitic gneiss. Phyllitic volcaniclastic rocks, a plagioclase crystal tuff, and a meta-volcanic hornblende gneiss (Horton 1977) are also found in this part of the belt. Younger rocks including the metaconglomerates, quartzites, marble, and manganiferous schist dominate the western part of the belt (Keith and Sterrett, 1931). The metaconglomerates are easily mapped and have been used by Keith and Sterrett (1931), Espenshade and Potter (1960) and Horton (1977) to define the large northeast-trending folds that form the major structures of the belt. The age of the conglomerates is unknown. This paper is part of an in-progress study on the Kings Mountain conglomerates.

Mapping by Horton (in preparation) in the Kings Mountain quadrangle has defined 5 different metaconglomerate beds (Fig. 1). Each metaconglomerate bed in this study is a sedimentary unit that contains variable amounts of pebble clasts and occurs at a given stratigraphic position in relation to other metasedimentary units. The beds are labeled A, B, C, D, and E in the order assumed to be oldest to youngest (Horton, personal communication). These metaconglomerate beds are located within or near Keith and Sterrett's Battleground Schist. More recent mapping by Horton and Butler (1977), however, has subdivided the Battleground Schist into several different rock types. The older beds A and B are pebbly lenses in a volcaniclastic phyllite; the younger beds, C, D and E collectively mapped as Draytonville Conglomerate by Keith and Sterrett (1931), are in quartz-rich metasiltstones. Mapping by Horton (in preparation) indicates that bed C has been repeated by folding in the study area. All conglomeratic beds described herein crop out on the west limb of the South Fork antiform (Horton, 1977, Horton and Butler, 1977).

The several metaconglomeratic layers recognized in the Kings Mountain belt are generally coarse-grained with pebble sizes ranging up to 70 mm in the long dimension and are poorly to moderately sorted. Pebble colors range

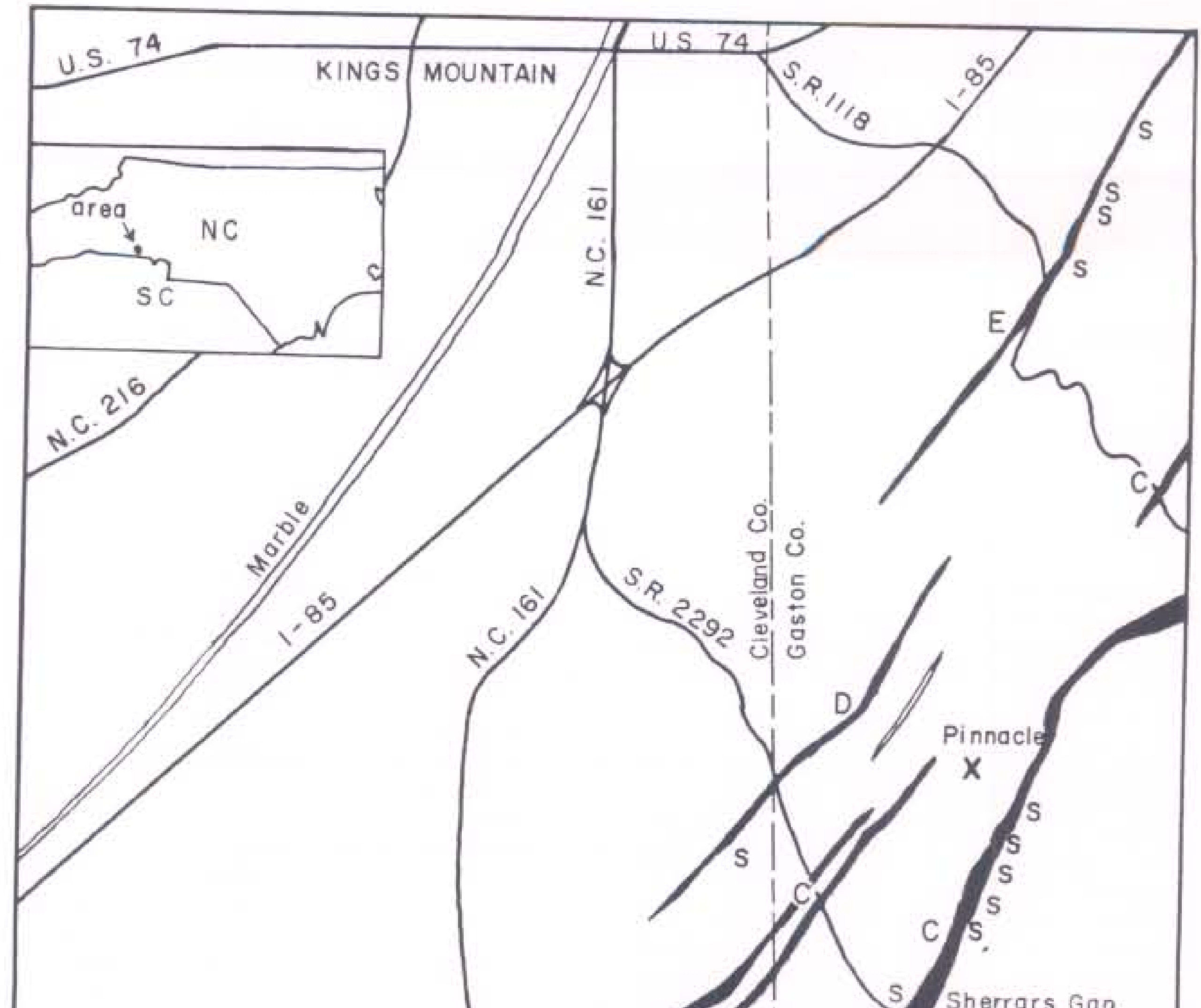

Figure 1. SOME CONGLOMERATIC BEDS SOUTHEAST OF KINGS MOUNTAIN, N.C.†

from white to dark gray in variable proportions depending on their locations, and may weather to orange-brown in color. In most outcrops, the pebbles are more or less elongated with their long axes essentially parallel to each other and to the plane of schistosity. The degree of elongation varies from place to place within a given conglomerate bed. The conglomerates commonly form ridges or knolls and often grade along strike into quartzites with sand-sized grains.

Appreciation is extended to Dr. J. Robert Butler, University of North Carolina at Chapel Hill, Dr. Victor V. Cavaroc, North Carolina State University at Raleigh, and Dr. J. Wright Horton, Jr., U.S. Geological Survey, Reston, Virginia for their many helpful comments and their reviews of the manuscript.

PREVIOUS WORK

Keith and Sterrett (1931) recognized two conglomeratic units, the Draytonville Conglomerate member of the Kings Mountain Quartzite and a conglomerate bed of the Battleground Schist. Keith and Sterrett described the Draytonville Conglomerate as a hard, massive rock which generally crops out in cliffs or ledges, some of which are very continuous. They considered the pebbles to have been rounded in their original form but flattened and recrystallized to an almost gneissic texture with subsequent metamorphism. The conglomerate mapped as part of the Battleground Schist is described as containing many small rounded pebbles of quartz in a matrix of the same composition as the surrounding schist.

King (1955) cited W.R. Griffitts as saying that the conglomerates found in the Kings Mountain Belt may be classified as either Draytonville or Battleground depending on their pebble shape but this shape distinction is not defined. Kesler (1955) realized the importance of the Draytonville Conglomerate in defining the structure of the Kings Mountain belt and considered them to belong to the oldest group of siliceous rocks in the area.

Kesler (1956, p.3) noted three main pebble types in the Draytonville Conglomerate at Dixon Gap: 1) milky quartz which makes up 90% of the pebbles seen, 2) black flinty or jasperoidal quartz, and 3) light gray quartzite. Kesler also questioned whether or not all the conglomerates mapped as Draytonville are at the same stratigraphic horizon.

Horton (1977) reported that the quartz pebble conglomerates are phenoclast supported, moderately sorted, and with average clast size being 1 cm. In thin section both the pebbles and the matrix are composed mainly of polygonized quartz. Most gray to dark gray pebbles seen proved to be quartz with up to 40 percent opaque oxides. Horton suggested that the conglomerates had a nearby source area based on the angularity of the clasts and dirty matrix, and that they may be intraformational. His suggested environment of deposition based on the coarseness of clasts and a nearby parallel belt of carbonates was in the littoral zone of an ancient shore line.

PETROGRAPHY

The descriptions of Kings Mountain belt conglomerates presented in this section are preliminary findings based on laboratory examinations of 90 slab-bed samples and 59 thin sections. Pebble sizes, shapes and colors (white vs. shades of gray) are determined from measurements made on slabbed samples. Pebble and total conglomerate mineral percentages are based on visual estimates in thin sections. In addition to sample locations indicated in Figure 1 conglomerate was collected from beds southwesterly to and including Draytonville Mountain, and northeasterly into the Bessemer City quandrangle.

Bed A

Bed A occurs as medium dark gray (weathering to buff), discontinuous lenses along a stratigraphic horizon in a volcaniclastic phyllite near the base of Keith and Sterrett's Battleground Schist. Lenses consist of angular to subrounded elongate quartz pebbles and less common phyllitic pebbles in a quartz-mica rich matrix. Pebble lengths range from 21 to 55 mm with a mean at 16 mm (n = 79, S. Dev. = 10). This bed consist of 65 percent matrix and 35 percent pebble sized clasts. Pebbles are 80 percent gray (of varying shades) and 20 percent white. Gray colors in quartz pebbles result from inclusions of fine-grained magnetite and specular hematite.

The amount of quartz seen in 10 thin sections of conglomerate from bed A varies from 10 to 20 percent where beds are phyllitic to 60 to 70 percent where the conglomerate is clast supported. Magnetite ranges up to 20 percent of the rock occurring in both quartz pebbles and in the matrix. White mica constitutes 15 to 60 percent of the rock with minor amounts occurring in some pebbles.

Bed B

Bed B is similar in color to bed A and may be composed in part of particles reworked from bed A. Bed B, like bed A, consists of relatively small lenses of coarser material in the Battleground Schist. Most pebbles in this conglomerate are angular to subrounded, 60 percent white and 40 percent gray colored quartz pebbles. This bed is made up of 68 percent matrix and 32 percent pebble-sized clasts. The quartz pebbles range in length from 4 to 20 mm with a mean at 7.4 mm (n = 26, S. Dev. = 4.2).

Examination of 6 thin sections reveals that quartz makes up 45-80 percent of this bed. Mica, appearing slightly finer grained than in bed A, makes up 15-45 percent of the conglomerate, and is restricted essentially to the matrix. Magnetite ranging from 2-10 percent is found in both the matrix and the quartz pebbles in anhedral grains. Euhedral actinolite and chloritoid grains are locally oriented parallel to the foliation. Small grains of kyanite are locally present. Garnets are in the more micaceous parts of the conglomerate and show strain fracturing.

Bed C

Bed C is the conglomerate which forms a major portion of the ridge of Kings Mountain. This bed crops out at Dixon Gap and is one of the beds originally mapped by Keith and Sterrett as the Draytonville Conglomerate. It is not a continuous conglomerate but grades along strike into a fine-grained quartzite. Bed C is distinctly lighter gray in color than beds A and B due to the greater proportion of white to gray quartz pebbles; 63 to 37 percent respectively. This bed is composed of 50 percent matrix and 50 percent pebble-sized clasts. Quartz pebbles several centimeters long have been observed in this bed, however the mean length is 8.8 mm (n = 207, S. Dev. = 5.1); color of the quartz pebbles ranges from white (little or no magnetite) to dark gray (containing significant amounts of magnetite). This conglomerate is essentially all clast supported except where it grades along strike into fine-grained quartzite.

Examination of 16 thin sections reveals that bed C is composed of 80-90 percent quartz, 5-7 percent mica and 3-5 percent magnetite. Kyanite, tourmaline, chloritoid and hematite (as a weathering stain) make up the remaining 2 percent. Most quartz occurs as pebbles; some quartz and essentially all other minerals occur in tne matrix. Veinlets of micas cut fractured quartz pebbles in some places. Chloritoid forms euhedral grains in the matrix and commonly occurs as radial sprays of crystals growing across the foliation. Where magnetite is found in the matrix it is coarse-grained and euhedral. At some places magnetite is so concentrated that the rock is strongly magnetic.

Bed D

Bed D is another of the conglomeratic units mapped by Keith and Sterrett (1931) as Draytonville Conglomerate. Horton (in preparation) has mapped bed D as stratigraphically above bed C because it is found on the opposite side of a manganiferous schist unit he considers to be a stratigraphic horizon marker. Bed D is light gray and essentially all clast-supported; pebbles are 80 percent white quartz and 10 percent gray quartz. This bed contains 40 percent matrix and 60 percent pebble-sized clasts. Pebble lengths in this bed range from 4 to 32 mm with a mean length of 11 mm (n = 104, S. Dev. = 6.1). Some outcrops show pebble deformation so extreme as to give the rock a gneissic appearance. Foliation occurs at a low angle to bedding.

Based on the study of 18 thin sections the overall composition of bed D is 95 percent quartz and 5 percent mica with trace amounts of hematite, magnetite, actinolite and chloritoid. Minor amounts of mica are present in the pebbles. Magnetite in this conglomerate is found mainly in the matrix. Where magnetite is present in the pebbles it is in coarse, euhedral grains. The matrix contains chloritoid in much smaller quantities than in bed C. Hematite is present as a red stain throughout the more weathered samples and as lath-shaped opaques in the matrix. Some needlelike actinolite grew parallel to the foliation.

Bed E

Bed E is another conglomerate unit which was mapped by Keith and Sterrett (1931) as the Draytonville Conglomerate. It crops out in the northern part of the Kings Mountain quadrangle and in the southern part of the adjacent Bessemer City quadrangle (Horton, personal communication). Bed E is very light greenish gray and in places is phyllitic although the conglomerate is essentially all clast suppported, being composed of 33 percent matrix and 67 percent pebble-size clasts. Pebble lengths range from 4 to 50 mm with a mean of 10 mm (n = 122, S. Dev. = 8.2). All the pebbles in this unit are white, generally subrounded quartz. The phyllitic areas are often distincly green in color due to the presence of chlorite. This bed shows the same foliation trend as beds C and D and foliation shows up in thin section. This unit is composed of 93 percent quartz, 5 percent mica and chlorite, and 2 percent pyrite weathering to iron oxides. Micas, chlorite, and pyrite occur in the matrix and occasionally along foliation planes that cross quartz pebbles.

DISCUSSION AND CONCLUSIONS

Significant differences in the conglomerates of the Kings Mountain belt are reflected in their total mineral compositions and natures of contained pebbles (Fig. 2). These differences suggest differing sources of pebbles for some of the beds, and indicate something about their environments of deposition.

Beds A and B are similar, both having a highly phyllitic matrix and occasional phyllitic pebbles that look like metavolcanic clasts. Quartz, mostly as quartz pebbles, averages less than 50 percent of these rocks, resulting in some portions not being clast supported. The rocks are dissimilar in that bed A has approximately twice as much gray quartz pebbles and magnetite as bed B. Bed A also appears to have somewhat larger pebbles than bed B. Iron-oxide bearing quartz pebbles may have been derived by erosion from iron formation type portions of the Battleground Schist (Keith and Sterrett, 1981 p.4). No pebbles as iron-rich as those in bed A are found in any of the younger beds.

Beds C, D, and E have similar grain sizes and overall are greater than 80 percent quartz. The dark gray, magnetite-rich pebbles in bed C are very similar in composition and texture to pebbles of similar color in beds A and B. Bed D has fewer dark pebbles than bed C and pebbles are slightly less angular. Considering its lower mica content and greater amount of rounded pebbles, bed D may be considered a more mature sediment compared to bed C. Beds C and D could be related to each other with some of the quartz and dark pebbles in bed D eroded from bed C. Bed E is different from all older beds in that it does not appear to contain magnetite-bearing quartz pebbles. This bed differs from both C and D in containing thin layers of chlorite and pyrite.

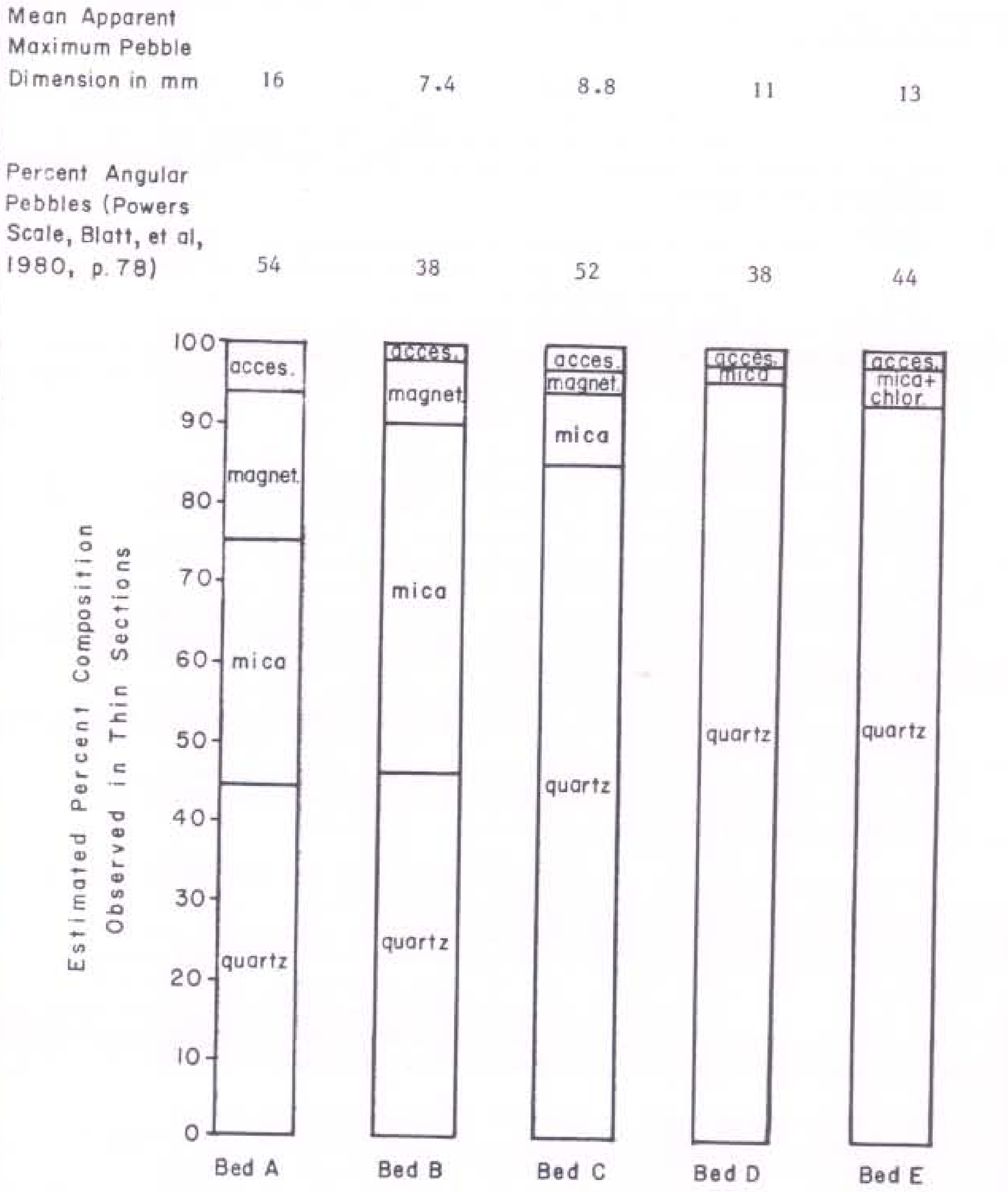

Figure 2. SIZE AND ANGULARITY OF PEBBLES AND TOTAL MINERALOGY OF CONGLOMERATIC BEDS NEAR KINGS MOUNTAIN, N.C.

Assuming that conglomerate bed A is the oldest and that they are progressively younger through E, some general conclusions may be drawn based on the data presented.

1. The consistent decrease of pebbles with large enough amounts of magnetite to give them a gray color over time most likely reflects a change in the nature of the source area. For example the pebbles may be metacherts (related to submarine volcanism?) that became less iron-rich with time.

2. It is possible that some rounded conglomerate pebbles in each of the beds B through E were derived from the reworking of older units. However, the continued appearance of angular pebbles and the volume of white pebbles needed to form beds C, D, and E, which probably could not have been derived soley from the older beds, suggest that a near-by source of first cycle quartz clasts was available to each of the beds.

3. The most significant compositional change occurs between beds B and C. The large decrease in micaceous matrix and corresponding increase in quartz clasts suggest a change in the environment of deposition between the two. One way of accounting for the differences between the two beds is to postulate a significant increase in energy in the environment of deposition of bed C which would more thoroughly winnow out or rework the sediments. An alternative and more likely method that could achieve the same results would be for the rate of deposition to decrease significantly between beds B and C so that the winnowing effects of waves and/or currents would have greater time to more thoroughly concentrate resistant particles contained within the volcaniclastic rocks. The significant changes in whole rock mineralogy, composition of pebbles and pebble-to-matrix ratio between beds B and C follow the same general but less dramatic trend of changes that are exhibited in all beds A through E.

The general rock types in the Kings Mountain belt and the nature of the conglomerate clasts suggest a volcanic source of pebbles. Some pebbles appear to have been rock fragments similar in composition to associated volcanic rocks. Most, however are quartz with variable iron oxide contents and may have been cherts formed as a result of submarine volcanism. The trend for fewer iron-rich pebbles to occur in successively younger conglomeratic beds could have resulted from a decrease in iron content (more siliceous composition) of successive volcanic eruptions with the passing of time.

During a pause or decrease in rate of volcanic activity (a decrease in the rate of deposition) pyroclastic rocks with contained chert beds would tend to be winnowed and reworked in littoral zones creating conglomeratic beds. Each conglomeratic bed would represent a separate pause in deposition and an opportunity for winnowing. A consequence of declining rate of volcanism would be that each succeeding pause may become longer thereby increasing the time for winnowing or increasing the maturation of each successive bed.

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Finite strain and regional implications of the deformed Draytonville metaconglomerate near Gaffney, South Carolina

Robert D. Hatcher, Jr., Department of Geology, University of South Carolina, Columbia, SC 29208 and Baylus K. Morgan, Department of Geology, Eastern Kentucky University, Richmond, KY 40475

INTRODUCTION

The Kings Mountain belt was recognized as a separate group of rocks by Keith and Sterrett (1931). King (1955) actually named the Kings Mountain belt and described the rocks therein. Subsequent studies by Espenshade and Potter (1960) resulted in more careful delineation of a number of the map units in the Gaffney-Kings Mountain area of North and South Carolina. More recent studies by Horton and Butler (1977), Horton (1977), and Schaeffer (this volume) have added considerably to our knowledge of the regional geology of the Kings Mountain belt in the type area.

Griffin (1971, 1972) has studied the southern extension of the Kings Mountain belt along the South Carolina-Georgia border and proposed the name Lowndesville belt for the rocks of this area. More recently, Horton (1981) recognized several large faults in the Kings Mountain belt along the North Carolina-South Carolina border. Griffin (1972) has also noted the presence of highly sheared and mylonitized rocks in the same zone along the South Carolina-Georgia border. Davis (1980) has suggested that the faults of the Kings Mountain belt are continuous with the Towaliga fault zone which resides along the northwest flank of the Pine Mountain belt in Georgia and extends northeastward across the Piedmont. This suggestion was made previously by Howell (1976).

The southern Appalachian region suffers from a paucity of finite strain studies. Relatively few such studies have been made (Muangnocharoen and Dunn, 1978) and almost none are published at this point. The Draytonville metaconglomerate was selected for such a study because of its easily recoverable pebbles within the conglomerate and the fact that they are highly deformed in this area. It was also selected because of the location of this rock unit within the Kings Mountain belt and the knowledge that this is a critical area for the understanding of the geologic history of the southern Appalachian Piedmont (Hatcher and others, 1980).

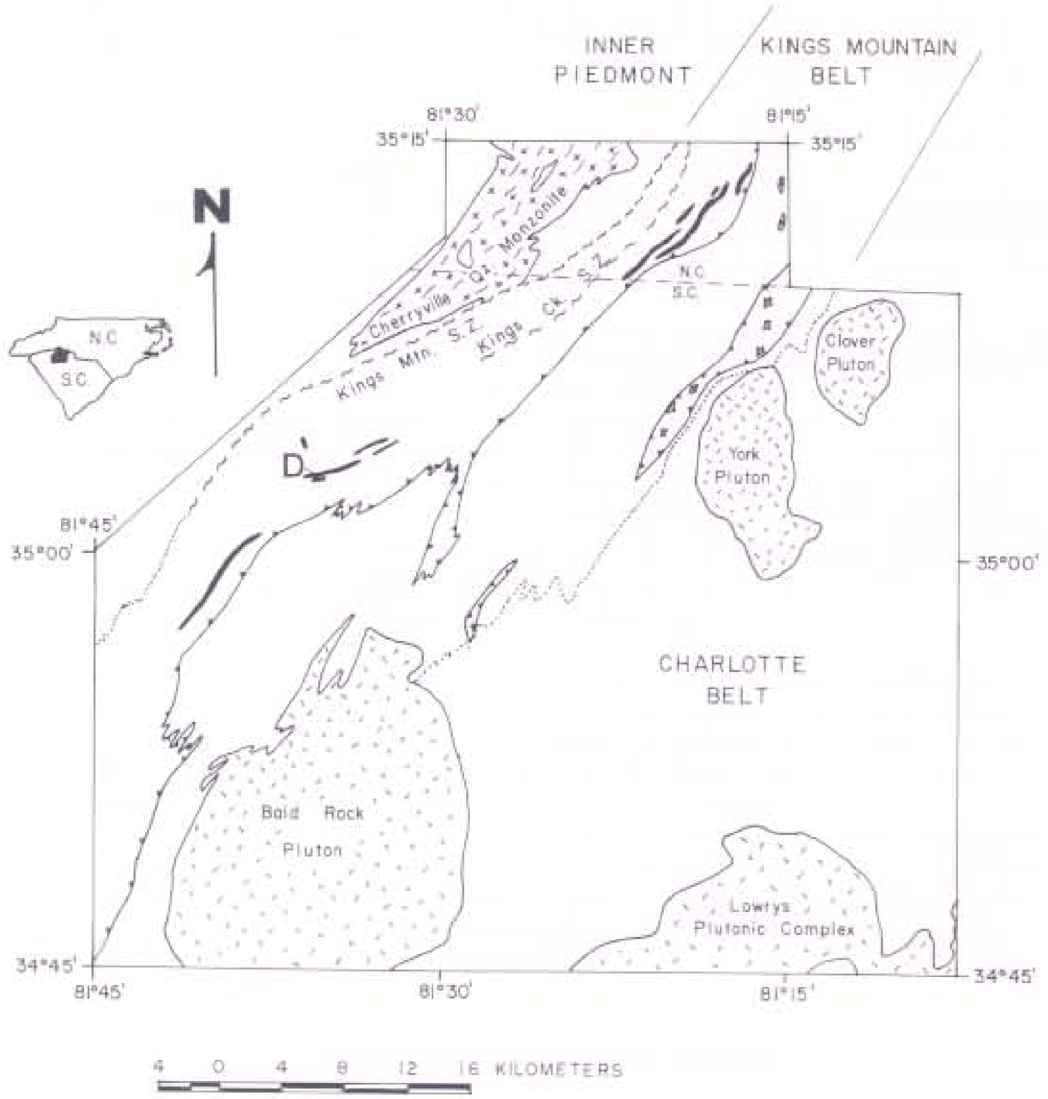


Figure 1. Geologic map of the Kings Mountain belt in part of the Carolinas showing the location of the study area (after Horton and Butler, 1977, Horton, 1981, and Schaeffer, this volume). D - Draytonville metaconglomerate localities studied. Metaconglomerate bodies are patterned black on the map. Barbed line is the proposed suture. Dotted lines are the subdivision boundaries of King (1955). Shear zones (S. Z.) are indicated by wavy lines.

The initial study was carried out as a senior research project at Clemson University. Critical reviews of the manuscript by Robert J. Hooper and Malcolm F. Schaeffer are appreciated.

REGIONAL GEOLOGY

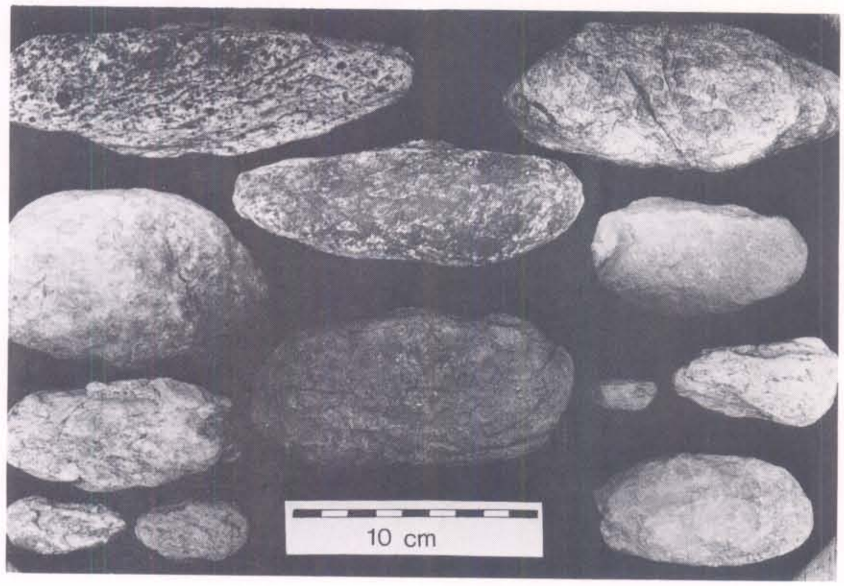
The rocks of the Kings Mountain belt may be divided into two fundamental groups: a group of mafic volcanics (amphibolites), metaconglomerate-quartzite (relatively clean), metasandstone, pelitic schist, marble and various granitic rocks; and a group of more felsic to intermediate metavolcanic rocks containing a considerable mafic component as well as rocks which have been described as quartzites in the literature (Espenshade and Potter, 1960), some metasedimentary rocks and a considerably greater variety of plutonic rocks. Detailed and reconnaissance geologic mapping by Horton (1977) and Schaeffer (this volume) both indicate that the former assemblage of rocks dominates to the west and the latter dominates to the east (Fig. 1). It is along the boundary between these respective groups of rocks that we find the highly strained metaconglomerates such as that at Draytonville Mountain. Despite the fact that the Draytonville metaconglomerate is not traceable much farther southwest (M. F. Schaeffer, pers. comm., 1981), no major fault as such has been recognized along the boundary. All faults described within the Kings Mountain belt in the area along the North Carolina-South Carolina line lie either to the east or to the west of the boundary. Both major faults recognized by Horton (1981) are of a post-metamorphic character, and the mylonites developed therein are retrogressive mylonites.

Rocks of the western sequence in the Kings Mountain belt appear to show a greater affinity for rocks lying to the west either in the Inner Piedmont or perhaps farther to the west in the Chauga belt of northwestern South Carolina and adjacent North Carolina. Rocks of the eastern sequence appear to be more closely related to those of the Charlotte belt lying to the east. It has been suggested that a suture resides along the Kings Mountain belt (Hatcher, 1980; Hatcher and Zietz, 1980; Hatcher and others, 1980). It is possible that the boundary between the eastern and western sequences is the suture. Its present state requires that it be a pre-metamorphic boundary.

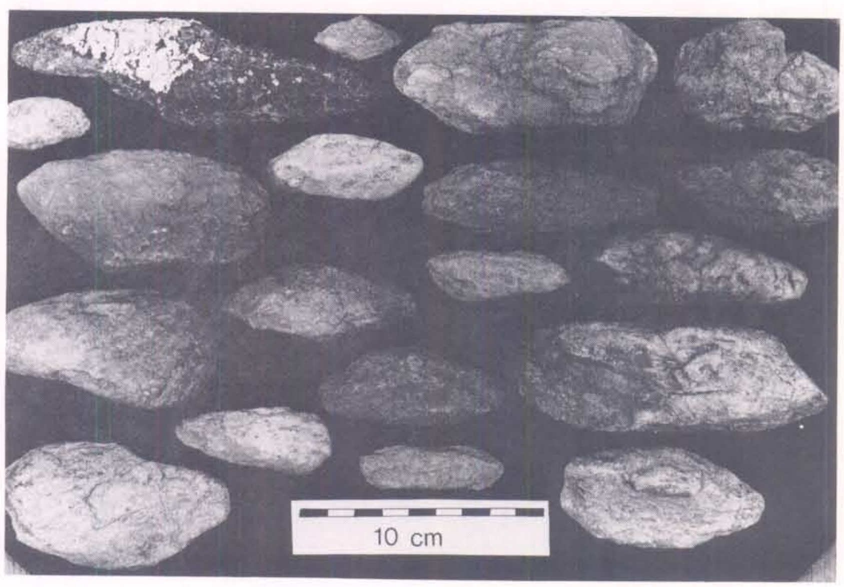
DRAYTONVILLE METACONGLOMERATE

Composition

The Draytonville metaconglomerate is a relatively clean conglomerate which consists of pebbles ranging in size up to 12-15 cm in length in a matrix made up dominantly of quartz (Fig. 2). Most of the pebbles are composed of vein quartz, although a few pebbles of other rock materials may occur here. Both the pebbles and the matrix materials are totally recrystallized. Microscopic grains within the conglomerate do not show any trace of the strain which is evident in the shapes of the pebbles today.



2A



2B

Figure 2. Elongate pebbles from the Draytonville metaconglomerate.
A. Pebbles showing no pressure solution, though some are fractured.
B. Pebbles showing pressure solution effects.

Mesoscopic fabric elements

Two well-developed foliations may be observed in the metaconglomerate of Draytonville Mountain. The earliest foliation, which may be S_2, is expressed as compositional banding (doubtless transposed bedding). A second foliation, S_3, is present as an axial plane foliation to upright folds, has a northeast strike and a southeast dip in this area. The S_2 and S_3 foliations of this paper correspond to S_1 and S_2 of Schaeffer (this volume). Several measurements of foliation orientations are shown in Figure 3.

Long axes of pebbles in the metaconglomerate are oriented parallel to the later upright folds which plunge gently to the northeast (Fig. 3). These orientations correspond to the general northeast strike of the Cherokee Falls synform (Horton and Butler, 1977; Schaeffer, this volume).

FINITE STRAIN DATA

More than 100 pebbles from the Draytonville metaconglomerate were collected and their respective major axes measured to determine the amount of the total strain involved in the deformation. Also, long axes of a number of pebbles were measured in place so that pebble orientations could be determined and determinations of the finite strain ellipsoid could actually be made. It is assumed for the purpose of this study that the pebbles were originally spherical.

The long (Z), intermediate (Y) and short (X) axes of the pebbles were measured using a caliper. These data are presented in Table 1. Ratios of long to intermediate and intermediate to short axes were calculated and from these data a Flinn diagram (Fig. 4) was constructed (Flinn, 1965).

Deformation strain ellipsoids were determined from each of the values measured and k values calculated from

$$k = \frac{a - 1}{b - 1} \qquad (1)$$

where a is the ratio Z/Y, b is the ratio Y/X. Values of k range from a high of infinity to a low of 0.1 with about 66% of them falling within the range of 1 to 3 (Fig. 5). However, many other values make up the entire range.

The range of k values (Fig. 4) may be attributed to several things. Perhaps some degree of inhomogeneous strain was present. However, a factor of greater importance is the occurrence of pressure solution within some pebbles in the Draytonville metaconglomerate (Fig. 2B). Since many pebbles were in contact with one another at the time they were being deformed, pressure solution effects would have occurred to change the shapes and volumes of all materials to some degree. Depositional sites of pressure-solved quartz are visible on a few of the pebbles collected (Fig. 2B) but not on the majority.

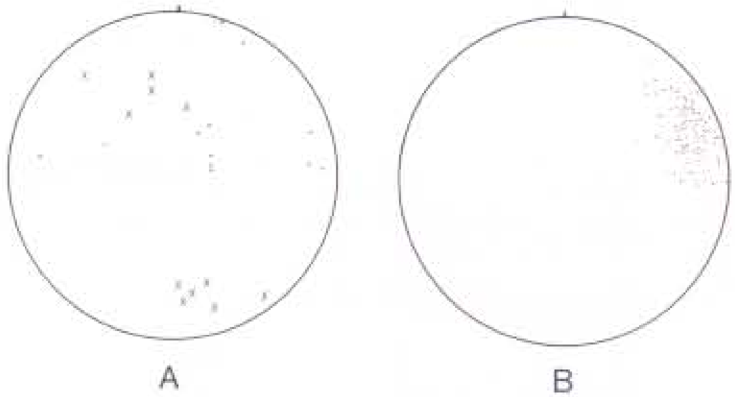


Figure 3. Mesoscopic fabric elements in Draytonville metaconglomerate. A. X - 11 poles to S_2, 0 - 12 poles to S_3. B. 143 long axes of deformed pebbles.

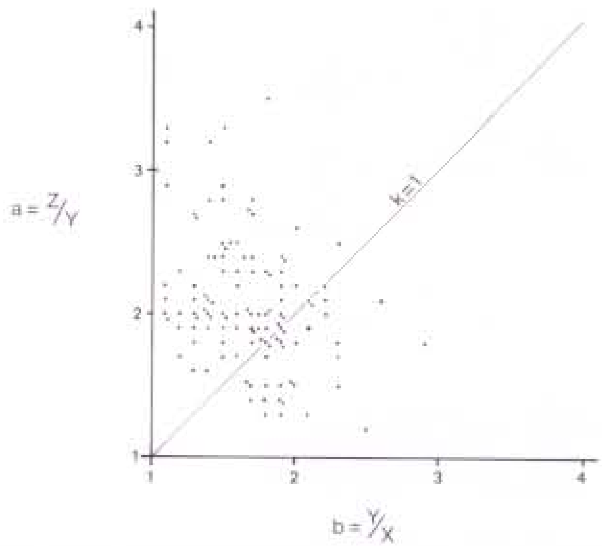


Figure 4. Flinn diagram showing the distribution of k values for Draytonville metaconglomerate pebbles. Points above the k = 1 line indicate elongation (cigars). Points below the line indicate flattening.

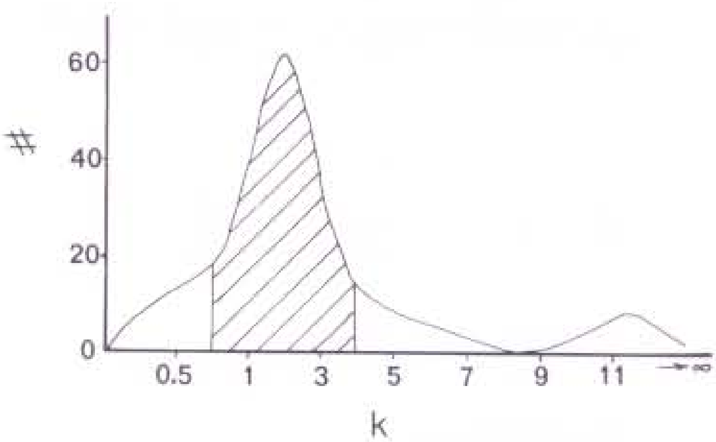


Figure 5. Frequency curve showing the distribution and slight bimodality of k values for Draytonville metaconglomerate pebbles. Approximately 66 percent of all k values lie within the striped area.

Table I. Finite Strain Data for Draytonville Metaconglomerate.

Sample #	X(Cm)	Y(Cm)	Z(Cm)	Vol.(Ml.)	Undeformed Diameter(Cm)	EXTENSION X	Y	Z	a=Z/Y	b=Y/X	K
1	3.2	4.7	11.9	85	5.46	-41%	-14%	118%	2.5	1.5	3
2	3.0	5.1	10.4	60	4.86	-38%	5%	114%	2.0	1.7	1.4
3	2.4	4.2	8.4	30	3.86	-38%	9%	118%	2.0	1.75	1.3
4	2.2	3.8	10.3	35	4.06	-46%	- 6%	154%	2.7	1.7	2.4
5	2.4	4.1	8.1	35	4.06	-41%	1%	100%	2.0	1.7	1.4
6	2.0	3.5	6.8	20	3.37	-41%	4%	102%	1.9	1.75	1.2
7	3.1	5.4	12.4	105	5.86	-47%	- 8%	112%	2.3	1.7	1.7
8	3.4	4.0	9.2	60	4.86	-30%	-18%	89%	2.3	1.2	6.5
9	2.4	3.4	7.0	20	3.37	-29%	.9%	108%	2.1	1.4	2.75
10	2.2	3.0	5.9	19	3.31	-34%	- 9%	78%	2.0	1.4	2.5
11	1.9	3.3	8.9	25	3.63	-48%	- 9%	145%	2.7	1.7	2.4
12	2.2	2.8	7.5	19	3.31	-34%	-15%	127%	2.7	1.3	5.7
13	2.5	4.5	8.2	39	4.2	-40%	7%	95%	1.8	1.8	1.0
14	2.7	4.6	8.7	48	4.5	-40%	2%	93%	1.9	1.7	1.3
15	2.1	3.1	8.6	20	3.37	-38%	- 8%	155%	2.8	1.5	3.6
16	1.2	2.2	3.1	3	1.79	-33%	23%	73%	1.4	1.8	.5
17	1.9	3.0	7.0	19	3.31	-43%	- 9%	111%	2.3	1.6	2.2
18	1.9	2.2	4.2	8	2.48	-23%	-11%	69%	1.9	1.2	4.5
19	2.3	2.4	7.3	20	3.37	-32%	-29%	117%	3.0	1.0	∞
20	2.0	3.3	7.8	25	3.63	-45%	- 9%	115%	2.4	1.65	2.2
21	4.0	6.6	16.1	190	7.13	-44%	- 7%	126%	2.4	1.45	2.2
22	2.1	3.1	7.1	20	3.37	-38%	- 8%	111%	2.3	1.5	2.6
23	1.8	3.4	6.7	19	3.31	-46%	3%	102%	2.0	1.9	1.1
24	2.2	4.1	5.5	21	3.42	-36%	20%	61%	1.3	1.9	.33
25	1.4	2.0	3.8	4	1.97	-29%	2%	93%	1.9	1.4	2.25
26	2.2	4.3	6.4	20	3.37	-35%	28%	90%	1.5	2.0	.5
27	1.6	3.7	9.3	24	3.58	-55%	3%	160%	2.5	2.3	1.2
28	1.6	3.0	5.4	10	2.67	-40%	12%	102%	1.8	1.9	.9
29	2.6	4.6	9.2	50	4.57	-43%	.7%	101%	2.0	1.8	1.3
30	1.6	3.0	5.6	15	3.06	-48%	- 2%	83%	1.9	1.9	1.0
31	2.7	4.1	9.7	40	4.24	-36%	- 3%	129%	2.4	1.5	2.8
32	2.0	3.1	7.8	20	3.37	-41%	- 8%	131%	2.5	1.55	2.7
33	2.8	5.3	8.1	58	4.8	-42%	10%	69%	1.5	1.9	.6
34	1.9	3.5	6.9	25	3.63	-48%	- 4%	90%	2.0	1.8	1.3
35	1.4	1.6	5.3	5	2.12	-34%	- 25%	150%	3.3	1.1	23.0
36	1.8	2.9	5.6	10	2.67	-33%	9%	110%	1.9	1.6	1.5
37	3.0	6.1	9.4	80	5.35	-44%	14%	76%	1.5	2.0	1.5
38	2.0	2.5	5.4	10	2.67	-25%	- 6%	102%	2.2	1.3	4.0
39	2.6	3.4	6.5	22	3.48	-25%	- 2%	87%	1.9	1.3	3.0
40	3.0	4.1	8.1	45	4.4	-32%	- 7%	84%	2.0	1.4	2.5
41	2.2	2.9	5.9	19	3.31	-34%	- 12%	78%	2.0	1.3	3.3
42	2.2	3.7	5.7	20	3.37	-35%	10%	69%	1.5	1.7	.7
43	1.9	3.2	4.7	15	3.06	-38%	5%	54%	1.5	1.7	.7
44	1.3	2.4	5.4	8	2.48	-48%	- 3%	118%	2.3	1.8	1.6
45	1.8	3.5	4.6	12	2.84	-37%	23%	62%	1.3	1.9	.3
45	1.6	4.0	4.7	15	3.06	-48%	31%	54%	1.2	2.5	.1
47	1.3	2.7	3.5	3	1.79	-27%	51%	96%	1.3	2.1	.3
48	1.6	4.7	8.6	20	3.37	-54%	39%	155%	1.8	2.9	.4
49	3.0	7.0	10.4	90	5.56	-46%	26%	87%	1.5	2.3	.4
50	3.0	4.3	9.0	63	4.94	-39%	-13%	82%	2.1	1.4	2.8
51	1.5	3.0	6.8	15	3.06	-51%	- 2%	122%	2.3	2.0	1.3
52	1.8	2.7	8.8	22	3.48	-48%	- 22%	153%	3.3	1.5	4.6
53	1.4	2.7	5.4	10	2.67	-48%	1%	102%	2.0	1.9	1.1
54	1.8	3.2	7.5	15	3.06	-41%	5%	145%	2.3	1.8	1.6
55	2.2	3.9	13.6	50	4.57	-52%	- 15%	198%	3.5	1.8	3.1
56	1.8	3.1	6.5	19	3.31	-46%	- 6%	103%	1.7	1.6	1.6
57	1.6	2.0	5.3	8	2.48	-35%	- 19%	114%	2.7	1.3	5.7
58	3.6	5.7	11.3	120	6.12	-41%	- 7%	85%	2.0	1.6	1.7
90	2.5	4.4	7.9	50	4.57	-45%	- 4%	73%	1.8	1.8	1.0
91	3.6	6.6	10.2	110	5.94	-39%	11%	82%	1.5	1.8	.6
92	1.4	3.1	6.2	15	3.06	-54%	1%	103%	2.0	2.2	.8
93	2.1	3.9	9.4	35	4.06	-48%	- 4%	132%	2.4	1.9	1.6
94	1.5	3.9	8.1	20	3.37	-55%	16%	140%	2.1	2.6	.7
95	2.9	6.1	12.6	95	5.66	-49%	8%	123%	2.1	2.1	1.0
96	1.6	1.8	3.6	3	1.79	-11%	.6%	101%	2.0	1.1	10.0
97	1.3	2.3	4.1	4	1.97	-30%	17%	108%	1.8	1.8	1.0
98	2.9	3.4	5.9	20	3.37	-14%	.9%	75%	1.7	1.2	3.5
99	2.4	3.2	5.9	19	3.31	27%	- 3%	78%	1.8	1.3	2.7
100	3.0	3.2	10.1	40	4.24	-29%	- 25%	138%	3.2	1.1	22.0
101	2.6	2.9	8.5	23	3.53	-26%	- 18%	141%	2.9	1.1	19.0
102	3.7	5.0	15.9	110	5.94	-38%	- 16%	168%	3.2	1.4	5.5
103	3.4	5.0	12.5	110	5.94	-43%	- 16%	110%	2.5	1.5	3.0
104	2.7	4.6	13.0	63	4.94	-45%	- 7%	163%	2.8	1.7	2.6
105	2.6	4.0	11.5	60	4.86	-47%	- 18%	137%	2.9	1.5	3.8
106	1.8	3.5	4.9	8	2.48	-27%	41%	98%	1.4	1.9	.4
107	1.0	1.9	3.4	3	1.78	-44%	7%	91%	1.8	1.9	.9
108	3.2	4.6	9.4	58	4.80	-33%	- 4%	91%	2.0	1.4	2.5
109	2.2	4.1	8.6	38	4.18	-47%	- 2%	106%	2.1	1.9	1.2
110	3.3	5.6	13.4	120	6.12	-46%	- 8%	119%	2.4	1.7	2.0
111	.8	1.8	3.3	2	1.56	-49%	15%	112%	1.8	2.3	.6
112	.6	1.3	2.9	2	1.56	-62%	- 17%	86%	2.2	2.2	1.0
113	1.0	1.4	2.9	2	1.56	-36%	- 10%	86%	2.1	1.4	2.8
114	1.1	1.9	3.4	3	1.78	-38%	7%	91%	1.8	1.7	1.1
115	2.0	2.4	5.1	10	2.68	-25%	- 10%	90%	2.1	2.2	.9
116	1.8	2.5	4.0	9	2.58	-30%	- 3%	55%	1.6	1.4	1.5
117	1.4	2.7	5.1	10	2.68	-48%	7%	90%	1.9	1.9	1.0
59	2.0	2.2	4.4	8	2.48	-19%	- 11%	77%	2.0	1.1	10.1
60	2.1	3.8	6.5	20	3.37	-38%	- 13%	93%	1.7	1.8	.9
61	1.3	1.8	4.3	4	1.97	-34%	- 9%	118%	2.4	1.4	3.5
62	2.2	3.3	5.7	15	3.06	-28%	8%	86%	1.7	1.5	1.4
63	3.6	6.8	12.1	98	5.72	-37%	19%	112%	1.8	1.9	.9
64	2.3	3.0	6.2	19	3.31	-31%	- 9%	87%	2.1	1.3	3.7
65	1.7	3.2	4.5	15	3.06	-44%	5%	47%	1.4	1.9	.4
66	1.0	2.1	4.5	8	2.48	-60%	- 15%	81%	2.1	2.1	1.0
67	2.1	2.8	4.4	10	2.67	-21%	5%	65%	1.6	1.3	2.0
68	1.4	2.7	5.9	10	2.67	-48%	1%	121%	2.2	1.9	1.3
69	1.9	2.9	5.1	18	3.25	-42%	- 11%	57%	1.8	1.5	1.6
70	2.8	4.2	7.9	36	4.10	-32%	2%	93%	1.9	1.5	1.8
71	2.1	2.4	5.1	10	2.67	-21%	- 10%	91%	2.1	1.1	11.0
72	2.5	4.1	9.1	40	4.24	-41%	- 3%	115%	2.2	1.6	2.0
73	1.5	2.4	5.9	10	2.67	-44%	- 10%	121%	2.5	1.6	2.5
74	1.2	2.5	4.7	6	2.25	-47%	11%	109%	1.9	2.1	.8
75	1.0	1.7	3.2	3	1.79	-44%	- 5%	79%	1.9	1.7	1.3
76	1.6	2.9	5.4	8	2.48	-36%	17%	118%	1.9	1.8	1.1
77	2.2	4.2	9.6	35	4.06	-46%	3%	137%	2.3	1.9	1.4
78	1.5	2.9	6.9	15	3.06	-51%	- 5%	126%	2.4	1.9	1.6
79	1.7	2.4	6.8	15	3.06	-44%	- 22%	122%	2.8	1.4	4.5
80	2.3	4.3	8.3	40	4.24	-46%	1%	96%	1.9	1.9	1.0
81	2.0	2.6	5.3	12	2.84	-30%	- 8%	87%	2.0	1.3	3.3
82	1.1	2.5	4.3	8	2.48	-56%	.8%	73%	1.7	2.3	.5
83	2.4	3.7	7.4	30	3.86	-38%	- 4%	92%	2.0	1.5	2.0
84	2.9	4.3	8.5	55	4.72	-39%	- 9%	80%	2.0	1.5	2.0
85	2.4	2.9	5.8	20	3.37	-29%	- 14%	72%	2.0	1.2	5.0
86	1.6	2.7	3.9	12	2.84	-44%	- 5%	37%	1.4	1.7	.6
87	1.5	1.6	3.5	3	1.79	-16%	- 11%	96%	2.2	1.1	12.0
88	.8	1.6	4.1	2	1.56	-40%	3%	163%	2.6	2.0	1.6
89	2.7	5.3	9.8	80	5.35	-50%	- .9%	83%	1.8	2.0	.8

Percent strain was determined for each of the samples in order to completely characterize the deformational effects of the pebbles. Each pebble that was collected was immersed in water and the displaced volume was converted to the radius of a sphere corresponding to that particular volume. The radius and diameter were then calculated. In Table 1 the elongation of each pebble is expressed as a percent of the undeformed diameter that must be added to the undeformed diameter to obtain the present axes in the deformed pebbles. Average values are X = d-43%d, Y = d+13%d and Z = d+102%d. The amount of material gained or lost parallel to each axis is readily apparent. However, this method may introduce a significant error because of material lost via pressure solution, since all pebbles were measured and the means represent all pebbles. An alternative method would be to calculate a sphere from measured pebble axes and calculated volumes of the ellipsoids. Axial changes could then be gotten from this method. However, measurement error may be enhanced with this technique.

DISCUSSION

The Draytonville metaconglomerate is a highly deformed and multiply-foliated mass of rock. However, parallelism of the pebble long axis orientations to S_3 and to the axis of the Cherokee Falls synform indicates perhaps that the deformation plan of the area may be relatable in terms of the finite strain ellipsoid. Pebbles in other nearby occurrences of conglomerate described by Horton and Butler (1977) indicate that deformation in the Draytonville metaconglomerate may be a local phenomenon. Pebbles at the other locality are almost spherical and are practically unstrained. Additionally, the pebbles at the other locality exhibit a slightly greater variety of composition, but overall the dominant lithology present in the conglomerate remains vein quartz and quartzite. Another possible interpretation of the Draytonville metaconglomerate is that it represents the strain emplaced by the formation of the possible suture within the Kings Mountain belt. However, this is inconsistent with the observed parallelism of the pebbles with S_2 and the axial zone of the Cherokee Falls synform.

SUMMARY OF CONCLUSIONS

1) Orientations of the later foliation, long axes of pebbles and the axis of the Cherokee Falls synform are parallel.
2) Finite strain values of most pebbles range from 2 to 4. General strain is most common but some pebbles have been flattened while others have been elongated.
3) Extreme variations in strain observed in the pebbles are probably caused by pressure solution effects upon individual pebbles. However, this process did not uniformly affect all pebbles.

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"The Old Iron District" — a legacy of iron mining and manufacturing in South Carolina

B. G. Moss, Division of Social Studies, Box 29,
Limestone College, Gaffney, S.C. 29340

Iron manufacturing in the Up-Country of South Carolina began with the settlement of Cherokee, Spartanburg, Union, and York Counties shortly after the defeat of General Braddock near Fort Duquesne in 1755. A large number of the emigrants who fled from the war in Pennsylvania settled in the areas from which early explorers had carried reports of large iron deposits that were literally cropping out of the ground. They reported finding three different types of ore, and an adequate fuel supply for the mining and smelting of the raw material, as well as adequate water routes for transporting the finished product to market. Although the promise of free land and the absence of armed conflict were factors in attracting these settlers, the prospects of future wealth based upon natural mineral resources was one of the major inducements for their coming south.

These settlers were courageous and enterprising Scotch-Irish and German immigrants who, although cut off from civilization and the world of progress, built furnaces and supplied themselves and their neighbors with iron for horseshoes, wagon wheel rims, harrowteeth, plows, and weapons.

By the time the Continental Congress declared Independence and the Revolution began, the northeastern part of Ninety Six District (Cherokee County, the eastern area of Spartanburg County, and the northernmost region of York County) was already being called "The Iron District." The capacity of the iron foundries located here to produce weapons soon attracted the attention of the British Army. Among the iron works capable of doing serious damage to the King's efforts were those of Colonel William Wofford, which were located near Spartanburg, and William Hill's Furnaces in York District. In an effort to put an end to their production of armaments, "Bloody Bill" Cunningham burned Wofford's foundry and a force of British Regulars led by a Captain Huck destroyed Hill's establishment. Hill's slaves and livestock were scattered and his partner, Colonel Isaac Hayne, was summarily executed. In spite of these repressive measures, numerous small forges continued to produce iron in the Up-Country.

Shortly after the War of 1812 the iron industry of the state consolidated on the banks of Broad River within present-day Cherokee County. By 1837 three large companies--the South Carolina Manufacturing Company, the Nesbitt Manufacturing Company, and the Kings Mountain Iron Company--had gained a control of the industry which they maintained until after the War Between the States.

The Kings Mountain Iron Company was the earliest organized unit of the three. Although the exact date of its organization is unknown, it was some-time prior to 1822 that Jacob Stroup and Edmund Fewell began the industry near the mouth of Kings Creek, for it was in that year that Fewell died, a major flood on Kings Creek destroyed the furnaces, and the company's assets were sold at public auction. After the sheriff's sale ended his first venture in the iron industry, Stroup married the widow of his former partner and built his second furnace, which he sold in 1825 to a New York group headed by Duncan P. Campbell.

At a site near Doolittle Creek, Stroup built a third furnace which he sold in 1826 to a partnership known as Emor Graham and Company. The other men involved in the purchase were James A. Black, Governor David Johnson, Jacob Deal, and P. R. Brice. Two years later the property was sold to the South Carolina Iron Manufacturing Company (not to be confused with the South Carolina Manufacturing Company).

The South Carolina Iron Manufacturing Company had been incorporated by Governor George McDuffie and other prominent men. Their major enterprise was the casting of both six and nine-pounder cannons and the production of round shot, grape, and canister for the state militia. To end the confusion over its name, and the name of the company operating near Cowpens battleground, the owners of the company rechartered it in 1836 and reinstated its original name--The Kings Mountain Iron Company.

The main operating site, which included one refining and heating furnace and four pairs of rollers, was located on the west bank of the Broad River and the south bank of London Bridge Creek about two-and-a-half miles below Coopervile.

In 1837 the company expanded its operations by rebuilding an old iron industry at the present site of Cherokee Falls. These works included three bloomeries, two refining furnaces, and two hammers. In the same year the company also built a charcoal furnace on Kings Creek, about four miles above the furnace of Stroup and seven miles east of their rolling mill on London Bridge Creek. The company continued to operate quite successfully until the War Between the States.

The South Carolina Manufacturing Company was incorporated in 1826 by Abner Benson, Andrew B. Moore, and Wilson Nesbitt. It constructed part of its works at Hurricane Shoals and another part on Thicketty Mountain, near the Cowpens battleground. Nesbitt had experience as an ironmaster since he had operated iron furnaces at Thicketty Mountain and Limestone Springs (now Gaffney) as early as 1811. However, he did not fully develop his ironmaking talents until he became the chief stockholder in the new company. When in 1834 the company reconstructed several pre-Revolutionary furnaces on Cherokee Creek and purchased 25,000 acres of ore land, they began to construct a rolling mill at Hurricane Shoals on the Pacolet River. This venture attracted several important investors: Vardy McBee, a wealthy Greenville landowner; Gabriel Cannon, later to be the lieutenant governor of the state, and a certain William Clark. The influx of capital from these new investors made it possible for the company to construct five furnaces, one train of rollers, three nail machines, and one hammer mill. Each year the new facilities converted an average of 390 tons of pig iron to merchant bar iron and nails.

In 1841 the state legislature authorized the South Carolina Manufacturing Company to increase its capital stock to $301,000. Utilizing part of this new capital, they built a tramway to carry the iron ore from the strip mines to the furnaces and to transport the pig iron from Cherokee Creek to the finishing plant at Hurricane Shoals.

The Nesbitt Iron Manufacturing Company was the largest and the most important of the three iron industries. When the company organized in 1835 with a capital of $100,000, the stockholders immediately purchased 8000 acres of land and began to set up a blast furnace near the junction of People's Creek and Broad River. A village was begun and named "Cooperville" in honor of Dr. Thomas Cooper, president of the University of South Carolina and a stockholder in the company. During the same year, a hotel was built by the corporation at Limestone Springs (four miles from Cooperville) and an Up-Country resort was developed.

The South Carolina Legislature rechartered the company in 1836 with a capital stock of $300,000, and the company began construction of the Ellen cold-blast furnace one mile up People's Creek. One hundred thousand dollars was invested in each furnace and the land necessary for its operation; the legislature, however, anticipated the company's growth and granted the organization the privilege of increasing its stock to $1 million within the next 14 years.

Over half the money from this second issue of company stock was used to purchase additional materials and to assemble them in order that the furnaces could be put into full production. Fifty-four thousand dollars was paid for 11,000 acres of land; sixty thousand dollars was used to erect dams, canals, buildings, and to install machinery; and the rolling mills and other improvements cost seventy thousand dollars. The remaining money was used to purchase slaves, horses, mules, cattle and hogs.

So that the river might be utilized as the chief means of energy in the manufacturing and in transporting the finished products, a canal was dug from the river to the South Twin furnaces. The entrance of the canal was upriver about one-fourth of a mile, and in order that the natural flow of the river could be used, the canal was dug on a level below the riverbed and a 300-yard-long dam was erected across Broad River. Water flooded the canal to a depth of six feet or more. As a precaution against overflooding, the canal was turned sharply away from the furnaces and angled downstream. A large earth dam impounded the water near the downriver end. As the water reached the level of the river, the river stopped flowing into the canal. Near the entrance of the canal, a water lock held water in a square reservoir used to float barges out into the river.

A wooden tramway was constructed from Limestone Springs to the furnaces so that horses could draw wagons of lime to the industry for use as flux. The same tramway transported engineers and visitors from the hotel to the industrial works.

The works consisted of several units: two high furnaces (cold-blast), one puddling oven, one eight-roller rollin mill of great power, one laying foundry for casting, two reheating ovens, one large machine shop, several lathes, an eight-fire forge, one flour and grist mill (the company owned 600 acres of corn land), one sawmill, one set ore stamper, a fine-nail factory containing seven machines, one store, a post office, and dwelling houses for superintendents and slaves.

The stamping mill was designed so that the available water power could be used to lift the mechanical hammers. A water system which contained over 25 miles of canals carried the water from every stream that emptied into People's Creek to a huge wheel which operated the stamping hammers. A trompe utilized part of the water to force air into the furnaces. Each of the other departments--the furnaces, the forges, the casting division, for example--depended on their own waterwheels for power. The eight waterwheels were kept operative by wheelwright W. R. Reid.

A bridge facilitated transporting ore and charcoal from the east side of the river, and for a small toll, the public could use the bridge. Local citizens proudly claimed that this bridge and the Ellis Bridge were the only two bridges over the Broad River in the Piedmont. As evidence of the superiority of their section of the state, they pointed out that the bridges were located within a few miles of each other.

Iron manufacturing opened a number of jobs for the local citizens. Miners, wagoners and charcoal burners represented the largest number of self-employed people to benefit from the thriving industry. The prospects for a profitable business looked good. However, a serious financial problem developed for the company through a series of events: the feud between President Andrew Jackson and the Bank of the United States; a widely spiraling inflation; and the stockholders' slowness in paying their installments. Only F. H. Elmore, Wade Hampton and Wilson Nesbitt paid their entire subscriptions. Before the company could collect in full from the other subscribers, the United States Bank charter was vetoed by President Jackson. Local banks began to over-speculate, because the federal bank was no longer able to put pressure on them. It was this over-speculation that brought about the financial crash of 1837.

Although the investors were unable to pay for their stocks, the company managed to survive, chiefly, by the superb management of funds secured on short-term loans.

Elmore, the newly elected company president, realized that these small loans, never exceeding $50,000, were not enough to get the industry into full production; therefore, early in 1839, F. H. Elmore and P. M. Butler journeyed north in search of capital. Dr. Thomas Cooper wrote to his old friend Nicholas Biddle, former president of the United States Bank, to ask for help in raising a loan of $150,000. After making inquiries of capitalists in New York, Biddle sent Cooper a disheartening report: "The prospects of obtaining the loan is not flattering." Biddle had read the signs correctly, for Elmore and Butler failed to secure the funds they sought. Almost immediately, negotiations were opened with English investors, but again terms could not be agreed upon. Later, Cooper asked President Van Buren for government assistance, but his plea was to no avail.

To sustain operations, seven of the company's stockholders borrowed individual amounts of money totaling $91,898.97 from the Bank of South Carolina. These loans were made on the strength of the company's operations under the management of J. B. Mintz, and the samples of iron which he had sent to the Washington Navy Yard for testing. The Navy found that these samples included 7/8-inch iron wire whose strength exceeded by 3.4 tons that of other equal-size iron wire tested at the yard, and 1-inch iron wire, which came within seven-tenths of a ton of meeting the requirements for 1 3/4-inch iron wire. Since the samples surpassed the maximum requirements imposed by the Navy, the Nesbitt Company received a contract for iron wire, shot and shell in 1847.

A specimen of the Nesbitt Company's iron was sent to England where it was made into steel at Sheffield, and declared equal to the steel which was made from the celebrated ores mined in Sweden. The prospects for a profitable operation looked so good that the state legislature approved the distribution of stock valued at $100,000. However, the inability to persuade the state legislature that it should appropriate sufficient funds to construct a system of canals to offer a cheap and rapid means to transport the finished products caused the company to sell its assets in 1850. The new company was known as the Swedish Iron Manufacturing Company.

With Charles W. Hammerskold as manager, the Swedish company was able to prosper even though it had a number of problems. Among its chief problems was the securing of fuel. Fifteen years of cutting oak timber and burning it into charcoal had denuded the timber land and left behind a strip of land south of the present sites of Blacksburg and Gaffney which are to this day called "The Coaling Grounds."

Pressure was brought upon the South Carolina Legislature to build railroads and canals so that coal could be brought into the area, but talk of secession took most of the legislature's time and nothing was done immediately about the needed transportation. Another problem which the company faced was how to extract the ore from its depth in the earth. The shaft method of mining was employed, then abandoned, as the company came to realize the high cost such operations entailed.

The production of 1856 can be cited as the output of a normal year of operation for the Swedish company. Although records of the North Twin and Ellen furnaces are not available, it is known that the South Twin produced 816 tons of metal, the Cherokee Ford rolling mill produced 400 tons of merchant bars and the Cherokee Ford bloomery produced 240 tons of pig iron blooms. The chief finished products were guns, shells, cannonballs, farm tools, millworks, rice mills, sawmill parts, Franklin stoves, cob mills, cooking stoves, nails, kettles and washpots. Not many records exist to show the quantity of items produced; however, the records which do exist show that the stamping mill produced one ton of nails per day.

To obtain a total picture of iron production in the state, it is necessary to include eight furnaces which had been constructed by 1856. One was located in Union, one in York and six in Spartanburg District (all but one of the eight being located in what is now Cherokee County). Four of these furnaces produced 1,506 tons of charcoal iron in an average year.

At the same time three rolling mills operating alongside the furnaces produced 1,210 tons of bar iron and nails. There were also two bloomeries which jointly produced 640 tons of pig iron. These statistics are clear evidence of the national importance of South Carolina as an iron-producing state prior to the War Between the States.

Shortly after the outbreak of the War Between the States, the Swedish investors sold their initial investment to the Magnetic Iron Company. The new company was chartered with a capital of $250,000. Almost immediately the company was given more contracts by the Confederate government than it could meet. Shot, cannonballs, tools and all sorts of special equipment were manufactured for the Confederacy. Cooperville took on new life and the future looked bright. The manufacture of iron was so important to the Confederacy that A. M. Latham, who had become the manager of the works, requested and received deferment from military duty for his workers. It is a tradition that some of the ironplating produced at Cooperville was used to construct the Confederate ironclads.

At the war's end, the company was near bankruptcy. It had lost all of its slaves, some of whom were skilled laborers valued at five times the regular price of a slave, and its capital consisted of Confederate cash and bonds, which had become valueless. Although the company was seriously damaged by the loss of military requisition and capital, continued public confidence prompted the owners to reorganize their operation in 1882 as the Magnetic Manufacturing Company. Within a few hours after the stock was offered for sale, one sub-division, the branch office in Chester, received $60,000 in subscriptions. The influx of funds enabled the company to refire the furnaces for the first time since the end of the war. However, since the new capital was not sufficient to replace the worn machinery, the company was never able to make a profit.

In 1889 the company was rechartered under a new board of directors as the Magnetic Iron and Steel Ore Company of Blacksburg. The company either bought or leased 10,000 acres of land and operated fourteen well-defined mines, some of which were within the town limits of Blacksburg.

By the turn of the century all of the furnaces were defunct in the "Old Iron District." South Carolina became one of the states in which iron manufacturing was totally abandoned.

Over a century-and-a-half has passed since the first ironmongers sent their salesmen through the hills and Piedmont of the Carolinas, Georgia, and Virginia to peddle their iron wares from backpacks and wagons. Today, many South Carolina families treasure as heirlooms some of the pots, pans, ornate andirons, and skillets which were manufactured in the "Old Iron District."

At the site of Cooperville the stone-walled canals remain as mute testimony to men's dreams, and at "The Furnace Place" near Cowpens Battleground, water trickles unchecked over a stone dam, built one hundred seventy years ago to harness the power of nature to do man's will. Ugly mining scars and stark slag and cinder piles remain in the South Carolina Up-Country as monuments to the ingenious industry of the manufacturing frontiersmen of

South Carolina. However, the chief reminder of the role that iron mining and processing had in developing the Up-Country of South Carolina is retained in the traditional name for Blacksburg--"The Iron City"--and in the name for the general area, a title treasured by the local inhabitants, "The Old Iron District."

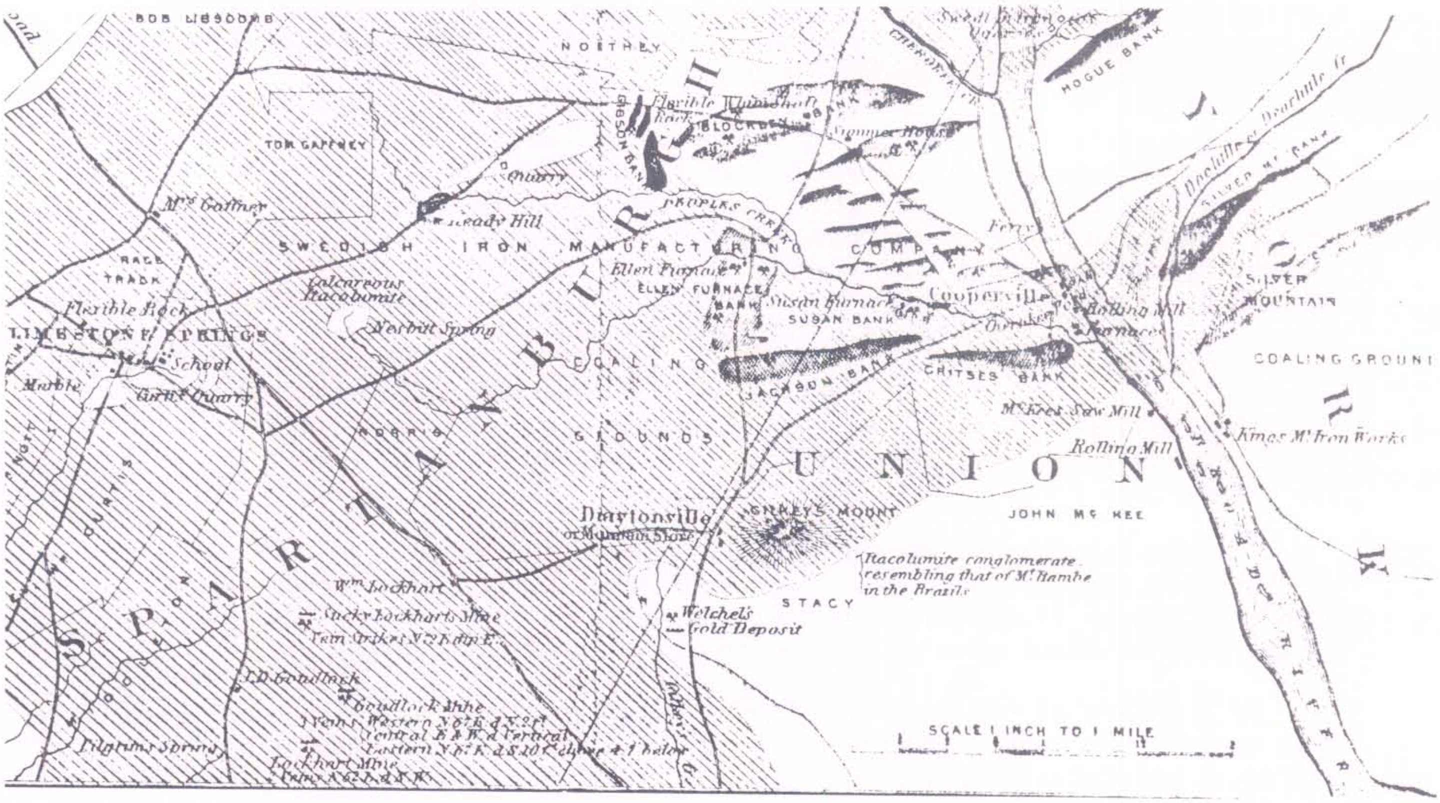

FIGURE 1. Modern place names should be added to Lieber's 1858 map of itacolumite, iron and limestone in Spartanburg, Union and York counties. All of the area shown in the illustration became Cherokee County in 1897. Limestone Springs is now a suburb of Gaffney; Blacksburg is located at the northernmost end of Doolittle Creek (not shown); Cherokee Falls is located on the southern bank of Doolittle Creek where it empties into Broad River; Gilkey Mountain is now called Draytonville Mountain. The twin furnaces are shown as two rectangles at the junction of People's Creek and Broad River.

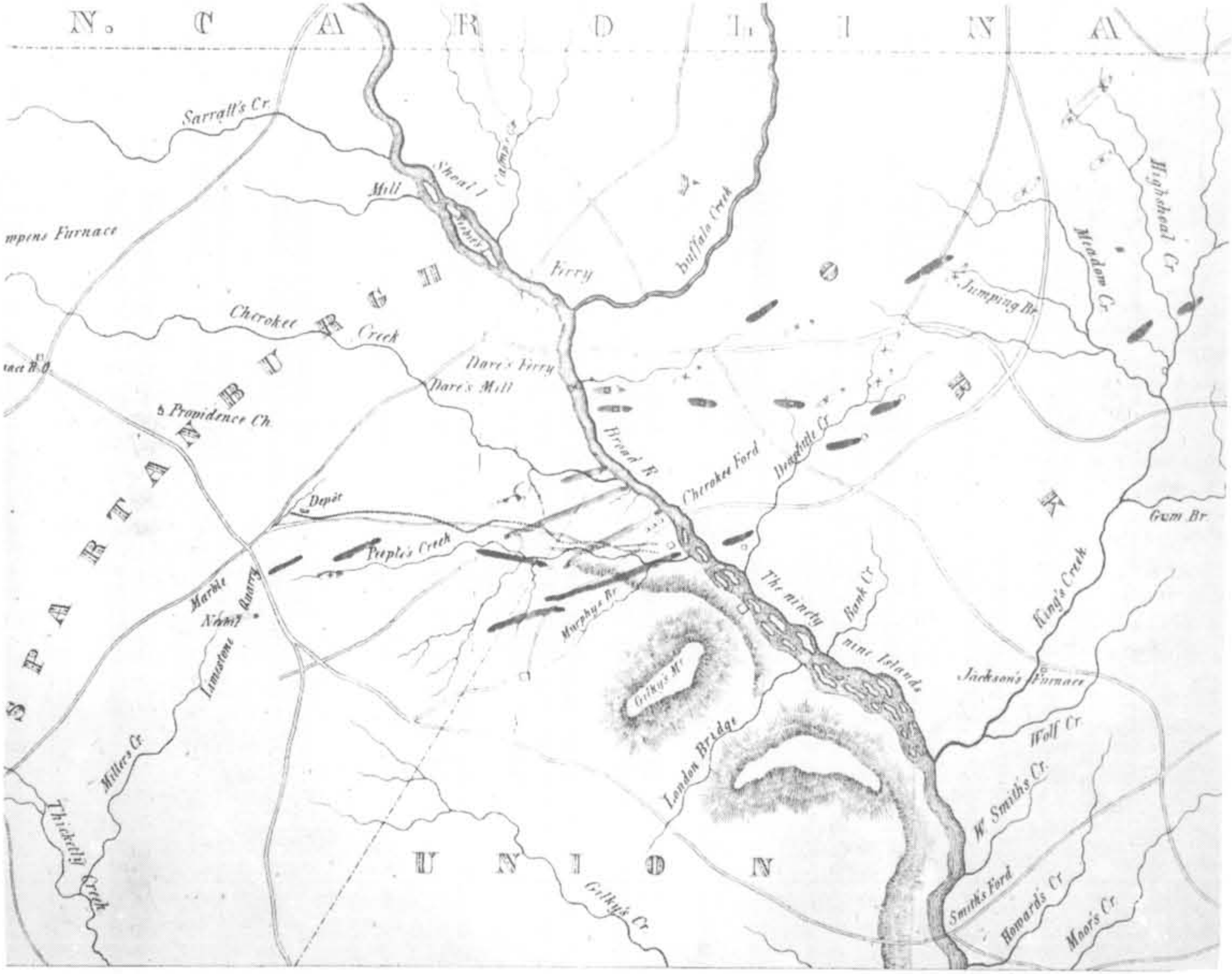

FIGURE 2. Some location names have changed since M. Tuomey produced this map in 1848. They are: Nesbit Limestone Quarry--Limestone Springs (suburb of Gaffney); Gilkey's Mountain--Draytonville Mountain; Dearlittle Creek--Doolittle Creek. The structures shown on the southwest bank of Broad River at Cherokee Ford are Cooperville. The tramway is shown running northwest from Cooperville to a depot north of Nesbit Limestone Quarry.

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The barite deposit at Kings Creek, South Carolina

W. E. Sharp, Department of Geology, University of South Carolina, Columbia, S.C. 29208 and C.A. Hornig, 455 Jefferson St., Montpelier, Idaho 83254.

INTRODUCTION

Barite was discovered in the York District of South Carolina in the early 1880's (Van Horn et al., 1949, p. 9). All known occurrences are confined to the Kings Mountain belt, a narrow zone of low grade metamorphic rocks bounded by higher grade rocks of the Charlotte belt on the southeast and the Inner Piedmont on the northwest. The sites of these prospects were described by Keith and Sterrett (1931) and Van Horn and others (1949) but relocation has been difficult because accurate topographic maps were not available until recently. Current geologic mapping (Horton and Butler, 1977; Godfrey, 1981; and Murphy and Butler, 1981) within the Kings Mountain belt has brought about an accurate location of virtually all of the reported barite occurrences as well as a few new ones.

The first production of barite was from small open pits at Kings Creek in 1885, and the ore was hauled by wagon to the railroad at Blacksburg (Wilson, 1958, p. 42). At the turn of the century, a railroad was built that passed through Kings Creek, and in 1910 a mill was erected by the Cherokee Chemical Co. for the grinding of barite. The principal use at that time was as a weighting agent in flour and sugar and this use continued until 1923 when the Pure Food and Drug Act was passed (Wilson, 1958, p. 42). Although initial production was from open pits along the slope of the hill (Watkins, 1915), the operation soon went underground and considerable production came from an incline that reached a depth of 200 feet (Van Horn et al., 1949, p. 14). Following the stock market crash of 1929, the mining continued on a lease basis and was finally taken over by the Clinchfield Sand and Feldspar Co. During World War II when labor was in short supply, the plant was mainly used for benefecation of ore from Tennessee (Van Horn et al., 1949, p. 9). In 1949 Industrial Minerals of York, South Carolina bought the mill and ore rights and set about to improve beneficiation and quarry operations. By 1953, the operation had been converted from mostly underground workings into an open pit (Wilson, 1958, p. 42). Production was then continuous until 1966 when a new plant a half mile to the north was built and emphasis was placed on crushing and storing colemanite imported from Turkey (Wilson, 1969, personal communication). Since then production from the quarry has consisted of white saprolite used in the manufacture of brick. To date the only successful operation for barite has been at Kings Creek where a large number of shallow dipping bands occur. At all other localities, the ore was removed by hand from small pits on steeply dipping veins and was transported by mule and wagon over dirt roads to the mill (Wilson, 1969, personal communication).

We would like to express our appreciation to Mr. L.G. Wilson, president of Industrial Minerals, for his cooperation and encouragement while mapping the deposit and to Dr. J. Wright Horton Jr. for his helpful criticism of the manuscript.

STRATIGRAPHY

Recent mapping in the Kings Creek quadrangle (Godfrey, 1981; Murphy and Butler, 1981) shows that the Kings Mountain belt in this area consists of a sequence of clastic sediments and interlayered volcanics in the southeast grading toward pelitic sediments in the northwest. Although no adequate criteria havebeen found to distinguish tops, it is tentatively assumed, as proposed by other workers in the region (Espenshade and Potter, 1960, p. 68; Horton and Butler, 1977, p. 101), that the volcanics lie near the base of the sequence. On this basis, the stratigraphic column starting at the bottom consists of mafic to intermediate tuffs and flows, felsic tuffs and flows including layers of massive dacite, white tuff, blue tuff, and at the top a pelitic sequence with manganese rich layers at the bottom and limestone units at the top. The map pattern of these units (Godfrey, 1981) suggests a fold structure along the trend of Kings Creek, and the stratigraphic sequence would make this an anticline plunging to the northeast. This is consistent with Horton and Butler's (1980) northeast-plunging South Fork antiform which dominates the structure of the eastern and central portions of the Kings Mountain belt.

The barite at Kings Creek is within Godfrey's white tuff unit. This unit is distinguished by a high sericite content and a homogenous white color, and consists largely of interlayered vitric-crystal tuff and crystal-vitric tuff. These rocks (Godfrey, 1981, p. 15-16) typically are composed of 50 % quartz, 28 % sericite, 10 % albite with lesser amounts of epidote, pyrite, and magnetite. The quartz shows undulose extinction and is commonly rounded and embayed. Twinning is common in the albite and the twin lamellae are often curved from deformation.

LITHOLOGY AT KINGS CREEK

The principal lithology at the Kings Creek deposit is a white quartz-sericite schist belonging to the white tuff unit of Godfrey (1981, p. 15). Close inspection of the rocks exposed in the quarry pits shows a number of distinct variations in the lithology, but the tracing of mappable units has proven extremely difficult because they tend to fade from one type into another.

Quartz-sericite schist

The dominant rock in the Kings Creek quarry is a quartz-sericite schist consisting of about equal amounts of intergrown fine grained quartz and sericite. The iron content of the rock is so low that upon weathering the soil remains a buff color. The unit grades through a number of color phases including white, gray, pink, speckled, and mottled.

The white phase consists of 10 - 30 % finely crystallized quartz in a matrix of 90 - 70 % minute sericite flakes. These areas have been extensively weathered so that a very deep saprolite has formed over it. This phase is now being mined from the east pit for use in making brick.

The gray phase consists of grit-sized quartz grains set in a matrix of sericite. The original grit-sized grains have been internally recrystallized so that each now consists of a multitude of unstrained minute quartz grains. Each clast was bounded by small magnetite grains.

The pink phase is dominantly fine-grained quartz with intergrown sericite. The schist shows two directions of mica growth corresponding to the intersection of two major foliations. Scattered through the section are chlorite, magnetite, and garnet. The rock is generally pale pink in color and where it has weathered has taken on a dark brown stain which seems to be confined to the sericite layers. This suggests the presence of manganese but the stain could not be traced to any of the garnets (spessartine ?)

The speckled phase consists of quartz-sericite schist which has little dark specks scattered through the rock at 5 to 10 mm intervals. X-ray powder diffraction photographs have shown these to be chalcopyrite.

The mottled phase has a poorly developed cleavage but has fine-grained bands of sericite with interspersed, hard, flattened, millimeter sized grains of quartz and feldspar. About 20 % of the rock consists of large grains of unstrained quartz and sericitized feldspar which are set in a matrix of fine-grained quartz, plagioclase, orthoclase, and sericite.

Chloritoid schist

On the north side of the quarries and interfingering with the quartz-sericite schist, the rocks are composed of a chloritoid schist. This rock is much richer in iron and upon weathering yields a deep red soil in marked contrast to the buff colored soil over the quartz-sericite schist. In outcrop the schist has a gray or bluish cast. In thin section, the rock consists of very fine grained quartz and sericite with elongate black opaques (graphite ?); cutting through the matrix are bands of coarse grained muscovite and chlorite with porphyroblasts of chloritoid at the center. Scattered through the rock are large idioblastic crystals of magnetite. Upon weathering, the magnetite crystals are released and can be seen in abundance where the soil has been washed by rain.

Quartzite

Scattered through the region of the quarry are small thin layers of saccharoidal sericitic quartzite. In outcrop, this rock is often soft and friable and may represent a metamorphosed bed of sand, chert or hydrothermal silicification. The quartz is completely recrystallized to small, unstrained, interlocking grains with interstitial sericite.

Barite

Most of the barite occurs as bands (Figure 1) within the quartz-sericite schist

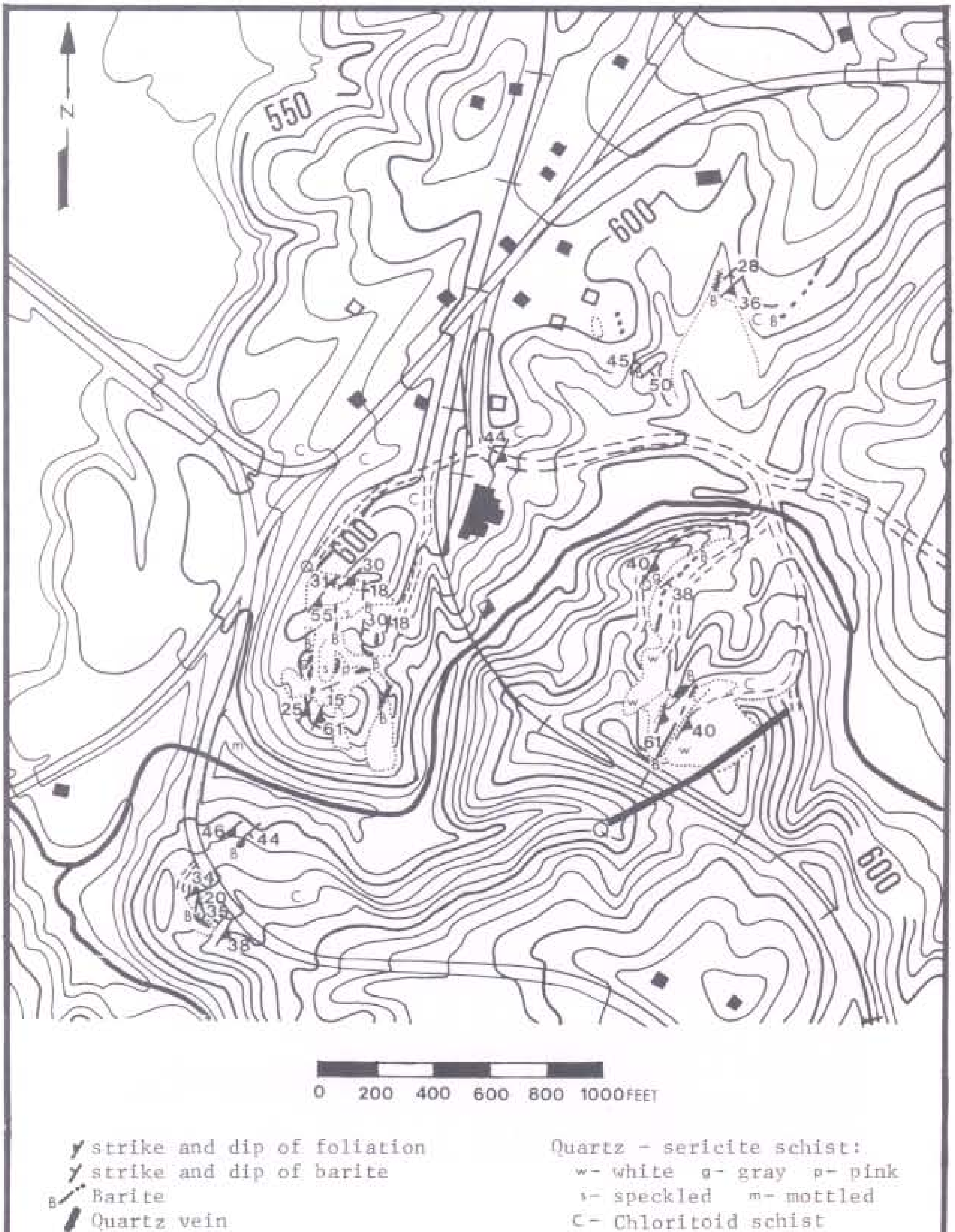

Figure 1: Map of the Kings Creek barite deposit.

unit. These bands may be either concordant (Watkins, 1915, p. 1074; Van Horn, 1949, p. 77) or discordant (Watson and Grasty, 1916, p. 537; Van Horn, 1949, p. 77) with the foliation of the schist (Figure 2). The barite occurs in three different forms (Wilson, 1958, p. 41): " 1) massive barite of 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 yielded 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."

The massive barite occurs in two dominant manners: non-foliated and foliated. The non-foliated barite is usually a white, medium-grained rock with little or no impurities. In some areas this barite shows banding parallel to foliation from a pink stain (hematite ?) or from a fine layer of galena. The foliated barite consists of an intergrowth of quartz and barite with interstitial sericite (Figure 3). This intergrowth caused problems with the early marketing of the barite (Watkins, 1915, p. 1075). The quartz grains appear embayed (Figure 3) with respect to the barite suggesting that the barite could have replaced a pre-existing sugary quartz band within the sericite schist (Hornig, 1973, p. 11, 37).

Figure 2. Barite band transgressive to the the dominant foliation in the west pit. The barite dips about 15° NW while the foliation (handle of hammer) dips about 40° SE.

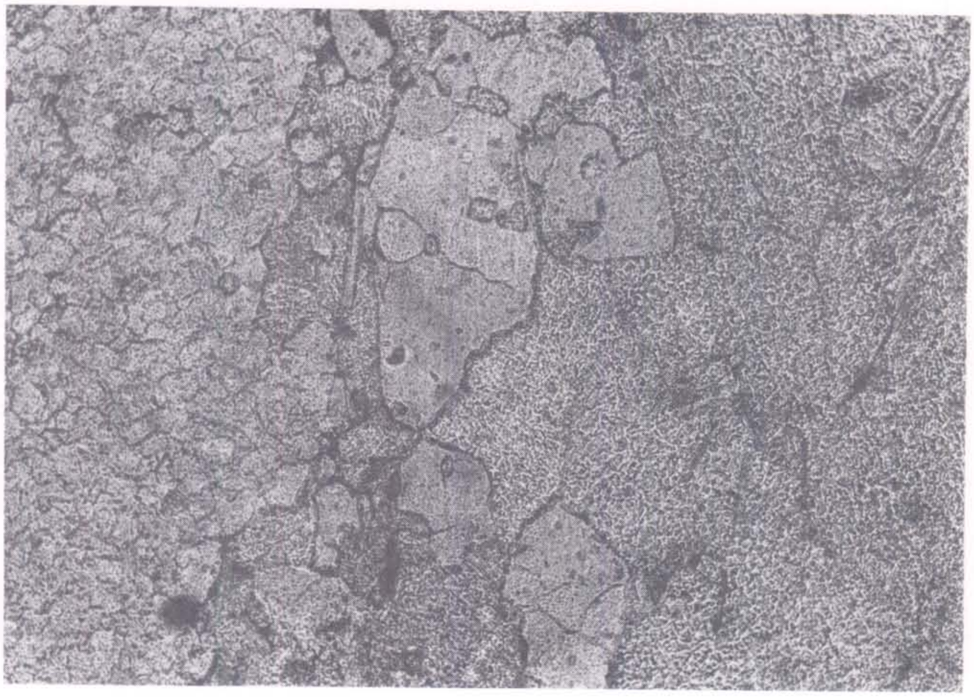

Figure 3. Photomicrograph in ordinary light of foliated barite showing a band of fine grained quartz (left) and coarse grained barite (right). Notice the embayed margins of the coarse grained quartz (center) where they are in contact with barite.

Quartz veins

Milky quartz veins ranging from a centimeter up to 10 meters in width occur scattered through the area. Some of the veins are strongly deformed and folded while others seem to transgress across all of the structures. This indicates the existence of several generations of quartz. In some places the quartz shows cubic vugs suggesting the former presence of pyrite, while in other places the quartz veins contain massive sunburst knots of tourmaline.

STRUCTURE

From the regional map relationships (Horton, 1977, Figure 3) and the map pattern of the Kings Creek quadrangle (Godfrey, 1981; Murphy and Butler, 1981), and an assumed stratigraphy of mafic and intermediate flows and tuffs at the base and sediments at the top, it is suggested that the barite deposits occur on the eastern flank of an anticline centered on Kings Creek and plunging to the northeast.

The rock in the quarry shows a pronounced foliation which strikes N 36° E and dips 26° SE. Compositional banding where seen generally seems to conform with the dominant foliation. Careful observation reveals a second but weaker foliation which also strikes N 36° E but dips 58° SE. The two foliations are readily seen in thin section where mica plates have grown in two distinct directions and the combination shows as an elongate maximum on the structural contour plot of foliations (Figure 4). Superimposed on this are younger kink bands striking N 17° E and dipping 40°SE, crenulations, and local mesoscopic folding of the dominant foliation.

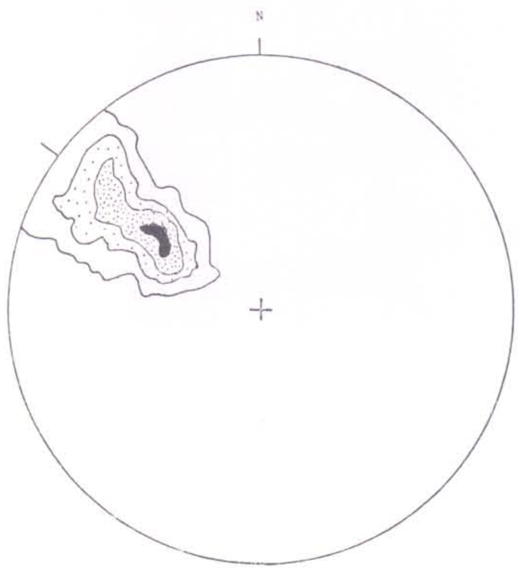

Figure 4. Lower-hemisphere equal-area plot of 189 poles to foliation. Contours are 13 - 10 - 7 - 4 %.

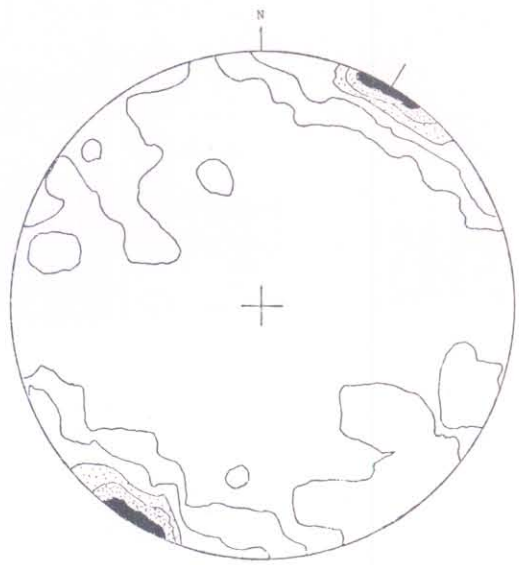

Figure 5. Lower-hemisphere equal-area plot of 115 poles to joints. Contours are 13 - 10 - 7 - 4 %.

Some of the barite bands are kinked and therefore must have been formed prior to that deformation. There have been several generations of quartz veins. Some show ptygmatic folding, suggesting they were affected by the early fold events while others have formed vuggy veins at the crests of crenulations. The more prominent quartz veins, often with black tourmaline, are vertical and strike about N 45° E. They range in thickness from 0.2 to 10 meters and range in length from 1 to 300 meters. They are clearly gash veins which cut across all of the deformational structures. Their orientation suggests they were formed by late stage faulting: either from an extensional normal event or from shearing along a north-south transcurrent event. Finally, the rocks in the quarry show a prominent vertical joint direction which strikes N 59° W (Figure 5).

THE ORIGIN OF THE BARITE

Until recently it has been generally assumed that the barite bands in the quartz-sericite schist were post-deformational hydrothermal veins (Stuckey and Davis, 1935, p. 353). The principal evidence was the purity of the barite, the replacement texture of quartz by barite in the foliated zone on both sides of the veins, the discordance between some of the veins and the foliation in the schist, the dissemination of barite and minor sulfides in the surrounding wall rocks, and the close association of the barite with sericite which could be hydrothermal in origin. Even so, it was curious that the barite was so massive and compact in texture, and that the veins were usually concordant with the foliation.

The recognition that important stratiform ore deposits often occur in terranes composed of felsic tuffs and flows similar to those occurring in the Kings Mountain belt suggests another interpretation. Volcanogenic ore deposits are now known to form from hot springs on the sea floor by the penetration and circulation of sea water into piles of hot volcanic rocks (Spooner and Fyfe, 1973, p. 297; Emery and Skinner, 1977, p. 26; Large, 1977, p. 554). The resulting hydrothermal circulation leaches the ore elements from the wall rock and reprecipitates them beneath and around the exit orifices (Edmund, 1980). This is particularly applicable to the case of barite which is known to have a close association with volcanogenic deposits (Kajiwara, 1973, p. 195) and for which a modern example has actually been discovered on the sea floor. Along the San Clemente fault zone about 70 km southwest of San Diego, California at a depth of 1800 meters, a line of cones, columns and irregular piles of barite 2 - 3 meters in height have formed from active hot springs (Lonsdale, 1979). Could the barite at Kings Creek have formed in an identical manner and if so, how should the field relations be interpreted?

If the hydrothermal deposition of barite at Kings Creek was syngenetic with the original sediment, then some of the original barite should still be present and it should behave during deformation and metamorphism in much the same way as original bedding. This interpretation is a likely possibility. Most of the barite occurs parallel to the dominant foliation and even if it were originally deposited as irregular masses, the extensional strain during deformation and metamorphism would flatten them into the plane of the foliation. Impure portions of the barite should preserve the foliation while pure portions might recrystallize sufficiently that the foliation is lost. Although barite bands transgressive to foliation could be folded original layers, they may also be remobilized barite which has filled northwest dipping gash veins opened during one of the fold events. For example, the bands dipping 25° NW are nearly perpendicular to the weak foliation dipping 58° SE.

To date, the accumulated evidence does suggest that the barite is hydrothermal and that it was emplaced prior to the late fold event that produced the kink bands. Specifically, the very low Th and U content is similar to other hydrothermal barites (Goldberg _et al_., 1969) and the low Sr-87 / Sr-86 ratios "suggest that the barite ... originated from a volcanic or hydrothermal environment and may contain primary strontium of a deep seated origin" (Goldberg _et al_., 1969, p. 288). Unfortunately, these values do not distinguish veins from sea floor hot springs. The structural evidence including undulose extinction and the kinking of the barite bands indicates the barite was emplaced prior to the late fold episode that produced kink bands in the dominant foliation. This is consistent with the Pb-isotope work on galena (LeHuray, 1980, personal communication) which suggests the barite was at least contemporaneous with the metamorphism. Whether the barite is epigenetic or syngenetic still remains unclear.

A crucial point is whether the foliated barite is an original sedimentary band which has been penetrated by the foliation or whether it is a replacement of foliated quartz-sericite schist adjacent to a vein. If the foliated barite represents syngenetic barite in the sediment, then the pure non-foliated barite must have been annealed during metamorphism. If the foliated barite is replacement around veins, then the barite could still be volcanogenic if the barite had originally been disseminated through the sediment. During metamorphism, the barite could have been "sweated out" of the rock and into the plane of schistosity as the deformation and metamorphism progressed and also into cross-cutting fractures with accompanying replacement of the wall rock.

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A model for the origin of metallic mineral deposits in the Kings Mountain belt

Harry H. Posey, Department of Geology, University of North Carolina at Chapel Hill, Chapel Hill, NC 27514

INTRODUCTION

A model for the formation of the Kings Mountain Belt (KMB) mineral deposits is proposed. Base metal deposits which include barite (± galena, ± sphalerite, ± chalcopyrite), iron oxides (± chalcopyrite), pyrite (± chalcopyrite), manganese oxides and graphite appear to have formed by syngenetic processes, are strata-bound, and represent a typical high fO_2 metal-bearing suite associated with the upper portions of many volcanogenic massive sulphide deposits. Pyrite-gold-quartz veins (± chalcopyrite) and some iron oxide concentrations, however, are related to the intrusion of the KMB tonalites. Ore textures suggest that the base metals were recrystallized and that sulphur was introduced during metamorphism.

Outcrop appearances of kyanite quartzites suggest that some are metamorphic equivalents of aluminum-rich sediments deposited in low-lying areas. The general stratigraphic succession of metallic deposits of the KMB is very similar to several Appalachian massive sulphide deposits, especially the Cambrian Chopawamsic deposits of central Virginia (Marr, 1981; Gair, 1978) and strata-bound barite and manganese deposits of the James River synclinorium of west-central Virginia (Espenshade, 1954).

This report is part of the author's dissertation studies on the origin of metal deposits of the KMB. I am grateful to Bob Butler and Paul Fullagar for their careful readings of the manuscript and to Larry Benninger for his assistance with the section on mineral equilibria. Butler furnished mineral location maps. Geoff Feiss furnished galena samples from Crowders Mountain. Cominco American, through Burt Sakrison, George Cole and George Koehler, provided field and laboratory support.

GEOLOGIC SETTING

The lithologic maps of Horton (1977), Horton and Butler (1977), Butler (1966, 1980), Wagener and Price (1976) and Keith and Sterrett (1931), and the mineral localities of Keith and Sterrett (1931), Stuckey (1965) and Butler (1980 and unpub.) provide foundations for the mineral deposition models of this report. Field examinations and ore microscopy studies provide a mineralogical framework, and ore textures outline some of the chemical conditions of ore deposition.

A simplified stratigraphic section drawn mostly from Horton (1977), Horton and Butler (1977) and Wagener and Price (1976) shows a lower intermediate to felsic coarse volcanic sequence overlain by finer volcanics which are themselves overlain by siliceous and minor calcareous rocks (Figs. 1 and 2). Horton (1977) suggests that the lower coarse volcanic rocks are intruded by comagmatic tonalite. The zone between volcanites and sedimentary rocks may be a unit of reworked volçanic rocks, but the textures and contacts have been obscured by metamorphism. Polymictic pebble conglomerates occur along at least one horizon within the upper silicic units. Stratigraphic relations between units east and units west of the Kings Creek fault are not clear.

A stratigraphic succession of metal deposits drawn mostly from the mineral localities of Keith and Sterrett (1931) and especially Butler (1980 unpub.) consists of: an iron-copper-gold concentration near the top of the tonalite intrusions; barite concentrations in the lower volcanite units which also occur along strike in finer-grained volcanic facies; a manganese horizon near the volcanite-sediment contact; a second laterally extensive iron horizon which is more pyritic than the first and more clearly stratabound; a third iron horizon; and a graphitic horizon at the top.

Iron, barite, manganese and possibly graphite horizons occur along the flanks of what is interpreted to be a shallow third-order basin adjacent to the tonalite intrusives. Kyanite quartzite and pebble conglomerate lenses appear concentrated in the axis of the basin.

ORE PETROLOGY

Iron-copper-gold zone

Polished sections from the Southern Gold and the McCaw iron mines are used to describe the lower iron-copper-gold zone (Figs. 1 and 2). Locations of these deposits are best shown in Butler (1980) and are mapped within the metatonalite units of the KMB. The deposits are of two types: (1) massive granular to foliated disseminated magnetite, and (2) pyrite-gold-quartz veins ($\pm$ chalcopyrite). The pyrite-gold-quartz veins seem to be concentrated near the top of the tonalite intrusions and often cross-cut the tonalite-volcanite boundary; the magnetite seems to rest exclusively within the tonalite. Thus, though the two types are spatially associated, they may be genetically distinct.

Ores of massive granular magnetite, partly replaced by hematite (Fig. 4) and foliated magnetite, also replaced by hematite, in metatonalite (Fig. 5) define the former type. The granular texture with 120° triple junctions (Fig. 4) indicates that magnetite was formed during metamorphism. Hematite almost always replaces magnetite grains along grain boundaries and cleavage planes leaving granular cores of unreplaced magnetite (Fig. 4). Some samples show complete replacement of magnetite by hematite but with preserved grain boundaries. Whether this replacement phenomenon is due to an increase in oxygen fugacity during metamorphism or during weathering cannot be ascertained from the polished sections of massive granular ores.

Metatonalite and quartz from the Southern Gold mine contain pyrite, magnetite-hematite, chalcopyrite, and manganese oxides. Magnetite-hematite grains occur in granular form but not in massive form. Also, some magnetite appears to have replaced lath-shaped crystals after or during the late stages of metamorphism as metamorphic folds and kinks are preserved. Magnetite formed

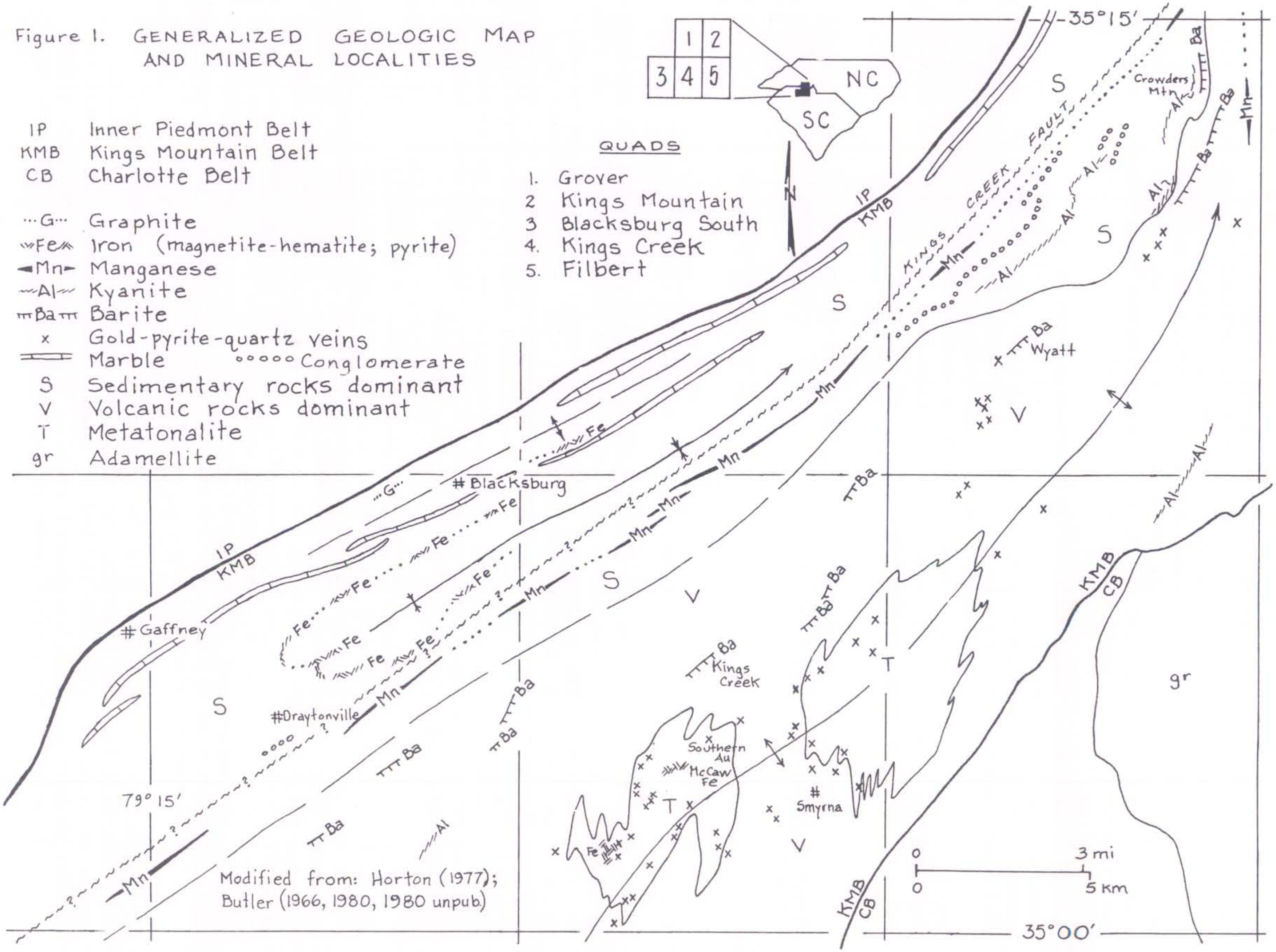

Figure 1. GENERALIZED GEOLOGIC MAP AND MINERAL LOCALITIES

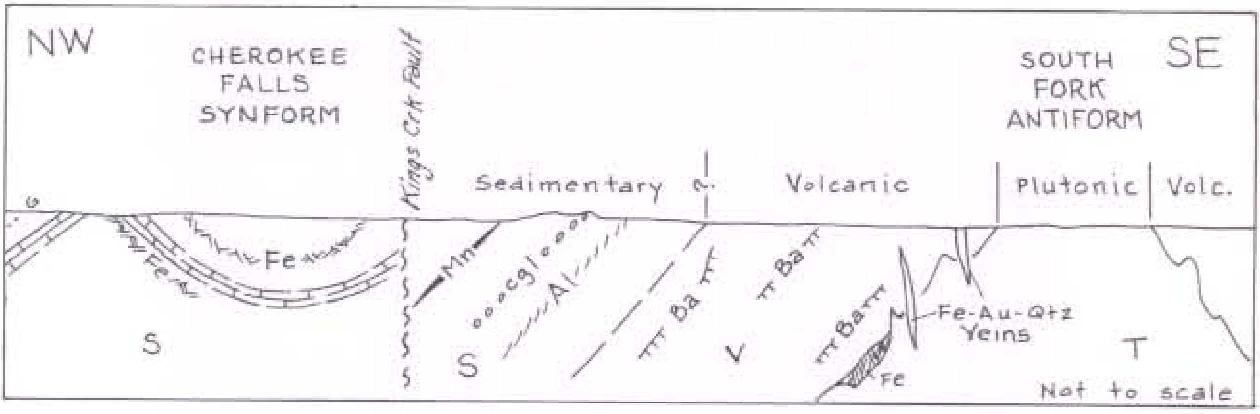

Figure 2. PROPOSED STRATIGRAPHIC HORIZONS AND LOCATIONS OF METAL CONCENTRATIONS, KINGS MOUNTAIN BELT, NC-SC. (See Fig. 1 for explanation)

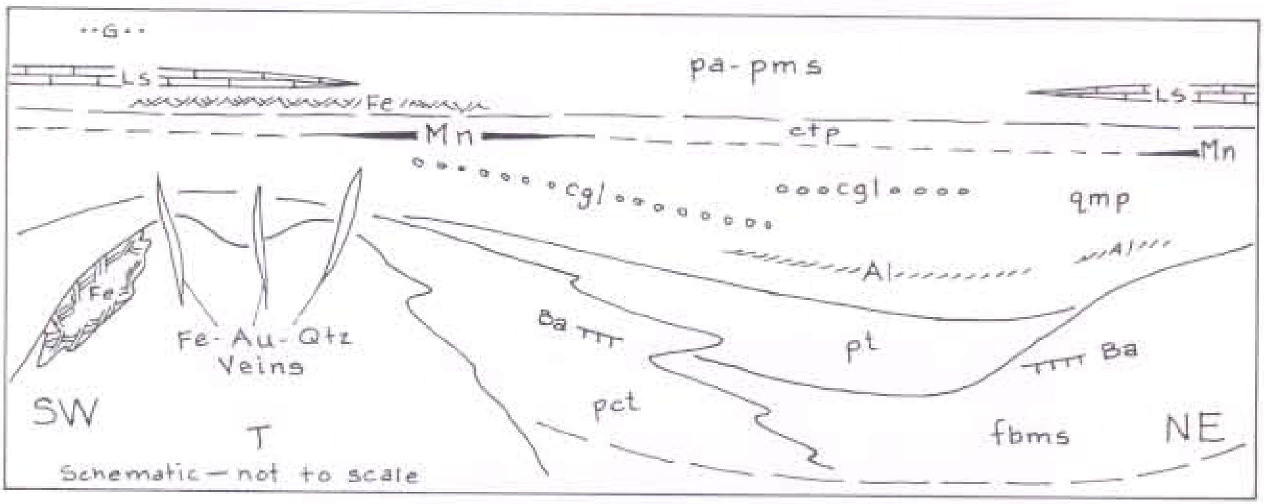

Figure 3. CROSS-SECTION SHOWING RELATIONSHIPS OF METAL CONCENTRATIONS AND PROJECTED BASIN, KINGS MOUNTAIN BELT, NC-SC. Lithologic units from Horton (1977): pct, plagioclase crystal tuff; fbms, feldspathic biotite muscovite schist; pt, phyllitic tuff; qmp, quartz mica phyllite; pa-pms, phyllite with amphibolite and phyllitic metasiltstone. See Fig. 1 for other symbols. Schematic - not to scale.

Figure 4. Massive granular magnetite (dark gray) replaced by hematite (white) along cleavage planes and grain boundaries. Black high relief mineral is quartz. McCaw iron mine, SC. Base of photograph is 0.49mm.

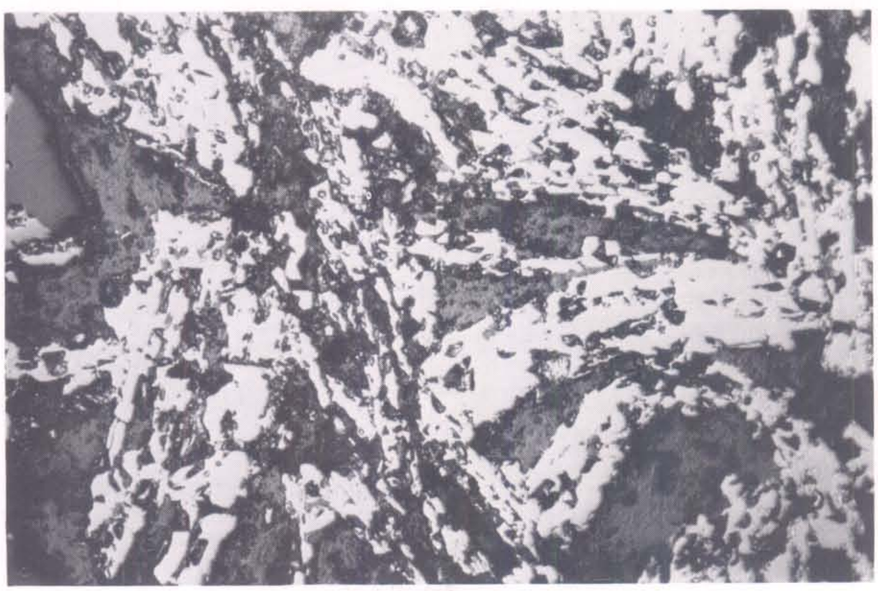

Figure 5. Foliated magnetite (white) replacing tabular minerals. Southern Gold mine, SC. Base of photograph is 0.98mm.

earlier would have developed granular texture during metamorphism. Euhedral pyrite grains are common and generally contain inclusions of magnetite-hematite and gangue minerals. Several elongate inclusions of magnetite within pyrite retain magnetite morphologies, suggesting that sulphur was introduced during metamorphism and that magnetite was oxidized to pyrite and hematite, their textures now indicating an equilibrium metamorphic assemblage (Fig. 6). Furthermore, the replacement of magnetite by hematite within pyrite suggests that hematite formed during metamorphism rather than during weathering.

Barite horizons

Barite occurs within several units of the lower volcanic sequences above the tonalites. If, as suggested here, the Kings Creek, Wyatt, and Crowders Mountain barite lenses (Fig. 1) represent a single sedimentary horizon, then parts of the plagioclase crystal tuff (pct) and the feldspathic biotite muscovite schist (fbms) units of Horton (1977) are volcanic facies equivalents. An alternative explanation is that conditions for barite formation occurred at more than one stratigraphic horizon and that lithologic conditions played a passive role in barite precipitation.

Several samples of barite from Crowders Mountain contain significant galena and traces of sphalerite. Granular textures between quartz, barite and galena + sphalerite suggest that all were recrystallized during metamorphism (Fig. 7). Sphalerite and galena form mutual boundaries along most contacts thereby representing equilibrium crystallization (Fig. 8). However, several sphalerite grains have replacement rims of galena suggesting perhaps a lead excess during the later, cooler stages of metamorphism (Fig. 9).

Chalcopyrite occurs in the Kings Creek barite deposits but was not observed in polished section.

Second iron horizon

Magnetite-hematite, pyrite and chalcopyrite occur within quartz-magnetite schists at numerous locations in the northern half of the Blacksburg South quadrangle (Fig. 1). Magnetite-hematite occurs in three dominant modes: (1) granular magnetite with quartz, (2) selective replacement of tabular gangue minerals (Fig. 5), and (3) inclusion or emulsion blebs within euhedral pyrite crystals. Hematite occurs with each magnetite concentration commonly along the outer rims of magnetite grains. Magnetite appears to have replaced the tabular mineral species after folding as it outlines folds and kinks. This type of magnetite occurs as replacement grains rather than granular intergrowths, suggesting that iron was introduced into these particular strata in the latter stages of metamorphism and may therefore not be of a primary stratigraphic origin.

Chalcopyrite occurs solely as emulsion blebs within pyrite euhedra (Fig. 10). The nature of the contacts between chalcopyrite and pyrite suggests equilibrium crystallization.

Manganese horizons

At least three Mn-Fe oxide phases occur within the manganiferous metasiltstone (mn) units mapped by Horton (1977): psilomelane, pyrolusite, and braunite

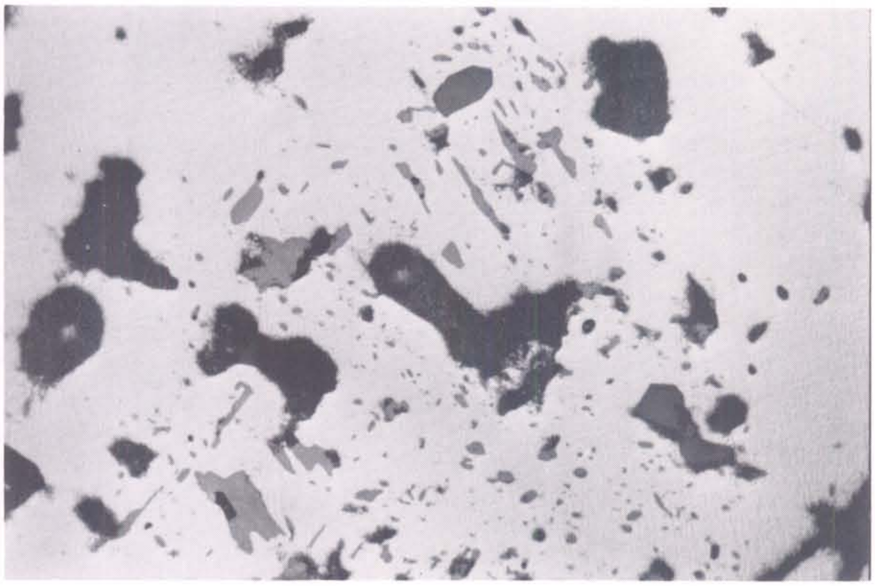

Figure 6. Vague triangular outline of remnant magnetite grain (dark gray) replaced by pyrite (white). Dark inclusions are gangue. Southern Gold mine, SC. Base of photograph is 0.49mm.

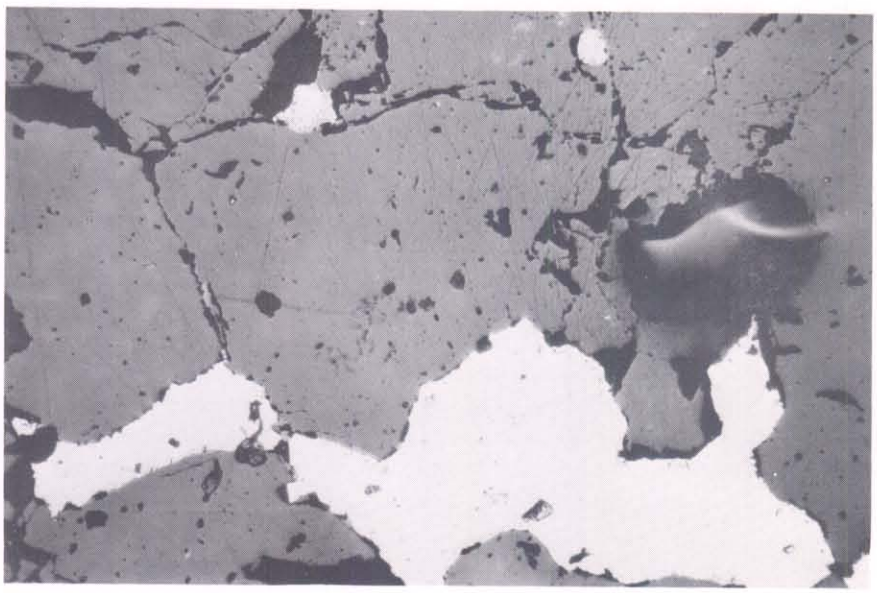

Figure 7. Granular barite (gray) and galena (white). Crowders Mountain, NC. Base of photograph is 0.98mm.

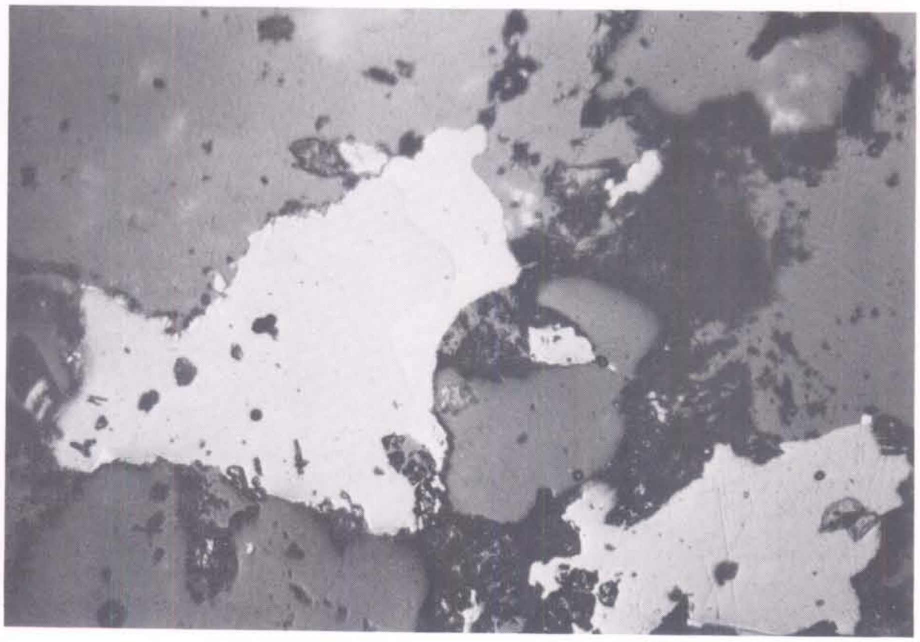

Figure 8. Mutual boundaries texture between galena (white) and sphalerite (light gray). Dark gray minerals are quartz (high relief) and barite. Note the thin transparent rim of galena along one edge of the sphalerite. Crowders Mountain, NC. Base of photograph is 0.49mm.

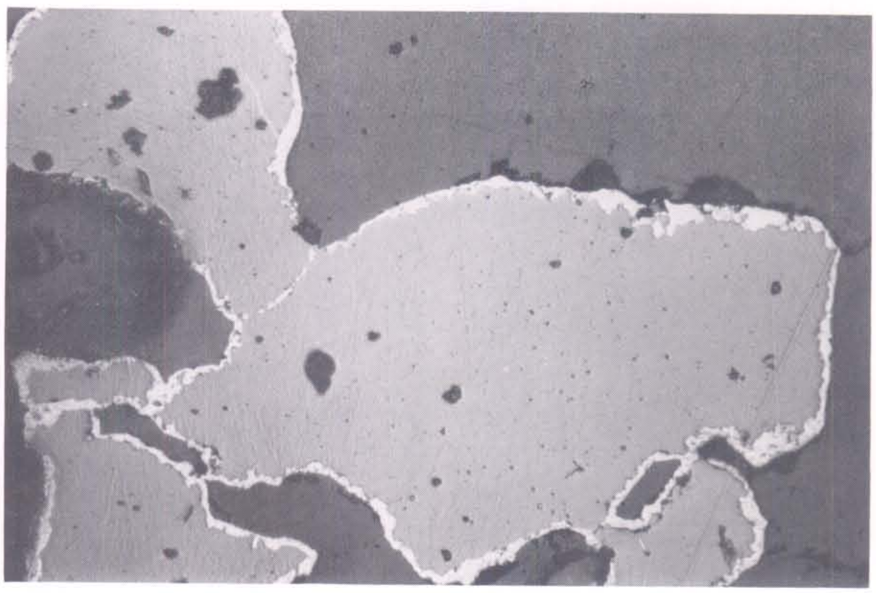

Figure 9. Sphalerite (light gray) with replacement rim of galena (white). Dark gray minerals are quartz (high relief) and barite. Base of photograph is 0.49mm.

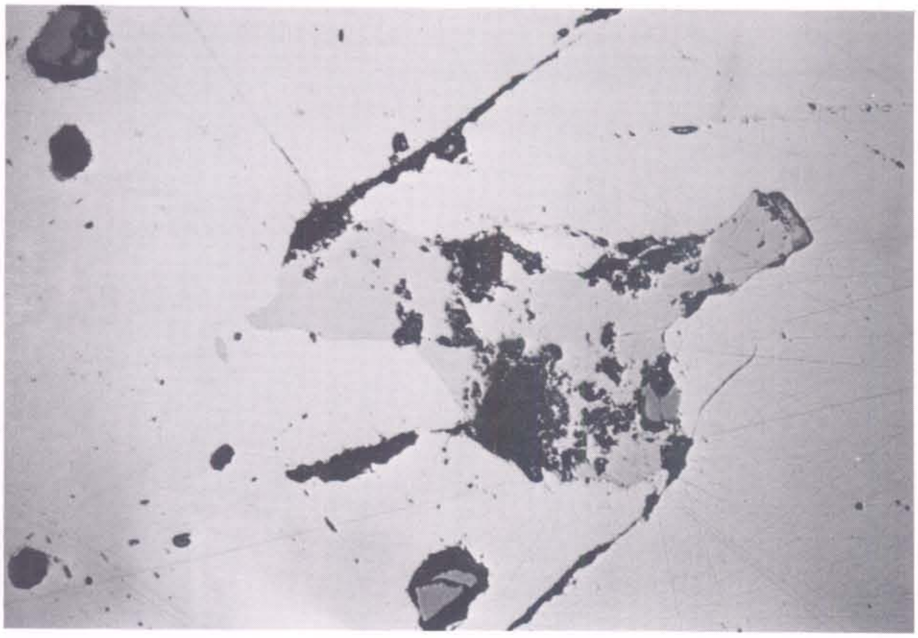

Figure 10. Chalcopyrite (gray) in pyrite (white). Dark gray minerals are quartz. 2.6 km north of Draytonville, SC. Base of photograph is 0.49mm.

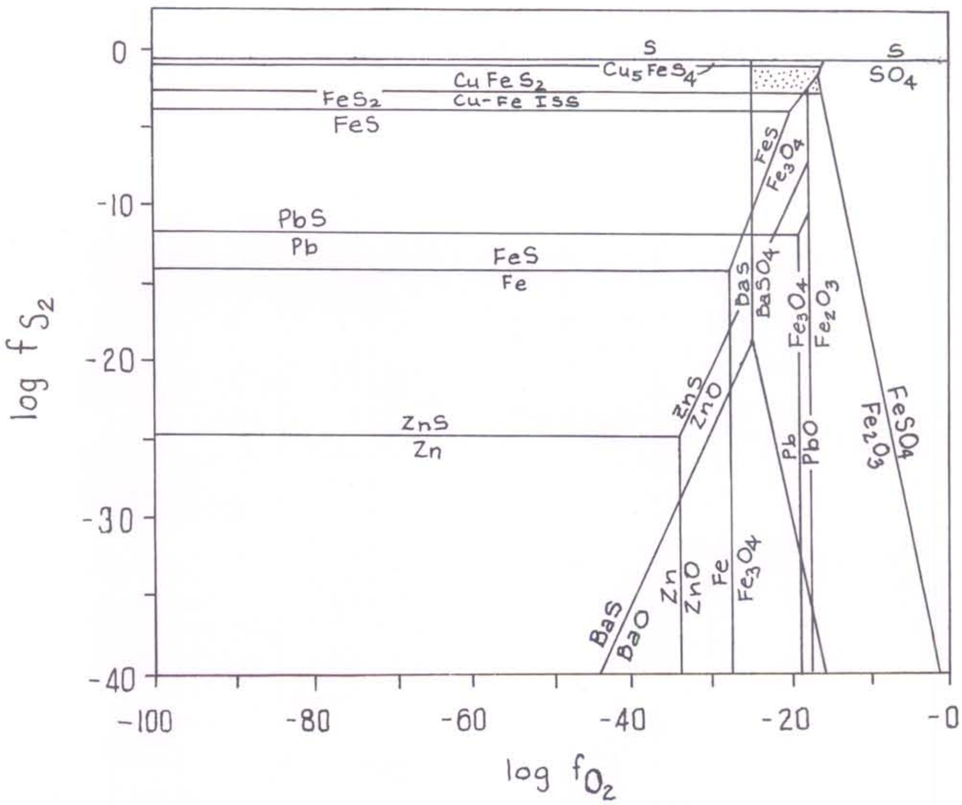

Figure 11. O_2-S_2 fugacity diagram showing the stability fields of O, S and SO_4 species of Fe, Cu, Pb, Zn and Cu (simplified for clarity) at 800°K (527°C). Stippled area outlines the overlapping fields of pyrite, barite, chalcopyrite, sphalerite, galena and magnetite. (Modified from Holland, 1959 and 1965).

(?) (Fig. 1). The more typical volcanic-affiliated Mn-oxides, hausmannite and jacobsite, have not been observed in polished section, suggesting that all of the Mn-oxide phases presently observed are weathering products. Their concentration along a single stratigraphic horizon, however, is strong indication of a sedimentary or volcanogenic origin.

Upper iron and graphite horizons

Except to note their stratigraphic position, the upper horizons of iron and graphite have not been studied. In outcrop they are more closely associated with limestone units than any of the underlying metal horizons, and it is suggested that they lie on opposite flanks of an unmapped anticline on the western boundary of the KMB (Fig. 1). The stratigraphic position of the upper iron and graphite is not well documented; they may in fact be older than the metalliferous units previously described. Precedence for this suggestion is found in Espenshade (1954) for similar graphitic schists of the Archer Creek Formation (probably lower Chopawamsic) of southwest Virginia; the graphite schists of southwestern Virginia underlie barite and manganese horizons.

It is not suggested that KMB metal deposits are strict stratigraphic equivalents of the Paleozoic rocks of southwest Virginia described by Espenshade (1954). However, rocks of both areas have broad similarities; metalliferous horizons formed under similar tectonic, sedimentary and volcanic conditions are likely to show similarities in the sequence of deposition from area to area. For these reasons the position of KMB graphitic schists within the metalliferous sequence should be regarded as more tentative than the other metalliferous units.

MODEL

It is assumed for purposes of modeling that the stratigraphic section introduced by Horton (1977) and Horton and Butler (1977) is an uninterrupted sequence from coarse volcanites through coarse and fine pyroclastics into terrigenous clastics and finally silicic and calcareous chemical and detrital sediments. The sedimentary sequence appears to be transgressive. It is also assumed that outcrop thicknesses are proportional to primary thicknesses except along synclinal and anticlinal hinges. Significant deviations from these assumptions are very likely, as olistostromes and lithologic repetitions due to folding and thrusting may have produced apparent thickening and thinning. However, in the absence of better exposures these assumptions seem reasonable.

Outcrop patterns shown by Horton (1977) suggest that quartz-mica phyllites in the north center of the Kings Mountain quadrangle may have been deposited in a small third-order basin. On the northeast and southwest flanks of that basin, barite, iron and manganese concentrated in response to volcanogenic processes perhaps related to rifting, island arc volcanism or back-arc spreading (Figs. 1 and 3). Pebble conglomerates and aluminous clays were concentrated in the center of the basin. The Al-rich clays, as suggested by Butler (personal communication), may have washed in from soils or hydrothermally altered zones nearby, a phenomenon similar to processes active today in Yellowstone Lake, Wyoming. The Mn horizon and its associated metaquartzites are flat across the top of the basin and thus represent a temporary filling of the basin. There appears to be no record of the third-order basin further up-section but limestones at the top of the sequence may represent transgression within the second-order KMB basin. Tonalites later intruded along the southwestern margin of the smaller basin, forming pyrite-gold-quartz veins near the intrusive margins.

The implications of the metamorphic textures are that sulfur, introduced during metamorphism, formed pyrite from magnetite; oxygen formed hematite from magnetite according to the reaction:

$$3Fe_3O_4 + S_2 = FeS_2 + 4Fe_2O_3$$

Ore textures are compatible with this reaction: replacement textures show that pyrite replaced magnetite and that hematite replaced magnetite, whereas equilibrium textures are preserved between hematite and pyrite. Equilibrium textures are also preserved between chalcopyrite-pyrite, sphalerite-galena, galena-barite, and sphalerite-barite. Replacement rims of galena around some sphalerite grains suggest a lead excess in the late phases of metamorphism.

DISCUSSION

Ore minerals of this study as shown in an oxygen-versus-sulphur activity diagram calculated at 800°K, express some of the geochemical conditions of metamorphism of KMB rocks (Fig. 11). 800°K (527°C) is a conveniently chosen temperature which approximates the KMB metamorphic conditions (upper greenschist to lower amphibolite). The stippled area of Figure 11 represents the overlapping stability fields of chalcopyrite, sphalerite, galena, pyrite, magnetite and barite.

The upper limit of sulphur fugacity is defined by the breakdown of chalcopyrite to bornite at log $fS_2 \approx -1$ while the lower limit is marked at approximately -3 by the chalcopyrite/Cu-Fe intermediate solid solution boundary. The lower limit of log oxygen fugacity lies at the barite-BaS boundary and is ≈ -25; the upper limit lies at approximately -18, the boundaries of sphalerite-$ZnSO_4$ and galena-$PbSO_4$. Both boundaries have been simplified for purposes of the diagram.

The FeS activity field coincident with the stippled area of Figure 11 ranges from about 0.1 to 0.01 (Toulmin and Barton, 1964), and increases with increasing pressure. Though pressure tends to increase the oxygen and sulphur fugacities of each reaction, the effects are minimal. For instance, at 525°C the pyrite-pyrrhotite boundary increases from log $fS_2 = -4$ at 1 kb to approximately -2 at 5 kb, and the pyrite-sulphur boundary increases from about -1 to 0.5 under similar pressure conditions (Toulmin and Barton, 1964).

The absence of bornite and pyrrhotite from the KMB mineral assemblage allows a fairly restricted interpretation of the origin of sulphur during metamorphism. High sulphur fugacities favor the precipitation of pyrite over pyrrhotite, but chalcopyrite-pyrite stability can be maintained over only a very narrow sulphur activity range before chalcopyrite breaks down to bornite at higher sulphur fugacities and pyrite to liquid sulphur (Fig. 11). The activity of S was probably restricted by the amount of available sulphur within the primary volcanic-sedimentary sequence. The overall reactions of the ore minerals of the KMB seem to have proceeded toward higher fugacities of O_2, S_2, and Fe, and toward lower fugacities of FeS.

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Variations in metamorphic grade in the Kings Mountain belt of north-central South Carolina

Joel P. Gregory, Department of Geology, University of North Carolina at Chapel Hill, Chapel Hill, NC 27514

The Kings Mountain belt attains its maximum width in north-central South Carolina near the border of North Carolina. Sediment samples were collected from 137 streams within the belt, and their heavy mineral fractions were analyzed. These analyses allowed a staurolite isograd to be defined, separating an area of upper greenschist metamorphic facies rocks in the center of the belt from rocks of the lower amphibolite facies along either flank.

The sediments were collected in the Blacksburg South, Kings Creek, Filbert, Wilkinsville, Hickory Grove, and Sharon 7½-minute quadrangles in South Carolina (Fig. 1). The rock types in the area are those mapped by Keith and Sterrett (1931) and later defined by King (1955) as the classic associations of the Kings Mountain belt. Horton (1977) gives detailed descriptions of the rock types in the belt immediately to the north of the Kings Creek and Filbert quadrangles. Wagener and Price (1976) mapped the Wilkinsville quadrangle, Butler (this volume) mapped the Blacksburg South quadrangle, and Murphy (Murphy and Butler, this volume) and Godfrey (1981) mapped the Kings Creek quadrangle.

The sediments collected are from first-order streams, except for a few samples. Thus, the minerals in them are from a limited drainage area and represent well the rocks from which they have weathered. Care was taken to ensure that the samples were not contaminated by road-fill or construction debris which might have been brought from another location.

The heavy mineral fraction of each sample, obtained by bromoform separation, was analyzed to identify each mineral species present. In all, sixteen varieties of non-opaque minerals and seven varieties of opaque minerals were identified. These included hematite, black hornblende, ilmenite, limonite, magnetite, pyrite, actinolite, andalusite, barite, biotite, chloritoid, epidote, garnet, blue-green hornblende, kyanite, monazite, piemontite, sillimanite, sphene, staurolite, tremolite, and zircon (Gregory, 1981). Particular attention was paid to the occurrence of staurolite since its first occurrence was used to define the staurolite isograd.

The staurolite isograd was defined by the first appearance of staurolite, whether it was a single grain in a sample or hundreds. Indeed, both cases did occur. Delineated in this manner, the isograd is roughly parallel to the general strike of the Kings Mountain belt, except where it attains closure in the Wilkinsville and Hickory Grove quadrangles (Plate 1). This configuration is in agreement with that of isograds defined in the belt to the north and east by Horton (1977) and Espenshade and Potter (1960).

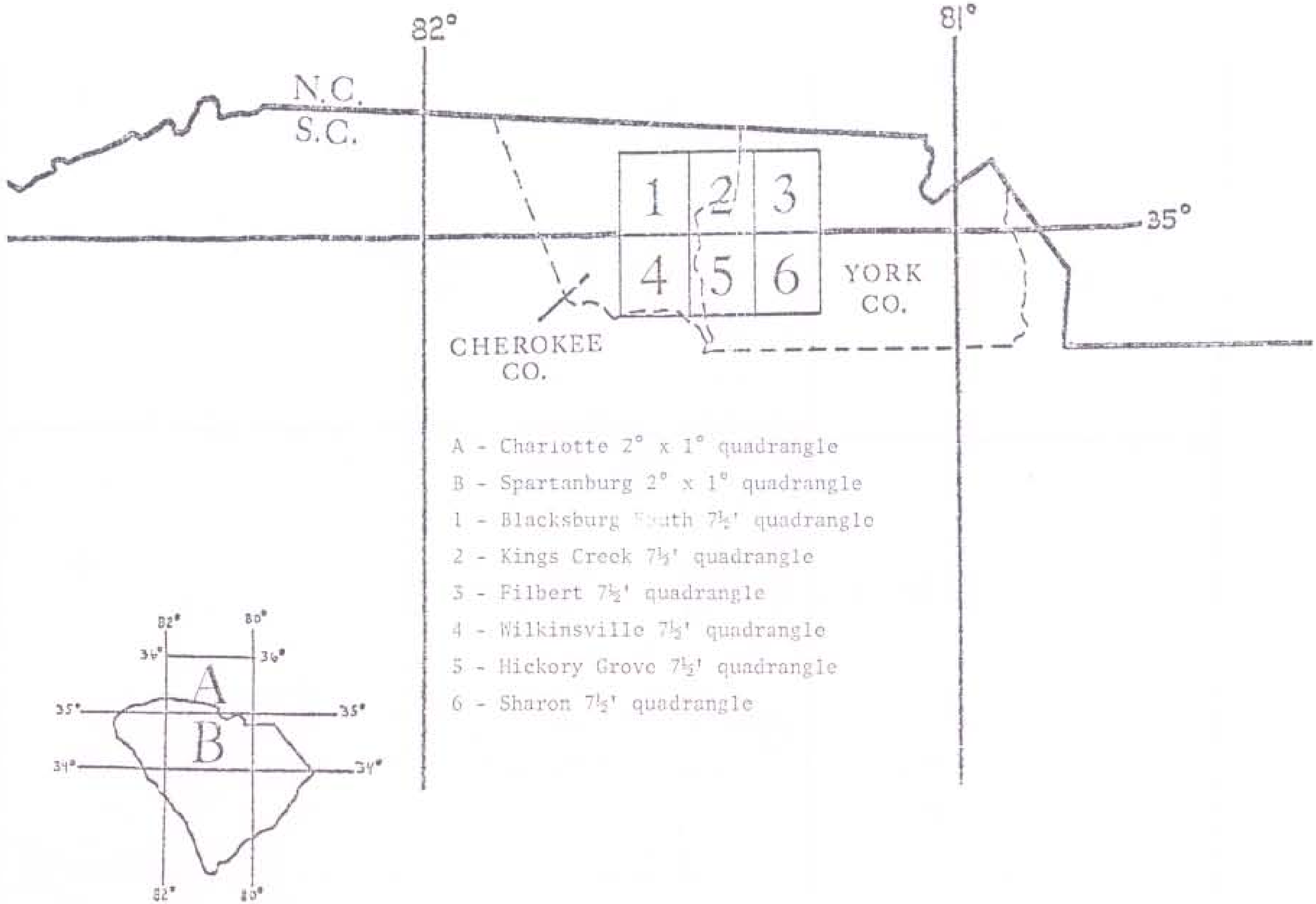

Figure 1. Geographic location of field area.

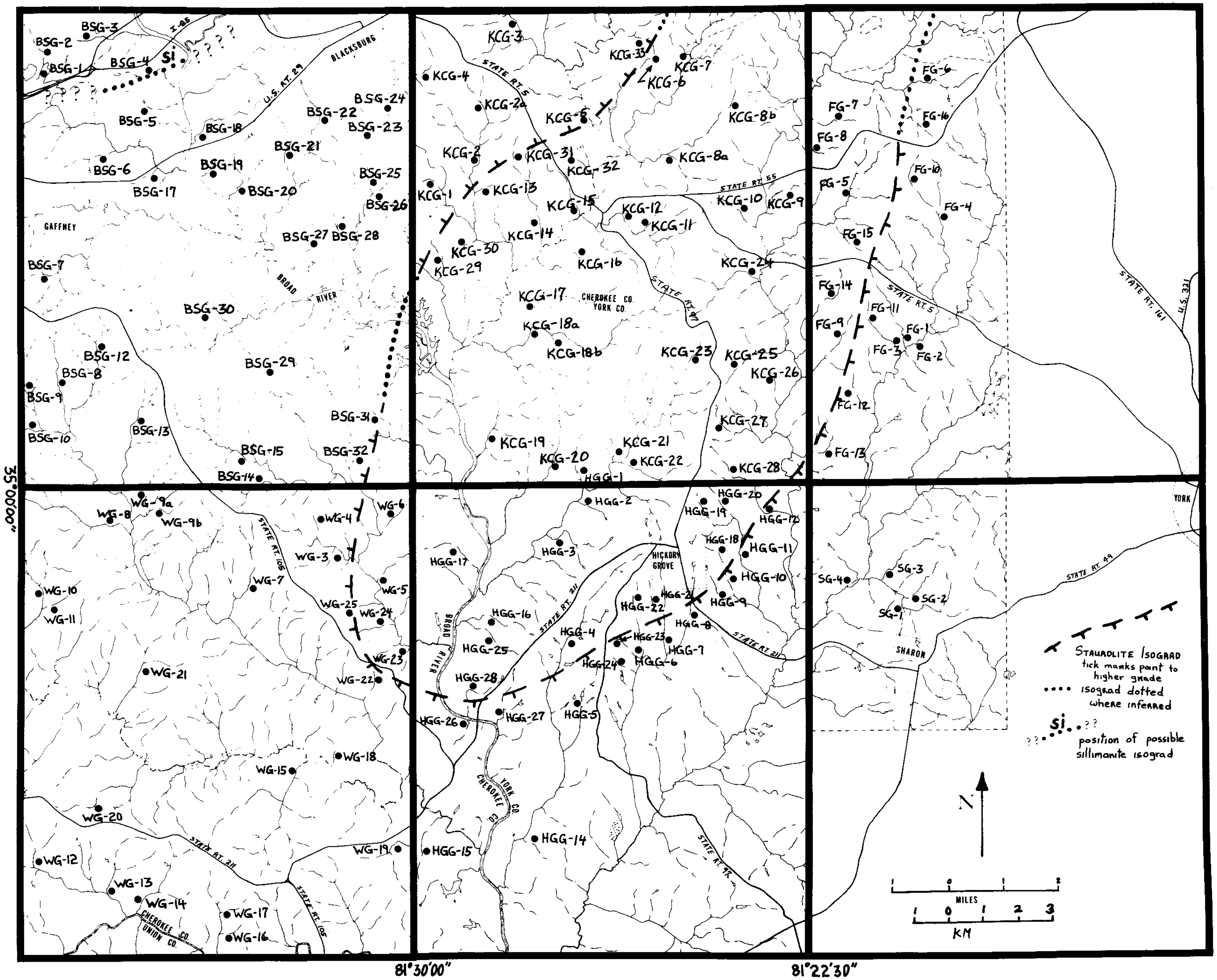

Plate 1. Map showing isograds and sample locations in eastern Cherokee and western York counties, South Carolina. Quadrangle names are given on Figure 1.

As presented here, the staurolite isograd separates rocks of the lower amphibolite facies from upper greenschist facies in the center of the map. Espenshade and Potter (1960) defined an albite-epidote amphibolite facies zone as an intermediate between the greenschist and amphibolite facies in rocks to the northeast. An almandine zone could be defined only by distinguishing almandine-rich from spessartite-rich garnets, which was not done in this study.

Since the position of the staurolite isograd is created by the intersection of the land surface with a staurolite isograd surface, it is interesting to speculate on the shape and origin of this surface. Naturally, since the lower grade rocks are enclosed by the higher grade rocks, and the land surface is essentially flat, the isograd surface probably has some kind of a synformal shape, assuming that it is not overturned or allochthonous. This shape could be produced by (1) the deformation of an originally planar and horizontal surface following progressive metamorphism, or (2) an originally synformal surface caused by thermal highs along the flanks of the belt and to the south after progressive metamorphism. This would occur if there was a variable paleogeothermal gradient with the isotherms flexing upward toward the edge of the belt.

The second interpretation appears to be the most likely. Since the major structure of the belt is antiformal (Horton, 1977; Horton and Butler, 1977) and the isograd surface is synformal, it is not readily apparent that post-metamorphic deformation could produce such a configuration. Stability data on staurolite (Ganguly, 1969; Winkler, 1979) shows that the first occurrence of staurolite is controlled mostly by temperature. It first becomes stable over a wide range of pressures, but within a narrow temperature range [~ 500°C at less than 1 kb; 575°C, 10 kb (Winkler, 1979)]. Thus, the first occurrence of staurolite and the transition from upper greenschist facies to lower amphibolite facies could be produced by variable geothermal gradients which bring the isotherms up higher in the crust along the flanks of the belt.

The presence of sillimanite in a few samples from the Blacksburg South quadrangle (BSG-1, 2, 3, 4) suggests a possible sillimanite isograd, but these samples are in the Inner Piedmont and do not represent the Kings Mountain belt. It is likely that a fault juxtaposes sillimanite-grade rocks of the Inner Piedmont against staurolite-kyanite grade rocks of the Kings Mountain belt and a true gradation in metamorphic grade does not occur (Butler, this volume).

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Intrusion of the Bald Rock batholith into Kings Mountain belt and Charlotte belt rocks, South Carolina

Susan M. van Gelder* and Harry Y. McSween, Jr., Department of Geological Sciences, University of Tennessee, Knoxville, Tennessee 37916
*Now at Mobil Exploration and Producing Services Inc., P.O. Box 900, Dallas, Texas 75221

INTRODUCTION

The Bald Rock batholith intrudes the boundary between the Kings Mountain and Charlotte belts in Union and Cherokee counties, South Carolina (Fig. 1). This body, with an outcrop area of 267 km^2, is one of the largest post-metamorphic granitic intrusions in the Piedmont. This report describes the petrologic characteristics of the batholith and geological implications for the Kings Mountain belt.

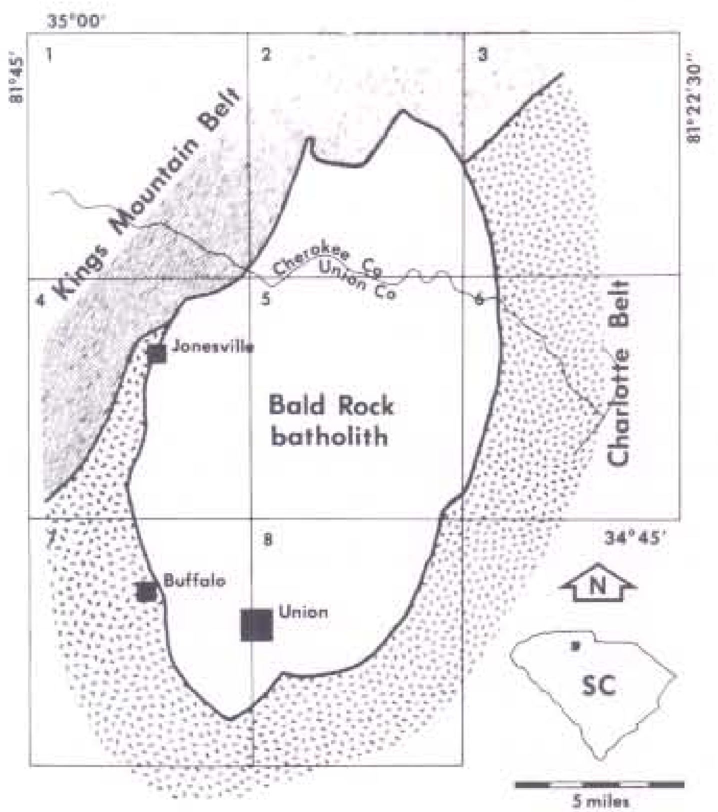

Figure 1. Map showing location of the Bald Rock batholith relative to the contact between the Kings Mountain and Charlotte belts in Union and Cherokee counties, South Carolina. Quadrangles numbered in their upper left corners are identified in the text.

We are grateful to J.A. Speer for sharing his data and ideas on the Bald Rock batholith, and J.B. Higgins and F.B. Keller for reviewing the manuscript. This work was supported by the South Carolina Geological Survey.

FIELD RELATIONS AND GEOPHYSICAL EXPRESSION

The Bald Rock batholith covers portions of the Pacolet Mills (1), Wilkinsville (2), Hickory Grove (3), Jonesville (4), Kelton (5), Lockhart (6), Union West (7) and Union East (8) 7.5-minute quadrangles (Fig. 1). Although the body is deeply weathered, there are a number of pavements of fresh to slightly friable bedrock. Country rock lithologies are mostly granitic gneisses, amphibolites and pelitic schists. Contact relations with these units are not exposed but are inferred to be sharp, as no exposures of transitional materials were found. The body is discordant, and dike swarms of granitic affinity tend to be confined within the batholith.

Gravity data (Talwani et al., 1975) show Bouguer gravity values of -20 to -28 mgal over the batholith. The lack of steep gradients reflects the fact that the batholith is enclosed by rocks with similar densities. A negative magnetic anomaly of about 100 gammas (U.S.G.S., 1977a) coincides with the mapped boundaries of the batholith, reflecting its relative mafic mineral content. The body also stands out as a radioactive high, generally about 500 counts per second above the country rocks on the aeroradiation map (U.S.G.S., 1977b). This anomaly may reflect the high content of radioactive accessory minerals or decay of K^{40} in granitic feldspars.

PETROGRAPHY

Granitic rocks of the Bald Rock batholith consist mainly of microcline, plagioclase, quartz, and biotite, with accessory allanite, epidote, titanite, muscovite, apatite, zircon, magnetite, ilmenite, pyrite and locally, hornblende, chlorite and garnet. Following the I.U.G.S. system of nomenclature for plutonic rocks (Streckeisen, 1975), the rocks are granites and quartz monzonites (Fig. 2).

Two major textural phases of the Bald Rock granite have been distinguished: a medium- to coarse-grained phase containing tabular, perthitic microcline megacrysts up to 7 cm in length; and a fine-grained, equigranular phase that intrudes the former. Fine-grained granite samples appear to contain more quartz and plagioclase than porphyritic rocks (Fig. 2). Five mappable variants of the porphyritic phase are recognized on the basis of modal and textural criteria. These are:

(I) 5-33% large (>2cm) megacrysts of varying size in a medium- to coarse-grained hypidiomorphic granular groundmass; color index (C.I.)=1-5;

(II) 17-20% small (<2cm) magacrysts of equal size in a dark, foliated and granulated groundmass; C.I.=6-7;

(III) 10-15% large (>3cm) megacrysts in a very coarse-grained, blocky groundmass; C.I.=1-2;

(IV) 5% medium-sized (∿2cm) megacrysts in a fine-grained, equigranular groundmass; C.I.=0-3;

(V) 15-30% large (>2cm) megacrysts in a dark, foliated groundmass; C.I.=8-10.

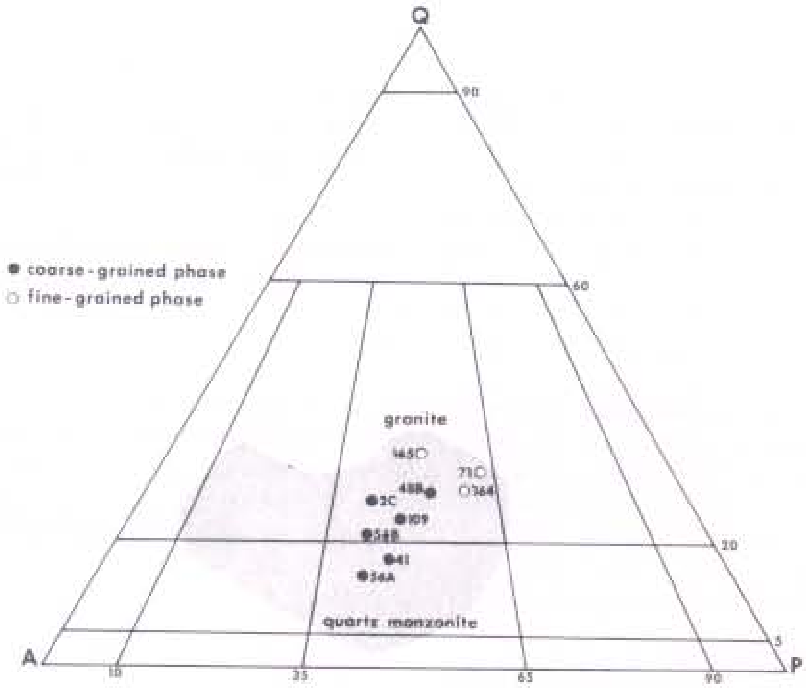

Figure 2. Modal classification (Streckeisen, 1975) of Bald Rock samples in terms of quartz (Q), alkali feldspar (A) and plagioclase (P). Fine-grained samples were point-counted in stained thin sections, and coarse-grained samples were point-counted using stained slabs greater than 9000 mm^2. Shaded area represents the compositional range of 24 Piedmont post-metamorphic plutons (Speer et al., 1980).

Areal distributions of the petrographic types are shown in Figure 3. Note that samples with the highest color indices (the only quartz monzonites) are found at the margins immediately adjacent to mafic country rocks. The only hornblende-bearing samples are found contiguous to amphibole-bearing country rocks. Granitic magma at pluton margins apparently was contaminated by assimilation. Low color indices and a paucity of megacrysts characterize the granite samples from the southeastern margin of the batholith. This portion of the body is in contact with quartzofeldspathic gneisses, which may have donated felsic contaminants through assimilation.

The broad {010} faces of tabular microcline megacrysts usually define a pronounced foliation in most outcrops. Ferromagnesian and accessory minerals are found together in mafic clots. Evidence for protoclasis (deformation of grains in an incompletely solidified magma) is present to varying degrees in all porphyritic samples. Granulated matrix material is common throughout the batholith, but granulation was either more intense or better preserved at marginal localities. Myrmekite is widely developed in samples with well-preserved protoclastic textures. Granoblastic textures indicate thermal annealing in the east-central portion of the batholith.

ENCLAVES, DIKES AND INTERNAL FABRIC ELEMENTS

Elongate mafic xenoliths ranging from several centimeters to over 20 meters in length are distributed throughout the batholith. These enclaves occur in swarms and are largest and most abundant near pluton margins.

Several generations of felsic dikes transect the porphyritic granite. These dikes probably represent a more highly differentiated, water-rich derivative of the earlier porphyritic phase. The oldest are synplutonic dikes, recognized by irregular contacts, bending and interruptions. These dikes apparently intruded with sufficient force to rupture the semi-solid granite and were deformed by subsequent movements of the plastic host material. Other granitic dikes have sharp, straight contacts, suggesting that they were injected into fractures that formed after the Bald Rock magma had solidified. A later series of thin alaskite dikes with pegmatitic centers is also present.

Perhaps the most striking feature of the Bald Rock batholith is the marked foliation produced by parallelism of tabular megacrysts in most exposures. The map pattern of this foliation (Fig. 4) shows generally steeply dipping megacrysts parallel to the margins and concentric about an area of random orientations in the east-central portion of the batholith, the same area which exhibits evidence of thermal annealing. Mafic enclaves and biotite-rich schlieren follow the same pattern. Xenoliths are elongated and internally foliated parallel to the megacryst orientations. Those in the center of the pluton tend to have high length to width ratios, up to 19:1, while xenoliths from the margins are more equant, usually about 6:1. Enclaves located near the margins nearly always have one tapered end, and in any one exposure, swarms of xenoliths are generally tapered in the same direction.

ORIGIN, EMPLACEMENT AND CRYSTALLIZATION

The parental magma of the Bald Rock batholith probably originated as a lower crustal melt (Fullagar and Butler, 1979) that was generated above a subduction zone in the mid-Paleozoic and rose without significant crustal contamination (as deduced from Sr isotopic data by Fullagar, 1971) after cessation of regional metamorphism. Emplacement at the boundary between the Kings Mountain and Charlotte belts was probably fortuitous, although the potential of this boundary as a magma conduit cannot be evaluated. At the depth of emplacement, disturbance of the country rocks was moderate, consisting mainly of the engulfment of many xenoliths and a few larger screens of country rock by the magma. Assimilation of xenolithic material caused local contamination of the magma near pluton margins.

Successive surges of magma in the east-central part of the batholith may have forced previously intruded, nearly solidified crystal mush radially away from the center of upwelling. Such deformation could produce the concentric foliation of megacrysts and xenoliths in the outer carapace. Repeated magma surges caused thermal recrystallization near the center of upwelling, and xenoliths in this area became more highly attenuated in response to prolonged heating. Outward force of the resurgent magma on the confined, nearly solidified material induced protoclasis and disrupted synplutonic dikes. Concentration of volatiles in the residual magma finally led to forcible emplacement of fine-grained granitic dikes.

IMPLICATIONS FOR THE KINGS MOUNTAIN BELT

Kings Mountain belt rocks flank the Bald Rock batholith on its western margin. These consist predominantly of crenulated muscovite and sillimanite schists, and a finely interlayered metavolcanic unit of metatuffs and amphibolites (Fig. 3).

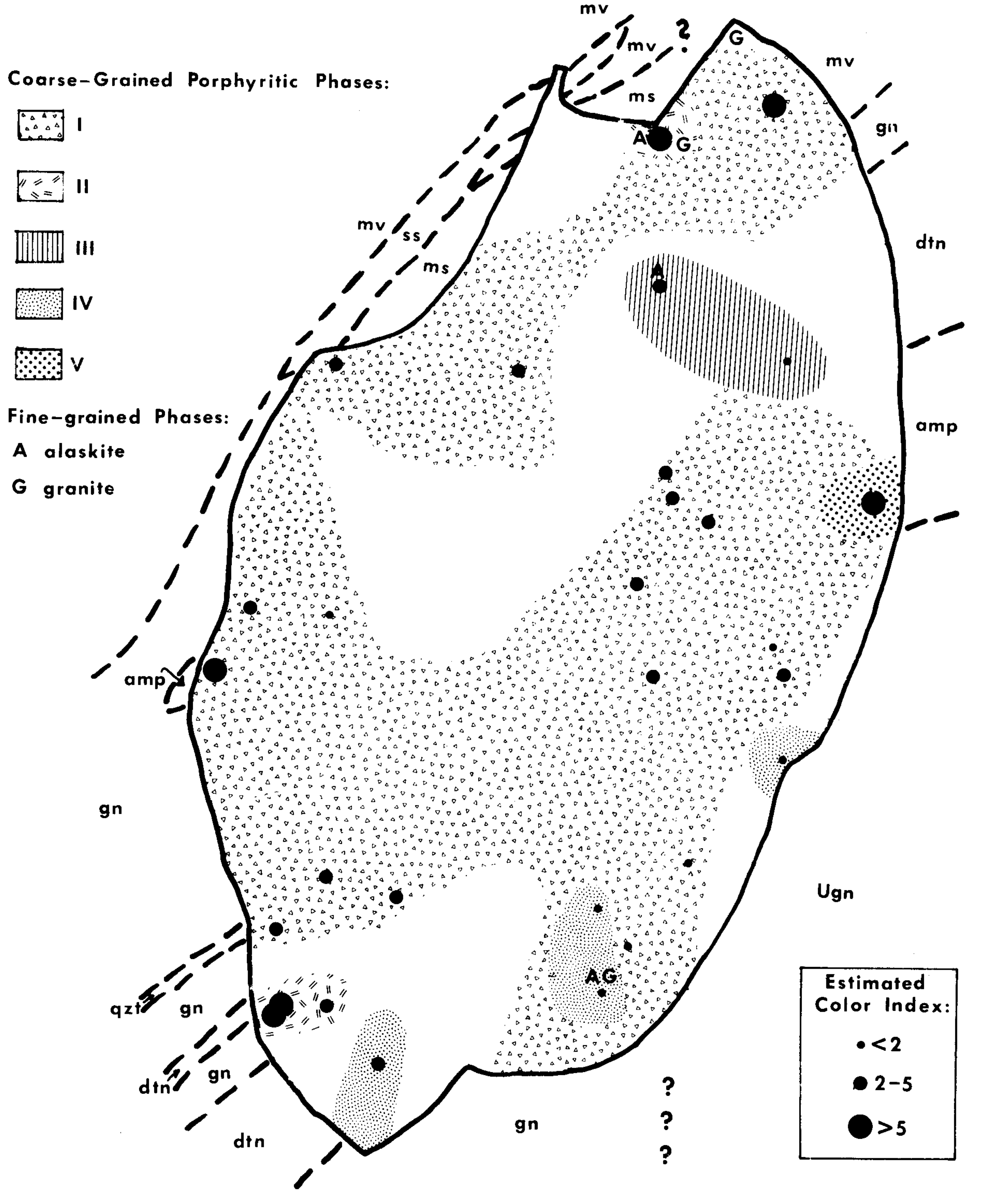

Figure 3. Distribution of petrographic variants (see text) in the Bald Rock granite. Sizes of circles indicate approximate color indices. No data are available from the unshaded areas. Country rock lithologies are: metavolcanics (mv), sillimanite schist (ss), muscovite schist (ms), amphibolite (amp), granitic gneiss (gn), meta-diorite and meta-tonalite (dtn), metaquartzite (qzt), undifferentiated gneisses (Ugn). Country rock units may differ slightly from those on Wagener and Price's (1975) map of the Wilkinsville quadrangle and Butler's (1966) map of York County. For orientation and geographic location, compare with Fig. 1.

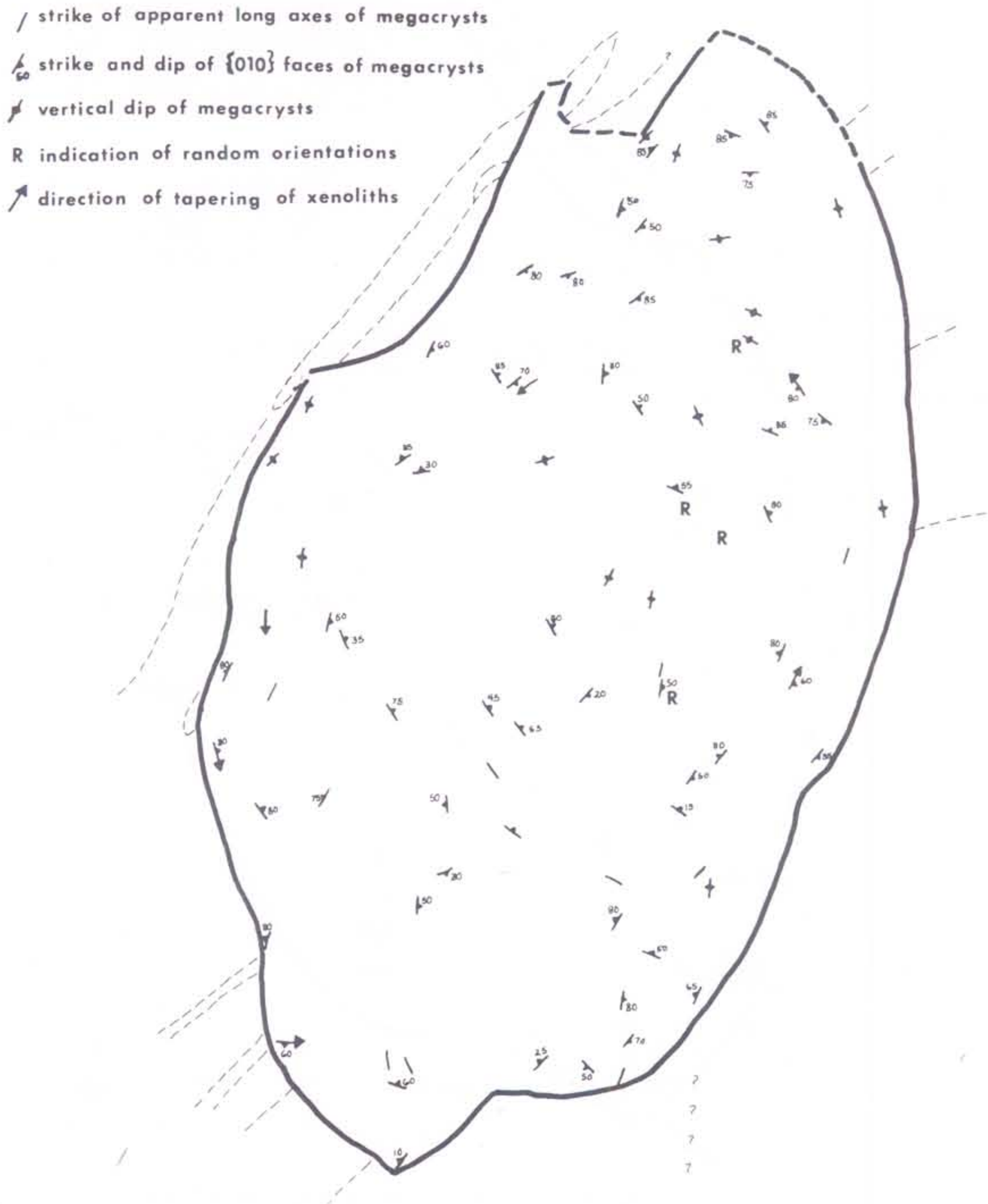

Figure 4. Internal fabric defined by tabular megacrysts and xenoliths in the Bald Rock batholith. Megacryst orientations in saprolite were measured in three dimensions, and apparent strikes of c axes were measured in pavement exposures. Each data point represents an average of several measurements. Strikes and directions of tapering of xenoliths were measured in pavements only. For orientation and geographic location, compare with Fig. 1.

Infolded quartzofeldspathic layers appear to be of metasedimentary origin, and not, as suggested by Wagener and Price (1975), the result of magmatic injection.

The Kings Mountain belt is generally thought to be of lower metamorphic grade (biotite or garnet) than adjacent belts (e.g. Hatcher, 1972). Sillimanite in the Kings Mountain belt schist units near the Bald Rock batholith certainly indicates a higher metamorphic grade, but could result from contact metamorphism. However, the sillimanite needles are oriented parallel to foliation, suggesting the possibility that these rocks may have experienced a more intense regional metamorphism. It therefore seems possible that the thermal peak of metamorphism may not have been the same in all areas of the Kings Mountain belt for any given metamorphic event, as suggested by Horton (1978). The Bald Rock granite has been dated at 388±3 m.y. (Kish et al., 1979), and is thus one of the earliest post-metamorphic granites now recognized in the Piedmont (Speer et al., 1980). If this age is correct, the regional metamorphism which preceded the intrusion may have been earlier in this area than in other parts of the Kings Mountain belt.

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Mineral age traverses across the Piedmont of South Carolina and North Carolina

Paul D. Fullagar and Stephen A. Kish, Department of Geology, University of North Carolina, Chapel Hill, NC 27514

INTRODUCTION

This paper presents new Rb-Sr radiometric age determinations for samples collected along three traverses in South Carolina and North Carolina (Fig. 1). These new ages are based on analyses of mineral plus whole-rock samples from plutonic rocks. Published mineral ages pertinent to our traverses are reviewed, including ages from several nuclear station site investigations.

Mineral ages provide information about the cooling history of a rock. Our data plus published ages, from several traverses which cross the different lithologic belts of the Piedmont, enable us to compare the cooling histories of these belts. Different cooling histories may imply different metamorphic histories, variations in timing of igneous activity, or differences in rates of uplift and erosion. Equally important, this study suggests several areas where more mineral ages are needed.

This study was supported in part by National Science Foundation Grant No. EAR7723227 and in part by funds from the South Carolina Geological Survey. Richard Tobiassen assisted with sample preparation and analysis; his careful help is much appreciated. J. R. Butler provided an unpublished map of southern Appalachian plutons that, with modifications, appears as Figure 1.

SIGNIFICANCE AND USE OF RB-SR AND K-AR MINERAL AGES

It is assumed that when a mineral crystallizes from a melt or recrystallizes during metamorphism, the radiogenic daughter products (^{87}Sr and ^{40}Ar) completely diffuse out of the mineral grain as long as it remains at high temperature. As a mineral cools, it reaches a temperature at which the daughter products accumulate and are not lost by diffusion. This temperature varies from mineral to mineral, and is called the blocking or closure temperature (Jäger, 1979; Dodson, 1973; Dodson, 1979). The following estimates are generally accepted for blocking temperatures (Jäger, 1979; Dodson, 1979):

Mineral	Daughter Product	Temperature, °C
Biotite	^{87}Sr, ^{40}Ar	300 ± 50
K-spar	^{87}Sr	325 ± 50
Muscovite	^{40}Ar	350 ± 50
Phlogopite	^{40}Ar	450 ± 50
Hornblende	^{40}Ar	525 ± 50

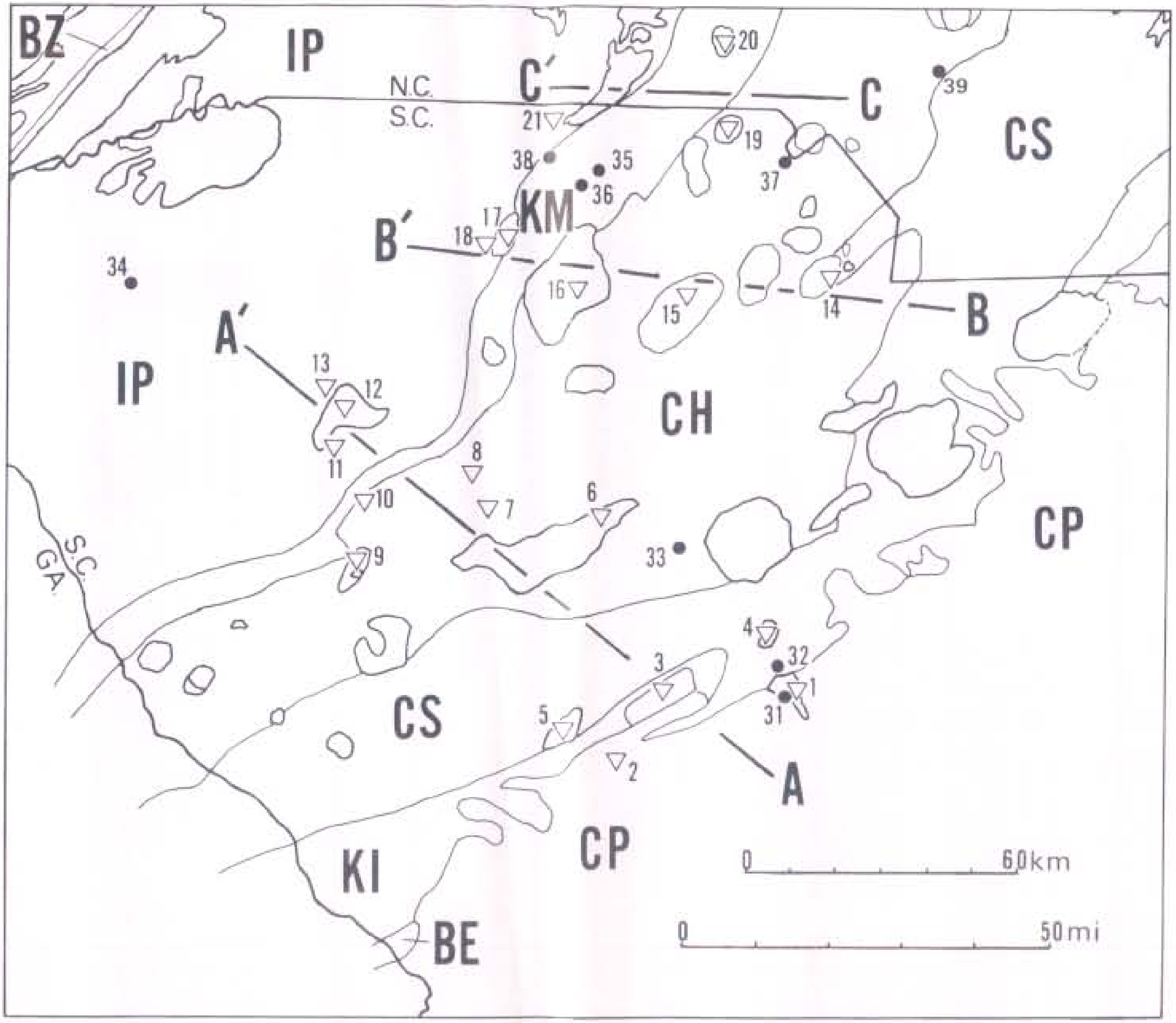

Figure 1. Generalized geologic map of the South Carolina Piedmont and adjacent North Carolina, showing the lithologic belts and major plutons. Symbols are: CP, Coastal Plain; BE, Belair belt; KI, Kiokee belt; CS, Carolina slate belt; CH, Charlotte belt; KM, Kings Mountain belt; IP, Inner Piedmont (and Chauga) belt; BZ, Brevard zone. Locations for new ages (1-2) are indicated by open triangles; locations for published ages are shown by solid dots (31-39); these location (sample) numbers are the same as used in Table 1, Table 2 and Figure 2.

Thus, a biotite with a Rb-Sr or K-Ar age of 400 m.y. would have cooled to 300 ± 50°C 400 m.y. ago. Of course, field and petrographic data should indicate whether attainment of the blocking temperature follows an igneous event or a metamorphic event.

From the metamorphic mineral assemblage, it may be possible to estimate the temperature and pressure conditions of metamorphism; if so, one can determine an average geothermal gradient. With this value, it is possible to estimate the depths at which different minerals (e.g., biotite and hornblende) of determined age reached their blocking temperatures. With several mineral ages from a sample of a metamorphic terrane, it sometimes is possible to calculate an average post-metamorphic uplift rate from their depth difference and age difference (Dallmeyer, 1975). Because of the necessary assumptions and uncertainties, these uplift rates are very approximate.

PUBLISHED MINERAL AGES

Table 1 summarizes all published mineral ages pertinent to this study. Where necessary, these ages have been recalculated using now universally adopted decay constants (Steiger and Jäger, 1977); all new ages (Table 2) also were calculated with these decay constants.

Sample locations for most of the published mineral ages are shown on Figure 1; latitudes and longitudes given in Table 1 are accurate to the extent possible from sample locations given in the published articles. Locations on Figure 1 for which ages have been published are labeled 31 to 39. (The actual published sample number is listed in Table 1 below the name of the sampled unit.) Samples and ages which need no discussion simply are listed in Table 1. Many of the samples analyzed from nuclear station sites were sheared (or produced by shearing) and showed significant evidence of post-crystallization disturbance; these ages were obtained to determine minimum ages for fault movement. These ages have no bearing on regional cooling history and are not included in Table 1. Table 1 does include several ages from the nuclear station site investigations for diabases and other rock units that also are not pertinent to the regional cooling history. These ages are listed simply to make them more readily available to interested geologists.

The biotite sample from the Columbia granite (no. 31) is described as being considerably altered to chlorite (Long and others, 1959). As this alteration would be expected to significantly lower the K-Ar age, the 235 ± 9 m.y. age is considered anomalously low and is not included in our summary diagram (Fig. 2) or subsequent discussion.

Location 33 is the Virgil C. Summer Nuclear Station site (Dames & Moore, 1974). Most of the ages from this location listed in Table 1 are for biotites separated from granodiorite; the 12 K-Ar and Rb-Sr ages listed are very consistent, ranging from 286 to 309 m.y. A K-Ar age of 47 ± 5 m.y. for laumontite crystals is considered to be a minimum age for fault movement at the Summer site. The K-Ar whole-rock age of 232 ± 14 m.y. for an aplite might suggest relatively young igneous activity; whole-rock K-Ar ages often are difficult to evaluate and this age is not included in our summary diagram (Fig. 2).

Table 1. Published Mineral Ages

No. on Fig. 1	Unit/Sample No.	Location	Material Analyzed	Method	Age, m.y.*	Reference	Comments
31	Columbia Granite L-124	Southwest Columbia (SC) 33°58'10"N, 81°02'53"E	Biotite	K-Ar	235 ± 9	Long, Kulp and Eckelmann (1959)	Much of biotite altered to chlorite, probably lowering age
32	Phyllite K-61M	Columbia North (SC) 34°03'42"N, 81°02'47"E	Muscovite	K-Ar	302 ± 10	Kulp and Eckelmann (1961)	Location from J. R. Butler (personal communication)
33	Virgil C. Summer Nuclear Station Granodiorite	Jenkinsville (SC)					
	SC2.1	34°17'51"N, 81°18'57"E	Biotite	Rb-Sr K-Ar	289 ± 15 297 ± 15	Dames & Moore (1974) "	Biotite separated from two portions of sample for Rb-Sr and K-Ar analyses
	SC2.3	" "	Biotite	Rb-Sr K-Ar	309 ± 15 294 ± 15	" "	" "
	SD3.3	" "	Biotite	Rb-Sr K-Ar	308 ± 15 303 ± 18	" "	" "
	NJ1.1	" "	Biotite	Rb-Sr K-Ar	293 ± 15 296 ± 17	" "	" "
	NK2.1	" "	Biotite-WR** Biotite	Rb-Sr K-Ar	286 ± 10 298 ± 17	" "	" "
	SC2.4	" "	Biotite-Chlorite and WR	Rb-Sr	293 ± 10	"	
	SH1	" "	Biotite	K-Ar	295 ± 17	"	
	Aplite SB2.2	" "	WR	K-Ar	232 ± 14	"	
	Laumontite crystals X1	" "	Laumontite	K-Ar	47 ± 5	"	Minimum age for fault movement
34	Granitic Gneiss K-728	Easley, SC	Biotite	K-Ar	295 ± 10	Kulp and Eckelmann (1961)	Specific location not given
35	Cherokee Nuclear Station Felsic Gneiss	Blacksburg South (SC)					
	B-51, 76 ft.	35°02'14"N, 81°30'47"E	Biotite	Rb-Sr	285 ± 10	Law Engineering Testing Company (1974)	
	B-64, 120 ft.	35°02'08"N, 81°30'47"E	Biotite	Rb-Sr	271 ± 10	"	
	BP-7, 59 ft.	35°01'52"N, 81°30'41"E	Biotite	K-Ar	302 ± 7	"	
	Mafic Gneiss B-28, 106 ft.	35°02'03"N, 81°30'52"E	Hornblende	K-Ar	296 ± 9	"	
	Pegmatite GTP7, Sta. 18	35°02'08"N, 81°30'41"E	K-spar	K-Ar	225 ± 1	"	Pegmatite is undisturbed and crosses shear zone
36	Felsic Gneiss S2A	Blacksburg South (SC) 35°00'16"N, 81°33'10"E	Muscovite	K-Ar	299 ± 9	"	
—	Diabase Dike 70	Kings Creek (SC) 35°03'12"N, 81°26'57"E	WR	K-Ar	236 ± 10	"	Location not shown on Fig. 1
—	Lanford Mine Diabase Dike	Ora (SC) 34°37'03"N, 81°54'06"E	WR	K-Ar	191 ± 7	"	" "
	Diabase	" "	WR	K-Ar	186 ± 6	"	" "
	*Mylonite	" "	WR	K-Ar	154 ± 4	"	" "
	Mylonite	" "	WR	K-Ar	154 ± 4	"	" "
—	Diabase Dike X81A-16A	Concord (NC) 35°28'45"N, 80°30'05"E	WR WR	K-Ar K-Ar	259 ± 10 243 ± 30	" "	Cuts shear zone near Gold Hill fault; location not shown on Fig. 1.
37	Catawba Nuclear Station Laumontite	Lake Wylie (SC)					
	Z3-B1, 89.4-91.0 ft.	35°03'04"N, 81°04'09"E	Laumontite	K-Ar	68 ± 30	Law Engineering Testing Company (1976)	Hydrothermal mineral in relatively late fractures
	Amphibolite A-7?, 55.0-55.5 ft.	" "	Biotite Hornblende	K-Ar K-Ar	306 ± 5 322 ± 9	" "	Mineral-WR isochron, 306 ± 10 m.y.
	Amphibolite A-32, 88.0-88.4 ft.	" "	Hornblende WR	K-Ar K-Ar	316 ± 12 307 ± 7	" "	"
	Adamellite A-32, 125.8-125.1 ft.	" "	Biotite	K-Ar	328 ± 8	"	Biotite-WR isochron age of 300 m.y.
	Adamellite Z3-B1, 101.2-105.2	" "	Zircon	U-Pb	532 ± 15	"	Concordia age; 2 zircon splits analyzed
—	Diabase Dike X81A-19A	Gold Hill (NC) 35°34'30"N, 80°17'30"E	WR WR	K-Ar K-Ar	237 ± 10 233 ± 10	" "	Cuts Gold Hill fault; location not shown on Fig. 1
38	Gaffney Marble L-120P	Gaffney (SC) 35°03'13"N, 81°38'54"E	Phlogopite	K-Ar	321 ± 11	Long, Kulp and Eckelmann (1959)	
39	Granite Drill hole 11	Concord SE Quad (NC) 35°17'27"N, 80°33'12"E	Biotite	K-Ar	396 ± 12	Worthington and Lutz (1975)	Analytical data not given
	Drill hole 14	35°16'42"N, 80°33'02"E	Biotite	K-Ar	425 ± 15	"	"

* Ages recalculated where necessary using recommended decay constants (Steiger and Jäger, 1977).

** WR = whole- or total-rock sample.

Table 2. New Rb-Sr Mineral Ages

No. on Fig. 1	Unit/Sample	$(^{87}Sr/^{86}Sr)_N$	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	Mineral and Whole-Rock Age, m.y.	Quadrangle, Latitude and Longitude	Rb-Sr Whole-Rock of Unit, m.y.
1	Columbia Granite					271 ± 3	Southwest Columbia (SC) 33°58'15"N, 81°02'15"E	285 ± 7*
	1767 Bio	1.5927	1061.3	14.55	229.3			
	1767 WR	0.7604	311.1	66.60	13.60			
2	Foliated Granite, Lexington County					274 ± 3	Gilbert (SC) 33°51'55"N, 81°28'03"E	—
	1998 Bio	1.9556	930.9	9.42	320.7			
	1998 WR	0.7158	195.2	197.5	2.86			
3	Lexington Granite					296 ± 3	Lake Murray West (SC) 34°00'42"N, 81°23'23"E	292 ± 15*
	1746 Bio	1.3178	751.3	15.83	145.5			
	1746 WR	0.7095	163.8	408.7	1.16			
4	Harbison Granite					309 ± 3	Irmo (SC) 34°07'18"N, 81°08'02"E	—
	1890 Bio	1.2241	647.6	16.64	118.3			
	1890 WR	0.7063	141.1	806.7	0.51			
5	Clouds Creek Pluton Bio, WR, Plag	(see Fullagar and Butler, 1979)				313 ± 3	Batesburg (SC) 33°56'48"N, 81°36'12"E	319 ± 27*
6	Newberry Granite					284 ± 3	Newberry East (SC) 34°22'21"N, 81°31'50"E	415 ± 9**
	2000 Bio	0.8254	838.4	82.45	29.76			
	2000 WR	0.7126	193.9	329.4	1.70			
7	Granite, Newberry Co.					255 ± 3	Newberry NW (SC) 34°24'43"N, 81°43'07"E	—
	2011 Bio	0.9403	521.6	23.97	64.40			
	2011 WR	0.7093	120.1	454.3	0.77			
8	Granite, Laurens Co.					249 ± 3	Joanna (SC) 34°28'44"N, 81°47'20"E	—
	2012 Bio	1.1121	772.0	20.25	114.7			
	2012 WR	0.7135	140.5	211.8	1.92			
9	Coronaca Syenite Bio, WR, Plag	(see Fullagar and Butler, 1979)				278 ± 3	Waterloo (SC) 34°15'21"N, 82°05'32"E	—
10	Cold Point Granite					269 ± 3	Laurens South (SC) 34°25'12"N, 82°02'44"E	—
	2014 Bio	1.2202	928.4	20.85	135.3			
	2014 WR	0.7120	179.4	224.7	2.31			
11	Rabon Creek Granite					265 ± 3	Fountain Inn (SC) 34°32'24"N, 82°08'47"E	—
	2015 Bio	1.6412	1060.6	13.62	246.0			
	2015 WR	0.7382	221.3	98.14	6.54			
12	Gray Court Granite					280 ± 3	Fountain Inn (SC) 34°37'37"N, 82°06'17"E	378 ± 24**
	1327 Bio	2.0705	1022.9	9.79	342.6			
	1327 WR	0.7218	194.2	162.1	3.47			
13	Reedy River Pluton					254 ± 3	Fountain Inn (SC) 34°41'11"N, 82°09'12"E	—
	2016 Bio	1.2110	633.2	13.86	138.7			
	2016 WR	0.7150	117.1	213.7	1.59			
14	Edgemoor Granite					314 ± 6	Catawba (SC) 34°49'29"N, 80°58'04"E	535 ± 30***
	777 K-spar	0.7992	353.5	60.82	16.97			
	777 WR	0.7491	122	61.8	5.75			
15	Lowrys Granite					330 ± 3	Armenia (SC) 34°49'43"N, 81°16'27"E	399 ± 4***
	789 Bio	4.7294	1467	6.92	855.1			
	789 WR	0.7501	214.9	70.29	8.88			
16	Bald Rock Granite					388 ± 5	Kelton (SC) 34°46'17"N, 81°33'18"E	—
	1575 Bio	0.7802	468.3	99.24	13.76			
	1575 WR	0.7082	155.6	676.6	0.67			
	1575 Plag	0.7058	104.5	973.0	0.31			
17	Pacolet Mills Granite					284 ± 3	Pacolet Mills (SC) 34°55'20"N, 81°44'46"E	415 ± 40**
	2019 Bio	0.8110	770.2	87.87	25.62			
	2019 WR	0.7131	163.8	353.8	1.34			
18	Gneiss, Spartanburg Co.					279 ± 3	Spartanburg (SC) 34°54'50"N, 81°46'56"E	—
	2018 Bio	1.2404	1183.7	26.80	134.5			
	2018 WR	0.7111	267.7	592.9	1.31			
19	Clover Granite					306 ± 4	Gastonia South (NC-SC) 35°07'55"N, 81°11'47"E	—
	1368 Bio	0.8058	760.4	95.31	23.30			
	1368 WR	0.7067	154.4	760.8	0.59			
20	Gastonia Granite					299 ± 3	Gastonia North (NC) 35°17'59"N, 81°11'30"E	—
	1843 Bio	1.1554	928.4	26.44	106.0			
	1843 WR	0.7069	157.3	630.7	0.72			
21	Gneiss, Cherokee Co.					242 ± 3	Blacksburg North (NC-SC) 35°08'24"N, 81°36'18"E	—
	2030 Bio	1.2565	553.3	10.60	159.1			
	2030 WR	0.7138	150.5	320.1	1.36			

* Fullagar and Butler (1979)

** Fullagar (unpublished data)

*** Fullagar (1971)

The Cherokee Nuclear Station site is designated location 35 (Fig. 1; Table 1). Ages from the report by Law Engineering Testing Company (1974) for four biotites and a hornblende separated from gneisses are fairly consistent, 271 to 302 m.y. (The samples showing shearing and slickensides generally have ages of 170 to 280 m.y.) K-feldspar from a pegmatite which is undisturbed and cuts a shear zone has a K-Ar age of 225 ± 1 m.y. K-feldspar ordinarily loses ^{40}Ar very easily. This might account for the relatively young age; on the other hand, the pegmatite may be relatively young. Because of difficulty of interpretation, this age is not included in our summary diagram (Fig. 2) or discussion.

The Catawba Nuclear Station site is location 37 on Figure 1 and Table 1. The Law Engineering Testing Company (1976) report on this site lists K-Ar ages of 306 to 328 m.y. for biotites and hornblendes separated from amphibolite and adamellite (Table 1). However, the report notes that evaluation of the data on an isochron diagram indicates that all samples actually have ages of about 306 ± 10 m.y. The 532 ± 15 m.y. zircon age is considered to be the time of crystallization of the host adamellite. Laumontite in relatively late fractures has a minimum age of 88 ± 30 m.y.; this was interpreted as a minimum age for the formation of the fractures.

Location 39 (Fig. 1) is in granite at the Newell copper-molybdenum prospect (Worthington and Lutz, 1975). Biotite was separated from granites from two cores; K-Ar ages of 396 ± 12 and 425 ± 15 m.y. were obtained (Table 1). It is difficult to evaluate these ages as no analytical results are given. For this reason, these ages are not plotted in our summary diagram (Fig. 2).

NEW MINERAL AGES

Table 2 lists Rb-Sr data, ages and locations for whole samples and their mineral separates from 21 different plutons. Numbers 1 to 21 also are used on Figure 1 to indicate sample locations. Data and ages were obtained using standard isotope dilution and mass spectrometry techniques (see Fullagar, 1971; Fullagar and Butler, 1979). Data for samples from locations 5 and 9 have been published (Fullagar and Butler, 1979) but are included in Table 2 as these samples were originally selected as part of our A-A´ traverse. If the time of crystallization (Rb-Sr whole-rock age) of a pluton is known, it also is listed in Table 2. A brief description of most of the plutons listed in Table 2 is given by Wagener (1977). Based on reconnaissance studies, the plutons at locations 1, 2, 3, 7, 12, 13, 17, 18 and 21 are deformed as evidenced by a distinct foliation, and thus these plutons are considered to be metamorphosed. The Edgemoor granite (location 14) exhibits no obvious foliation, but its mineralogy suggests that it also has been metamorphosed (Fullagar, 1971). The other sampled plutons (locations 4, 5, 6, 8, 9, 10, 11, 15, 16, 19 and 20) lack deformation and thus are, or at least appear to be, post-metamorphic.

TRAVERSES

Three traverses (A-A´, B-B´, C-C´) are shown in Figure 1. The sample and location numbers in Figure 1 (1-21; 31-39) correspond to those in Tables 1 and 2. The ages for these samples are plotted in Figure 2, which shows how the mineral ages vary along the traverses. (Where necessary, ages were projected parallel

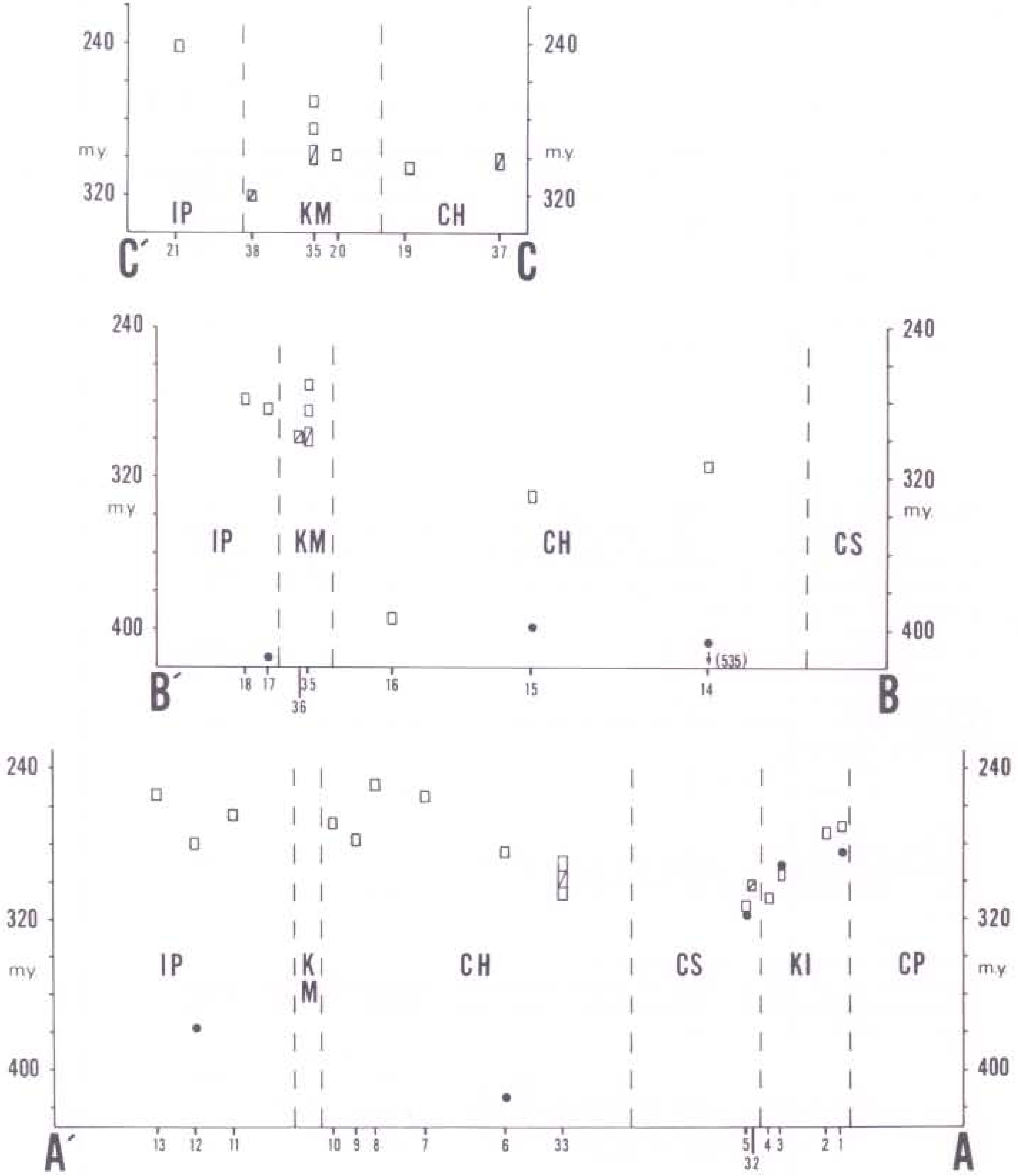

Figure 2. Plot of sample location versus mineral age. A-A', B-B', and C-C' correspond to the traverses on Figure 1. Numbers along the x-axis are the sample location numbers used in Figure 1 and Tables 1 and 2. CP, KI, CS, CH, KM and IP represent the lithologic belts of the Piedmont (see caption for Fig. 1). Open boxes represent Rb-Sr mineral ages; boxes with diagonal line represent K-Ar mineral ages. Solid dots represent Rb-Sr whole-rock ages.

to regional strike until they intersected the closest traverse.) Location 35, the Cherokee Nuclear Station site, is half-way between traverses B-B´ and C-C´; ages from samples at this site were plotted on both B-B´ and C-C´ in Figure 2.

Analytical uncertainties (1 σ) for the new Rb-Sr mineral ages are approximately ± 1 percent, or about the size of the rectangle used in Figure 2 to represent the ages. The analytical uncertainties vary for the published mineral ages, but generally are ± 2 to 5 percent; these uncertainties are not indicated on Figure 2. Rb-Sr whole-rock ages (solid dots, Fig. 2) have variable analytical uncertainties; these are given in Table 2.

For the nuclear station sites (locations 33, 35, 37), several minerals give identical or nearly identical results (Table 1); these replicate ages are not indicated in Figure 2, but are readily available in Table 1.

DISCUSSION

First, it must be noted that more mineral (and whole-rock) ages are needed, especially along traverses B-B´ and C-C´. Most of the mineral ages available are for biotites; more ages for hornblendes and other minerals could make it possible to estimate average rates of uplift. Because we lack adequate age data on different minerals from the same rock sample, we will not attempt to calculate uplift rates.

Figure 2 shows that the youngest mineral ages (240 to 260 m.y.) are found in the western Piedmont, and the ages generally are older (~ 300 m.y.) in the eastern Piedmont. This pattern probably indicates that the western Piedmont was uplifted, eroded and cooled more recently than most if not all of the eastern Piedmont.

More mineral ages are available for traverse A-A´ (Fig. 2) than for the other two traverses. These ages consistently increase from the Inner Piedmont to the eastern edge of the Carolina slate belt. In the Kiokee belt, the ages decrease from about 310 to 270 m.y., going west to east. The mineral and Rb-Sr whole-rock ages in the Kiokee belt and adjacent Carolina slate belt are identical within analytical uncertainties. This agreement in age shows that this area cooled rapidly following igneous crystallization and metamorphic recrystallization. The Kiokee belt is unusual compared to the rest of the Piedmont as it is an area of significant Hercynian deformation and metamorphism (Fullagar and Butler, 1979; Snoke and others, 1980). The Rb-Sr whole-rock data (Fullagar and Butler, 1979) for the Coronaca syenite (location 9, Fig. 1) suggest an age of about 300 m.y., essentially the same as the 278 m.y. mineral age (Table 2). If this suggestion is correct, at least portions of the Charlotte belt also may have cooled rapidly following crystallization.

Traverse B-B´ (Fig. 2) shows the same general pattern as A-A´, but many more ages are needed, especially in the Charlotte belt. The virtually identical biotite, muscovite and hornblende ages for the Kings Mountain belt indicate rapid cooling as these minerals have different blocking temperatures. The mineral age for the Bald Rock granite (location 16) is 388 ± 5 m.y., indicating the pluton cooled below 300 ± 50°C at that time. This date is anomalously old in comparison to the rest of the traverses where the blocking temperature was reached 240 to 330 m.y. ago. Clearly, it would be interesting to have additional mineral ages from the Charlotte belt along traverse B-B´

The northernmost traverse, C-C´ (Fig. 2), is similar to the other two. The pattern of mineral ages becoming older to the east would be even more striking if the approximately 400 m.y.-old K-Ar biotite ages (Table 1) from the eastern Charlotte belt (location 39, Fig. 1) had been included. The phlogopite sample from the Gaffney Marble (location 38) is somewhat too old for the general age pattern, but this could reflect the relatively high blocking temperature for this mineral. The Clover granite (location 19) is spatially and probably temporally related to the York granite. The Rb-Sr whole-rock age of 322 ± 6 m.y. for the York granite (Fullagar and Butler, 1979) and the biotite age of 306 ± 4 m.y. for the Clover granite (Table 2) suggest rapid cooling of this part of the Charlotte belt subsequent to crystallization; the identical hornblende and biotite ages from location 37 lead to the same conclusion.

CONCLUSIONS

1. Mineral ages are approximately 240 m.y. in the western Piedmont, and except in the Kiokee belt, increase to about 300 m.y. to the east; the sampled rocks have not been at temperatures higher than 300 ± 50°C since these times.

2. The mineral age patterns show several anomalies:
   a) Minerals from the Kiokee belt rocks become younger toward the east.
   b) In the Charlotte belt, several mineral ages (Bald Rock, granite at Newell prospect) are approximately 400 m.y.

3. Rapid cooling of much of the Piedmont is indicated by the same rock unit having essentially identical hornblende and mica ages, or nearly identical mica and Rb-Sr whole-rock ages.

4. Additional ages are needed.

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The Lowndesville belt north of the South Carolina-Georgia border

Villard S. Griffin, Jr., Department of Chemistry and Geology, Clemson University, Clemson, South Carolina 29631

INTRODUCTION

The cataclastic/mylonitic Lowndesville belt occurs north of the Georgia - South Carolina border as a narrow belt running east-northeastward through northern Abbeville and Greenwood Counties (Fig. 1). In this area of low rolling mature topography, the Lowndesville belt is expressed by a vague ridge system, most pronounced toward the Savannah River near the Georgia - South Carolina border.

The higher grade amphibolite facies migmatitic Inner Piedmont belt lies adjacent to the Lowndesville belt on the northwest and the somewhat lower grade Charlotte belt (low amphibolite to greenschist facies) lies to the immediate southeast (Fig. 1). Lying approximately two to five km southeast of the Lowndesville belt in the Charlotte belt is a narrower cataclastic/mylonitic zone less than one km wide (Fig. 1), which has been named the Cold Spring cataclastic zone (Griffin, 1978, 1979). The cataclastic and mylonitic rocks in this zone are similar to those within the Lowndesville belt.

The Lowndesville belt most likely is the southwestward extension of the Kings Mountain belt of King (1955) and Overstreet and Bell (1965a, 1965b) and a possible extension of the Appomattox line of Jonas (1932); refer to Griffin (1970, 1971, 1978). On the other hand, it has been argued that the Lowndesville belt may as likely be an extension of sericitic rocks lying farther northeastward in the Carolina slate belt (Kesler, 1972). However, strong arguments remain for continuity of the Lowndesville belt with the Kings Mountain belt (Griffin, 1972, 1977; Horton, 1981). The greatest probability of connection is that both belts coincide with the sharply defined southeastern boundary of the Inner Piedmont belt throughout South Carolina. This major boundary continues southwestward as a narrow cataclastic/mylonitic zone throughout Georgia and most likely into Alabama (Griffin, 1970, 1971, 1978; Whitney and others, 1978; Bentley and Neathery, 1970).

The reason for preparing this paper is to provide a summary of a 1:24,000 scale mapping study carried out by the author and his undergraduate students in this area since 1969, which has recently culminated in a detailed map report (Griffin, 1979). These summarized results add information on the

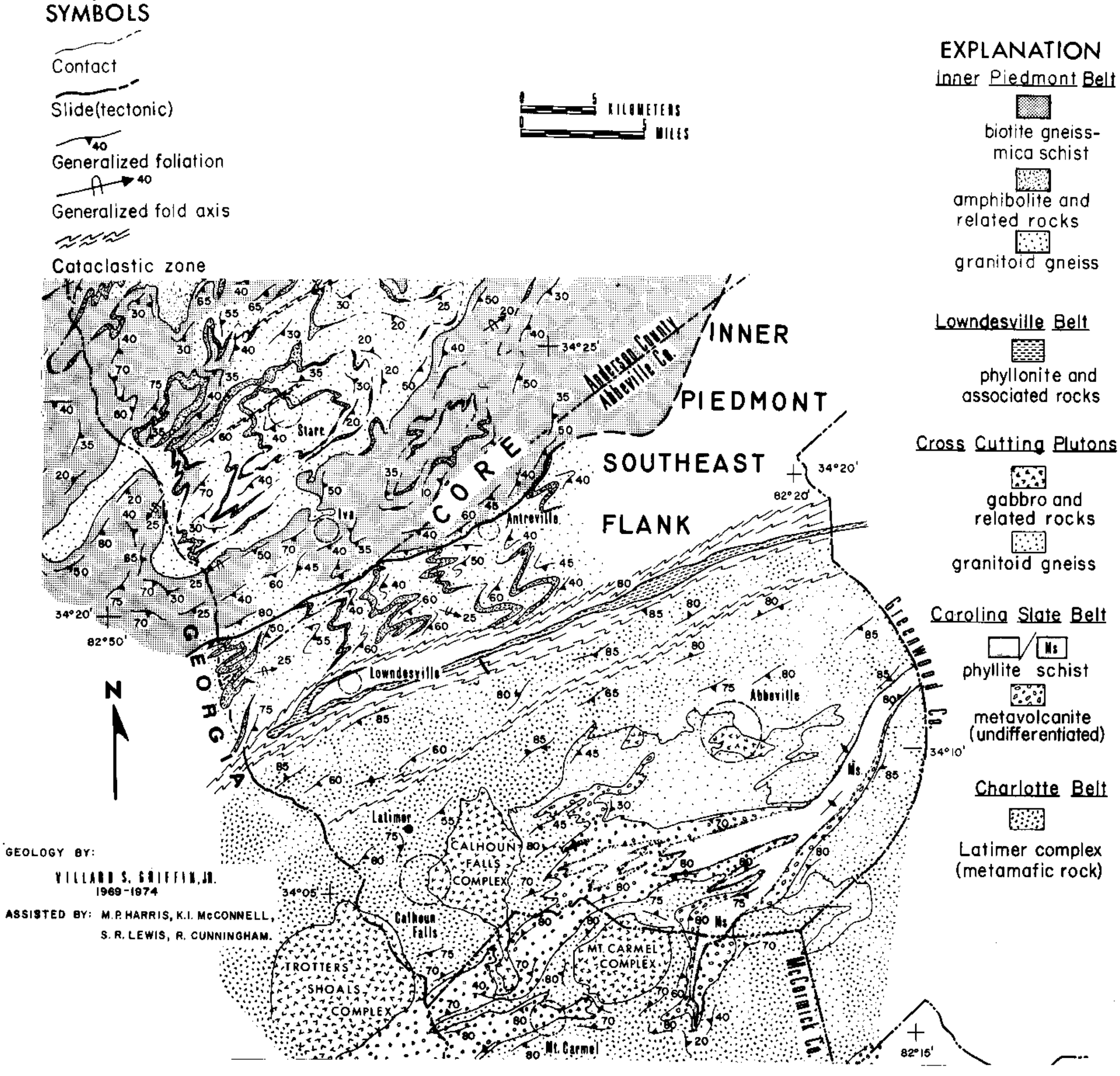

Figure 1. Geologic map of the Lowndesville belt northeast of the South Carolina Georgia border (modified from Griffin, 1978, Figs. 3a and 3b).

likely extension of the Kings Mountain belt from the area of this weekend's field trip southwestward toward the Georgia state line. I thank Arthur Maybin, Arthur Nelson and Paul Nystrom for critically reviewing this paper and providing numerous helpful suggestions for which I am most grateful. This research has been supported by the Earth Sciences Section of the National Science Foundation (grants GA-16164 and GA-16164 A#1) and the South Carolina Geological Survey.

BELT CHARACTERISTICS

General traits

The 2 to 4 km wide Lowndesville belt passes through the hamlet of Lowndesville, South Carolina (Fig. 1). It narrows to less than 2 km in width at the Savannah River and continues southwestward into Georgia as a cataclastic (mylonitic) zone (Griffin, 1970; Whitney and others, 1978). To the northeast, the Lowndesville belt maintains a width of about four km or more as it passes from Lowndesville across Abbeville County into Greenwood County. In eastern Greenwood County and in western Laurens County the cataclastic/mylonitic characteristics are less discernible as local migmatization takes hold through the appearance of granitoid neosome (mobilizate), and a general coarsening in grain size of the rock types is noticeable.

Rock types

The common rock type exposed in the belt between the Georgia border and the Greenwood - Laurens County line is a muscovite (sericite) quartz phyllonite. This rock is readily distinguishable from similar looking muscovite-sillimanite-quartz schist in the nearby Inner Piedmont core and quartz-sericite phyllite in the nearby Carolina slate belt by a well-developed fluxion structure. This cataclastic foliation (in the sense of Higgins, 1971) yields "button" or "fish-scale" clots of mica upon weathering into soil. In thin section the phyllonite consists of quartz, muscovite/sericite, and minor quantities of opaques, including hematite which is probably a weathering product. The textures are generally granoblastic with attenuated fold closures and muscovite/sericite clots isolated by a wavy intersection of two or more foliations yielding a fluxion texture similar to that described in the Brevard zone beyond the northwestern side of the Inner Piedmont belt (Roper, 1972).

Quartzite is intimately associated with the phyllonite, and it appears to be compositionally gradational with the micaceous unit along strike. Layers of quartzite about 0.3 m or more thick occur in the area near the Savannah River at the fold closure of the phyllonite formation (Fig. 1). These layers may represent relic sedimentary bedding surfaces.

Mafic rocks also occur within the Lowndesville belt. The most abundant is a fine grained amphibolite or amphibole schist which is found at various places in the belt. This amphibolite is finer grained and more schistose than amphibolites occurring in either the adjacent Inner Piedmont or Charlotte belts. Additional mafic rock types were found in only a few locations. These are a sheared metagabbro found on the northwestern side of the belt about 3.2 km southwest of Lowndesville and meta-basalt similar to massive greenstones occurring in the Charlotte belt to the southeast. The exact relationships of these latter two rock types to mafic rocks in adjacent belts is uncertain at present.

A manganiferous, and possibly graphitic, biotite schist is either tectonically or stratigraphically interspersed among other rock types, especially within the phyllonite unit east of Lowndesville. The grain size is medium to fine and the foliation is well-developed. This rock was definitely recognized in only a few exceptional road cut exposures.

At least four exposures of ultramafic rocks occur in and around Lowndesville. The rocks look similar to others occurring nearby in the adjacent belts, and they are composed of talc and chlorite with minor serpentine. A well-developed schistosity characterizes these rocks.

All of the above rocks have been subjected to varying degrees of cataclasis. However, blastomylonites and some mylonitic rocks are best developed at both margins of the Lowndesville belt. These may be described as melanocratic feldspar augen blastomylonite and leucocratic blastomylonite. In thin section most specimens show some degree of unrelieved strain in their textures, but recrystallization seems to predominate. Post-deformational (or possibly late synkinematic) recrystallized textures include strain-free quartz, with straight polygonal contacts between mineral grains. Microbreccia ("flinty crush-rock") occurs as steeply dipping dike-like exposures throughout the belt. These late polydeformational zones represent episodes of brittle fracturing post-dating the major cataclastic movements along the Lowndesville belt, and are like those reported by Snipes and Birkhead (1974) and Snipes and others (1979).

STRUCTURAL CHARACTERISTICS

In map pattern, where the Lowndesville belt narrows in bottle-neck fashion at the South Carolina - Georgia border the phyllonite/quartzite in this portion of the belt closes in a fold, with compositional layers swinging around the closure and dipping northeastward (Fig. 1). The phyllonite/quartzite crops out over a wider area here but thins where it extends northeastward as two zones. The southeastern phyllonite zone continues across Abbeville County and extends through Greenwood County where it coarsens in grain size, becoming a muscovite schist in Laurens County, probably in response to an increase in metamorphic grade. The northwestern phyllonite zone narrows and pinches out just north-northeast of Lowndesville.

Only a few lineations were observed in the Lowndesville area, and these are stretching lineations produced by elongated sericite/muscovite. The bearing and plunge of these lineations are generally northeastward, with plunges of approximately 40°. The cumulative foliation pole diagram (Fig. 2) is a partial great circle girdle, indicating both shallow as well as steep dips of compositional layering and schistosity/fluxion foliation. Steep dips, however, predominate, except near the axis of the belt in the

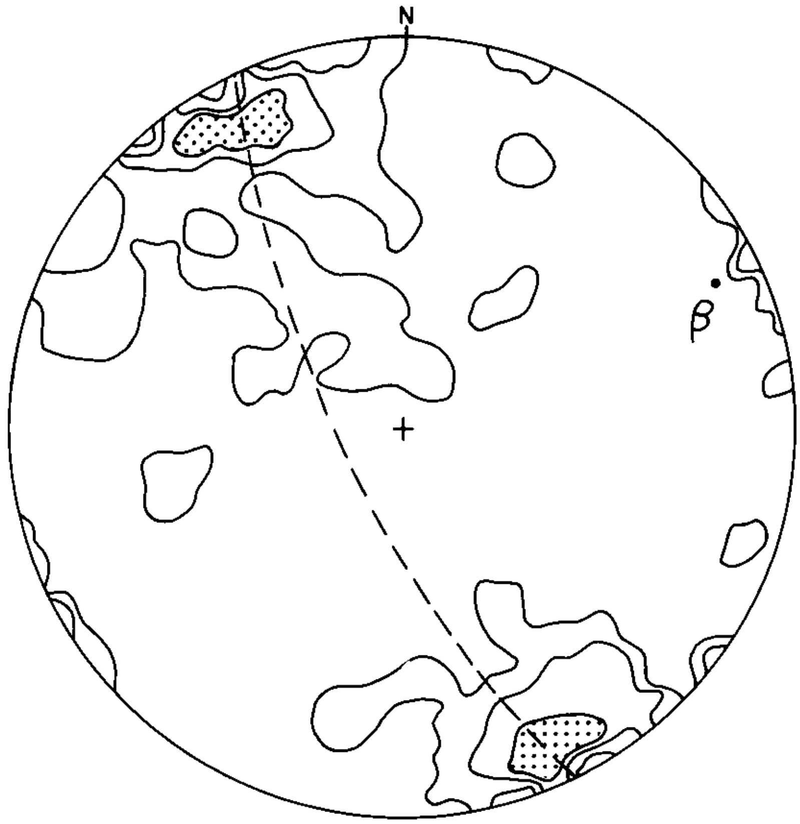

Figure 2. Cumulative π - diagram of all foliation and compositional layering poles from the Lowndesville belt in the vicinity of the type area (from Griffin, 1979, Fig. 34).

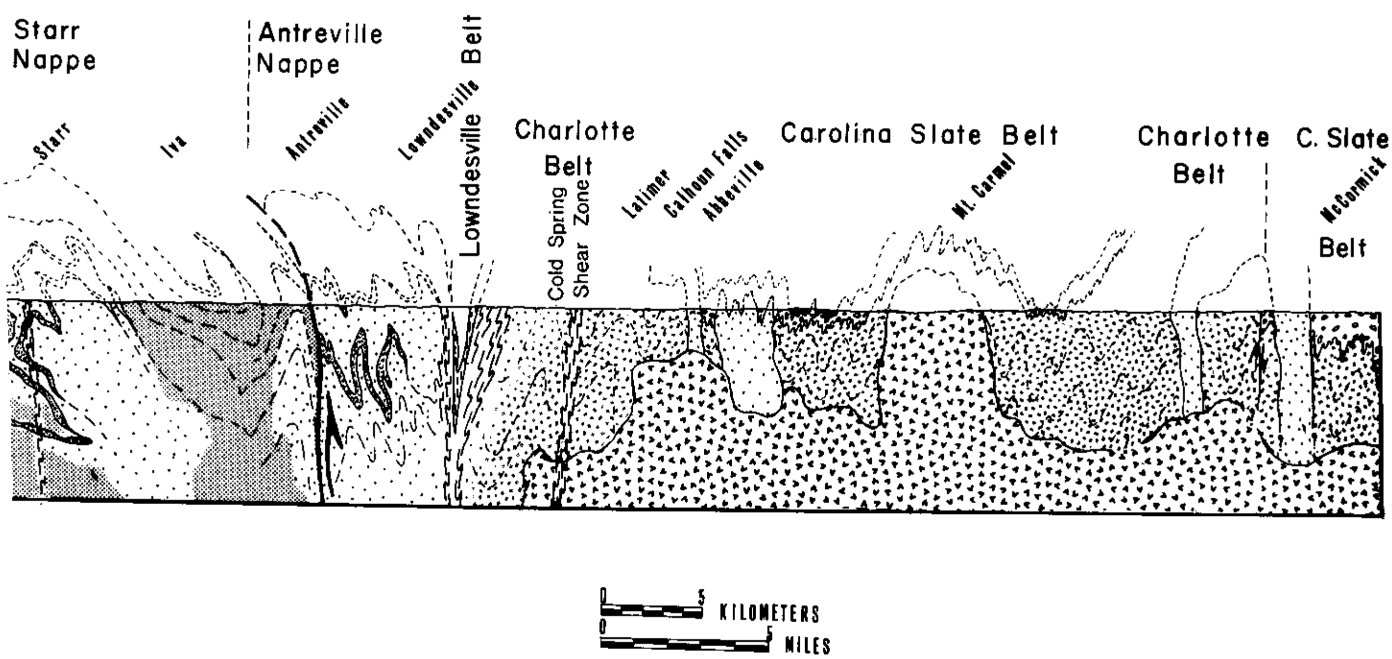

Figure 3. Cross section through the Lowndesville belt and adjacent belts shown in Figure 1 (modified from Griffin, 1978, Fig. 4) Refer to Fig. 1 for symbols.

Lowndesville area, and to the southwest at the quartzite/phyllonite fold closure in the vicinity of the Savannah River. A steep crenulation cleavage cuts the gently dipping foliation east of Lowndesville in a talc schist outcrop at the axis of the belt.

The above observations concerning the map pattern, outcrop data and π - diagram lead me to conclude that the Lowndesville belt is a deep, tightly folded synformal structure (Fig. 3), plunging toward the northeast. The cataclastic/mylonitic deformation has narrowed the belt considerably, perhaps as much through a flattening process as through a smearing process, and most likely has extensively deepened the axial keel. Probably the northwestern phyllonite zone, which is attenuated east of Lowndesville, represents a limb sheared away on the infrastructural Inner Piedmont belt side. An alternate interpretation would be that this attenuated northwestern zone is actually the original closure or nose which has been refolded by right-lateral strike slip motion between the Inner Piedmont and Charlotte belts. I do not favor this alternate hypothesis, however, because I have found no particular minor structures, such as cleavages, lineations, minor faults or en echelon drag folds which should unambiguously have accompanied a deformation plan of this type.

STRATIGRAPHY

Stratigraphic relationships within the Lowndesville belt have been obscured by the intense cataclasis to which the rocks have been subjected. At present, it has not been possible to clearly distinguish between tectonic interleaving of various rock types and original stratigraphic interlayering because of the extensive transposition of various s-surfaces. Nevertheless, the phyllonite, because of similarities in mineral composition, and thus in chemical composition may be stratigraphically correlative with aluminous and siliceous quartz muscovite sillimanite schist, and quartz sericite phyllite of the Inner Piedmont and nearby Carolina slate belt. Were such a stratigraphic correlation valid, it would likely be that this portion of the Piedmont had been a coherent tectonic/stratigraphic framework since at least early Paleozoic times (see Griffin, 1978, 1979).

REGIONAL AND TECTONIC IMPLICATIONS

The Lowndesville belt occupies a narrow zone between the infrastructural Inner Piedmont belt and the more massive Charlotte belt in this area (Griffin, 1978, 1979). It is the major tectonic boundary in this area, and the nature of the belt reflects directly on the tectonic history of the adjacent belts which comprise most of the southeastern Piedmont. The likely continuation of this tectonic boundary both northeastward, and southwestward, where many significant traits similar to those of the Lowndesville belt exist, indicates the belt is a segment of an extensive cataclastic - tectonic zone that occurs along the southeastern edge of the Inner Piedmont from Alabama to northern North Carolina. Consequently, at least some of the major geologic processes described as having operated in the Kings Mountain shear zone (Horton, 1981) and in the Middleton - Lowndesville cataclastic zone of Georgia (Whitney and others, 1978) may likely apply to the Lowndesville belt in the type area, and vice versa.

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The Middleton-Lowndesville cataclastic zone in the Elberton East quadrangle, Georgia

R.W. Rozen, Group Seven, Inc., 777 S. Wadsworth Blvd., Lakewood, CO 80226

INTRODUCTION

The Kings Mountain belt is a linear belt of metamorphosed sedimentary and igneous rocks in the Carolinas that separates the Inner Piedmont belt from the Charlotte belt. Within the Kings Mountain belt are occurrences of faulting and cataclasis that have been noted by previous authors (Keith and Sterrett, 1931; Griffin, 1970; Horton, 1981). In the vicinity of Elberton, in northeastern Georgia (Fig. 1) the metasedimentary rocks associated with the Kings Mountain belt in Abbeville County, South Carolina, are not present, apparently pinching out near the Savannah River (Overstreet and Bell, 1965; Price, 1969; Griffin, 1972). The cataclastic rocks associated with the Kings Mountain belt in Abbeville County (referred to as the Lowndesville zone by V.S. Griffin, 1972) continue into Georgia as a narrow zone of intense cataclasis separating the Inner Piedmont from the Charlotte belt. Because the lithologies change between Lowndesville, S.C. and Elberton, Ga. the zone was originally referred to as the Middleton cataclastic zone (Rozen, 1978). Later work by Davis (1980), Whitney and Stormer (1980), Whitney, Wells, and Rozen (1980), showed this zone to be continuous between Lowndesville, S.C. and Madison, Ga. and indicated that this zone most probably connects with the Towaliga fault zone in west central Georgia. Within the Elberton, Georgia area the Middleton-Lowndesville cataclastic zone averages 600 meters wide (2,000 feet) and is composed of cataclastic equivalents of the adjacent Inner Piedmont and Charlotte belt rocks. The mylonitic rocks within this zone range from protomylonites to ultramylonites with maximum cataclasis generally centrally located within the zone.

I would like to thank Norman Harthill and Mark Youngkin for constructive criticism and help. J. Wright Horton, Jr. and J. Robert Butler provided valuable updates, ideas, questions, and directions. I would also like to thank James Whitney for all of his help over the years.

FIELD DESCRIPTIONS AND PETROLOGY

Within the Elberton, Georgia area the Middleton-Lowndesville cataclastic zone separates the Inner Piedmont and the Charlotte belt, with each belt different in petrology, geophysical signature, structural orientation, and degree of metamorphism (Fig. 2). The southeast flank of the Inner Piedmont belt is composed of interlayered porphyroblastic

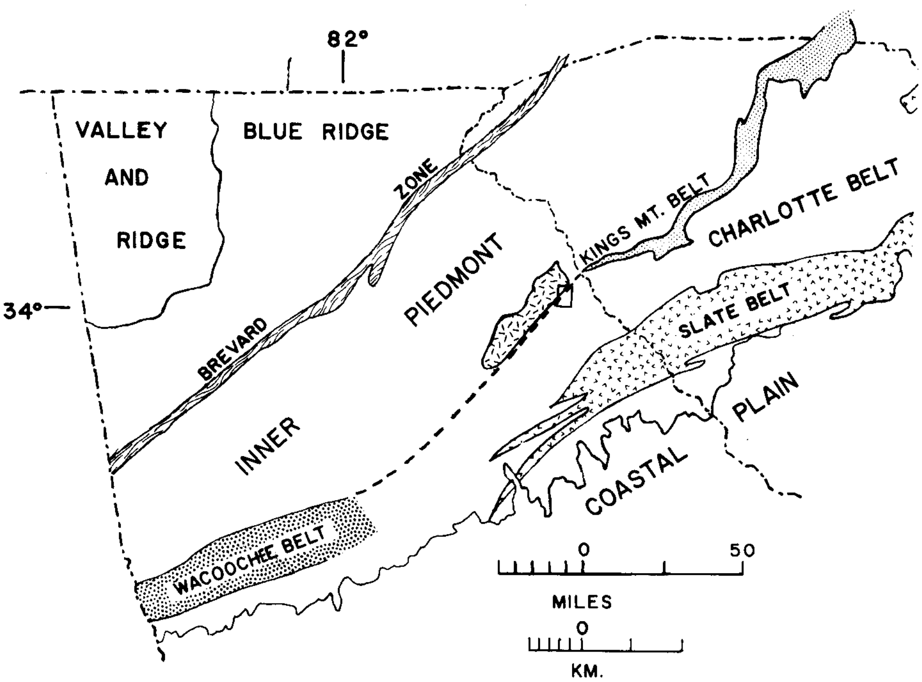

Figure 1. Map showing metamorphic belts of Georgia and South Carolina. The Elberton East quadrangle is represented by a small rectangle.

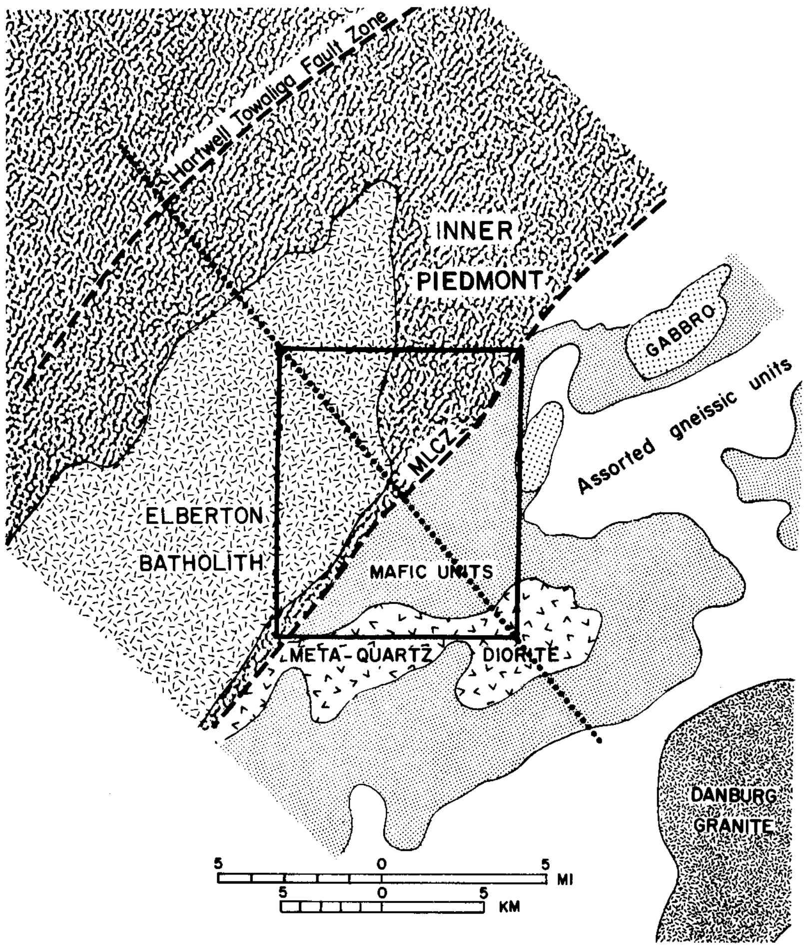

Figure 2. Geology of the Elberton, Georgia area (Rozen, 1978). Rectangle is the Elberton East quadrangle. Dotted line is the trace of geophysical profiles in Figure 3. MCLZ is the Middleton-Lowndesville cataclastic zone.

microcline gneiss and biotite schist. This microcline gneiss/biotite schist series is considered to be an eugeosynclinal igneous and sedimentary sequence metamorphosed to mid-amphibolite grade. Northwest of these rocks are higher grade granite gneisses and associated schists of the Inner Piedmont core (Griffin, 1972). The Inner Piedmont flank near Elberton has been intruded by the post-metamorphic Elberton granite which is approximately 320-350 m.y. B.P. in age (Whitney, Hess, and Mose, 1980). The Charlotte belt primarily consists of an assemblage of gabbros, norites, pyroxenites, basalts, ultramafics, and minor sedimentary units which have been metamorphosed to mid-amphibolite grade. The nature of metamorphism of the Charlotte belt rocks differs from that of the Inner Piedmont flank in that there has been extensive retrograde metamorphism within the Charlotte belt that is not evident in the Inner Piedmont.

The rocks of the Middleton-Lowndesville cataclastic zone can be divided into three groups: 1) the Inner Piedmont or felsic side; 2) the central cataclastic zone; and 3) the Charlotte belt side or mafic side. All groups have cataclastic features, but these features are better developed and better exposed in the felsic and central zone than in the mafic zone. Unlike the Kings Mountain belt in Abbeville County, there are no metasedimentary lithologies associated with the cataclastic zone near Elberton, Georgia. On the Inner Piedmont flank and the Charlotte belt sides the rocks are a mixture of cataclastic and undeformed or less deformed country rocks. Within the central zone the blastomylonites to ultramylonites have been so deformed, silicified and recrystallized that correlations between these rocks and the surrounding country rocks are highly tenuous. Some of the rocks within the central zone have been depleted in iron (less than 1% FeO) and enriched in silica (greater than 71%) suggesting hydrothermal alteration. The degree of metamorphism evident in the Middleton-Lowndesville zone is less than either the Inner Piedmont or Charlotte belt rocks indicating that movement occurred after peak metamorphism. Because of the abundance of epidote, biotite, and white mica with the absence of amphiboles within these cataclastic rocks, greenschist grade of metamorphism is proposed. The degree of recrystallization of the mylonitic rocks in the Elberton area appears greater than that near Lowndesville, South Carolina (Griffin, 1972; Rozen, 1978). This increased amount of recrystallization may be caused by greater uplift (i.e. more erosion) which has exposed deeper parts of the zone in the Elberton area. The greater uplift may be the reason for the lack of sedimentary units in the Elberton area.

STRUCTURE AND GEOPHYSICS

The structural fabric of the Middleton-Lowndesville cataclastic zone is different from that of the Inner Piedmont flank or the Charlotte belt. The foliation and folding pattern of the Inner Piedmont flank trend northeasterly and predominantly dip steeply to the southeast. The structure of the Charlotte belt is more variable, with foliations and fold axes trending primarily north-northeast and east/west and dipping nearly vertical. In the Elberton area, the strike of the Middleton-Lowndesville cataclastic zone is N45°E with the northwest part of the zone dipping moderately to the southeast and the southeast part of the zone dipping steeply to the northwest. This synformal structure of the zone is echoed in mesoscopic folds within the zone and is similar to the Brevard zone in this regard (Roper and Justus, 1973). The structure and petrographic attributes of the Middleton-Lowndesville cataclastic zone are best explained as a tight synclinorium along which reverse or thrust faulting has occurred. Evidence of strike-slip faulting, reported for the Towaliga fault zone (Grant, 1967), was not observed in the Elberton or Lowndesville area (Griffin, 1972; Rozen, 1978). The mylonitic fabric of the zone was formed after peak metamorphism, under greenschist grade conditions. Along this zone, there is local evidence of later brittle normal faulting that has affected the Elberton batholith (Rozen, 1978; Davis, 1980).

In the Elberton Georgia area the Middleton-Lowndesville cataclastic zone coincides with a major discontinuity in gravity, aeromagnetic, aeroradioactivity, and seismic data. The zone is an area of steep gradients in aeromagnetics, and aeroradioactivity data and is located on the Piedmont gravity gradient (Fig. 3). This gravity gradient is not relative to topographic expression and may reflect changes in the lower crust (Whitney, et. al., 1980). The COCORP seismic line, which ran through the Elberton, Georgia area, indicates that the Middleton-Lowndesville cataclastic zone is a major crustal discontinuity, possibly extending to the Moho.

HISTORY OF MOVEMENT

Because of the proximity and structural relationships of the Middleton-Lowndesville cataclastic zone with the Elberton batholith, 320-350 m.y. Rb-Sr radiometric ages obtained from the batholith can be used to approximate the ages of movement along the cataclastic zone. (Whitney, et. al., 1980). A granite similar to the Elberton granite cross-cuts the cataclastic zone near Madison, Georgia (Davis, 1980) and in the Elberton area the granite is faulted along brittle fracture planes parallel to the Middleton-Lowndesville cataclastic zone (Rozen, 1978). A two stage history of movement is proposed for the Middleton-Lowndesville with the first movement being ductile reverse or thrust faulting occurring before 350 m.y. B.P. during a plate convergence episode. This compressional phase was then followed by a tensional phase of brittle faulting presumed to be Triassic or Jurassic.

CONCLUSIONS

The Middleton-Lowndesville cataclastic zone is a continuation of structural elements of the Kings Mountain belt into northeastern Georgia. It differs from the Kings Mountain belt by the lack of metasedimentary lithologies. The Middleton-Lowndesville zone is composed of a series of intensely deformed cataclastic rocks. The zone differs in structure from the adjoining Inner Piedmont and Charlotte belt rocks and this structure is believed to have formed during a period of compressional forces. The Middleton-Lowndesville cataclastic zone is probably part of a feature that includes the Kings Mountain shear zone and the Towaliga fault zone and is a major tectonic feature in the Appalachian Piedmont.

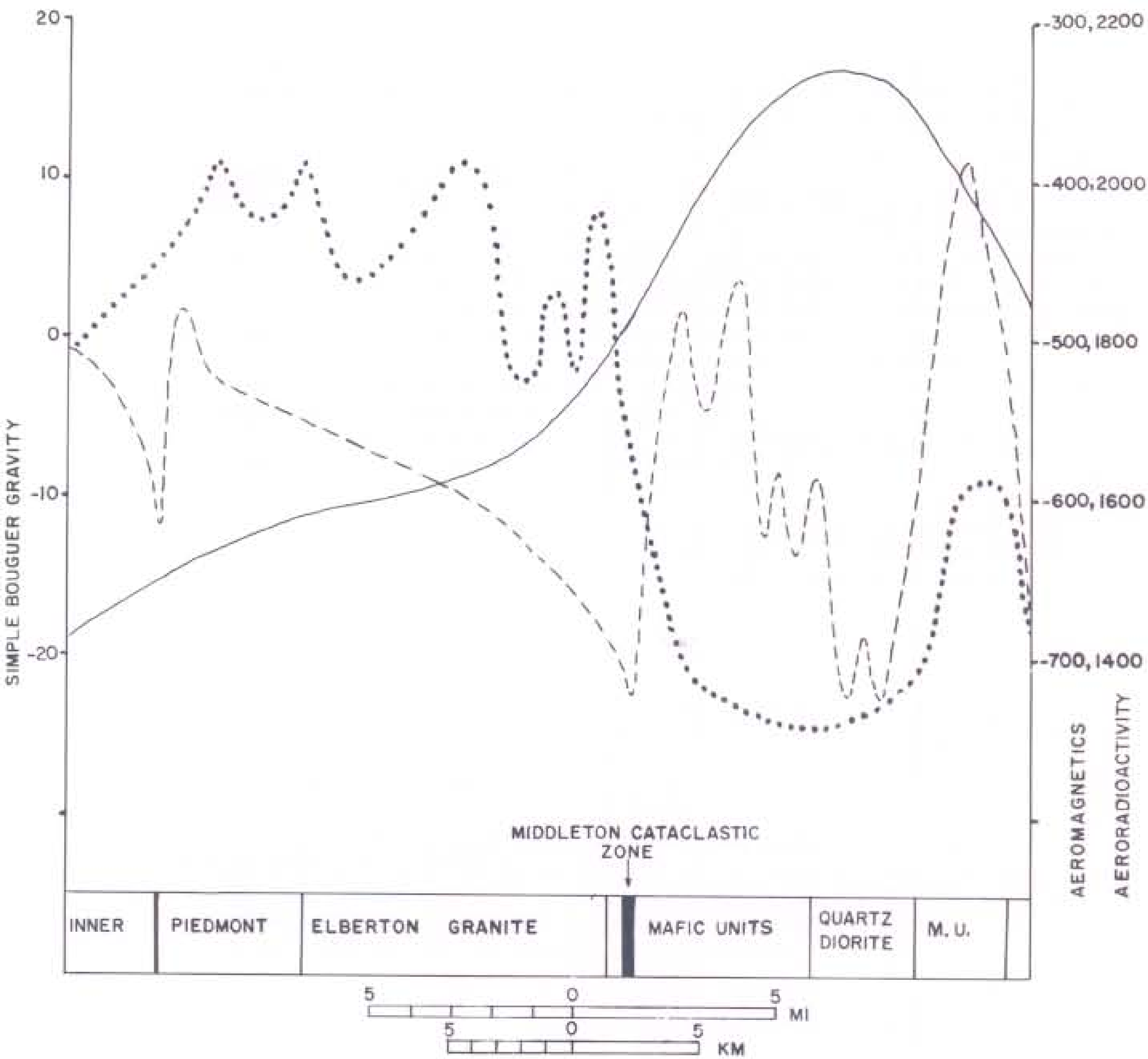

Figure 3. Geophysical profiles across the Middleton-Lowndesville cataclastic zone. Solid line represents simple Bouguer gravity in milligals (Long and others, 1972). Dotted line represents aeroradioactivity in counts per second (Zietz, 1977b). Dashed line represents aeromagnetics in gammas (Zietz, 1977a).

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Polydeformed rocks of the Lowndesville shear zone in the Greenville 2° quadrangle, South Carolina and Georgia

Arthur E. Nelson, U.S. Geological Survey, MS 926,
Reston, Va. 22092

INTRODUCTION

The Lowndesville shear zone, well exposed near Lowndesville, S.C., is a polydeformed zone of high strain, that forms a tectonic boundary for the southeast side of the Inner Piedmont belt (Fig. 1). Price (1969) and Griffin (1970, 1978, 1979) first mapped this shear zone and called attention to the cataclastic rocks associated with it. The zone ranges from a little less than 1 to almost 2 km in width and has been mapped for more than 75 km. In western South Carolina the Kings Mountain belt (King, 1955; Overstreet and Bell, 1965; Griffin, 1970, 1979) is juxtaposed to the Inner Piedmont along this shear zone. The Kings Mountain belt, as used herein, refers to a group of metasedimentary rocks exposed in the Lowndesville area that have been locally referred to as the Lowndesville belt (King, 1955; Griffin, 1970, 1979). The Kings Mountain belt terminates at the Savannah River (Griffin, 1970), and to the southwest, in Georgia, the Lowndesville shear zone separates the Charlotte belt from the Inner Piedmont. Deformation along the shear zone has affected rocks from each belt adjacent to it.

Middle and upper amphibolite-facies granitoid gneiss, amphibolite, and mica gneiss and schist form the Inner Piedmont on the northwest side of the shear zone. On the southeast side the Kings Mountain belt is underlain by greenschist-facies sericite schist, sericitic quartzite, and talc schist together with amphibolite-facies mica schist. The Charlotte belt is underlain by amphibolite-facies mica gneiss and schist, and plutonic rocks (Nelson and Clarke 1978).

The Lowndesville shear zone probably is part of a major fault zone in the southern Piedmont that extends from Alabama to North Carolina and possibly beyond (Griffin, 1970, 1971; Hatcher, 1972, 1979; Hatcher and Zietz, 1978; Horton, 1981; Milton, 1980) (Fig. 2). Rozen (1978) mapped this shear zone as the Middleton-Lowndesville cataclastic zone in the area south of Elberton, Ga. (Fig. 1). Davis (1980) reported that the Middleton-Lowndesville fault zone (Lowndesville shear zone) extends across Georgia along an aeromagnetic anomaly, which suggests that it

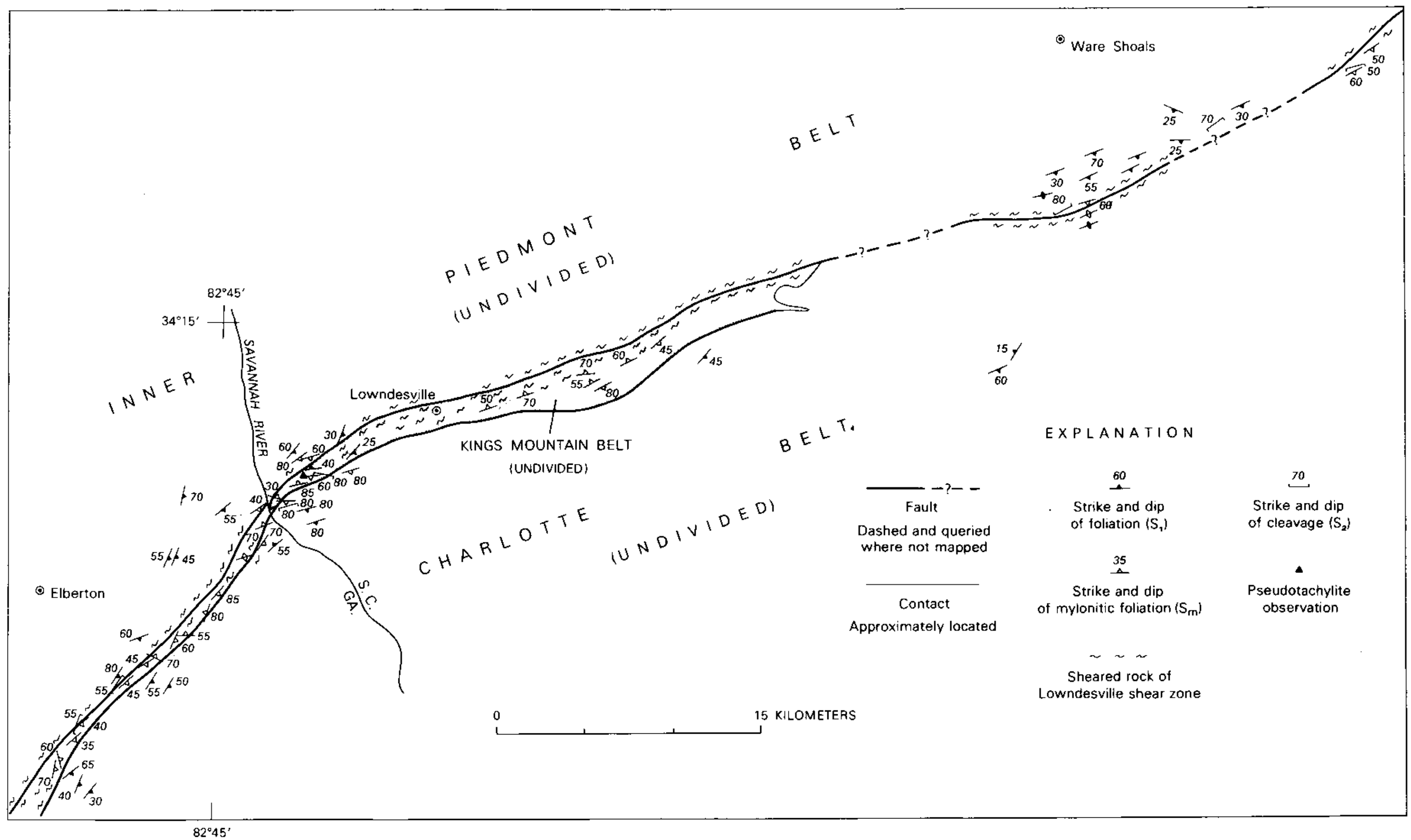

Figure 1. Map of southeastern part of the Greenville quadrangle showing the Lowndesville shear zone, the Inner Piedmont belt, the Kings Mountain belt, and Charlotte belt.

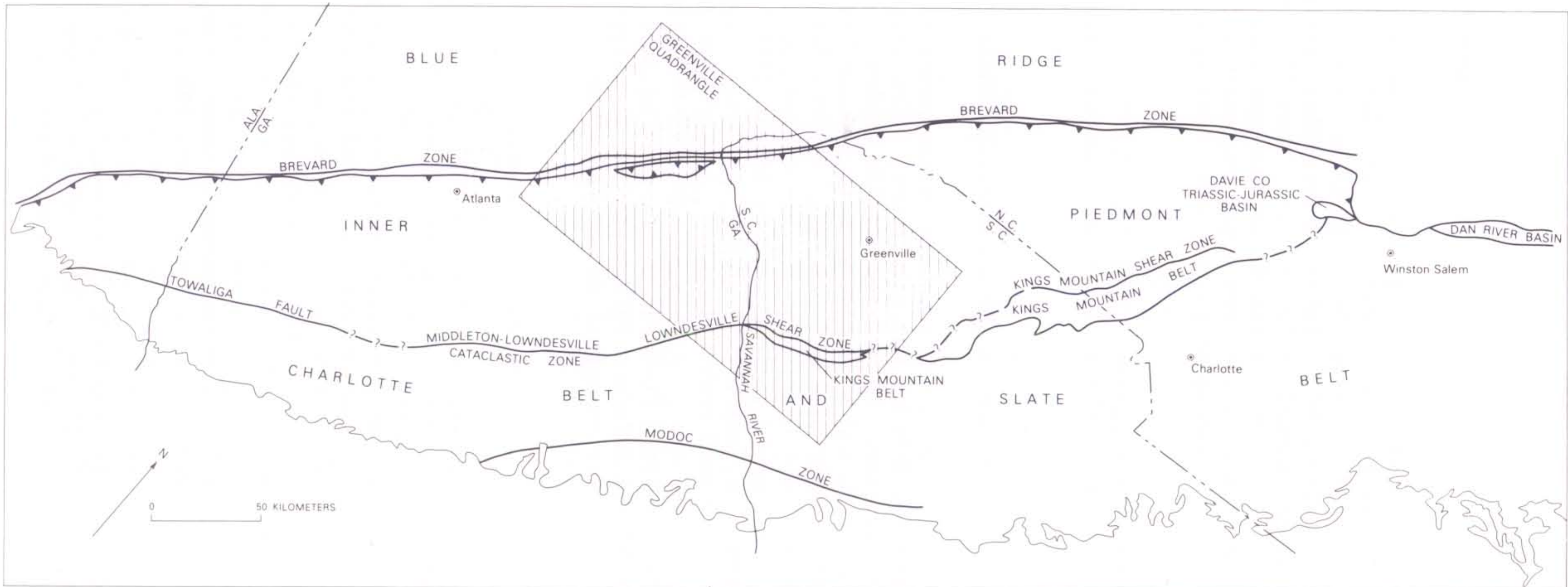

Figure 2. Generalized geologic map of part of the southeastern Piedmont showing major lithotectonic units, the position of the Lowndesville shear zone with its extent to the southwest and probable continuation to the northeast.

joins the Towaliga fault zone (Fig. 2). The Lowndesville zone probably joins the Kings Mountain shear zone in North Carolina (Horton, 1981). The Lowndesville and the Kings Mountain shear zones are approximately on strike with each other, have similar deformation fabrics, and both separate the Kings Mountain belt from the Inner Piedmont belt. Farther northeast along the strike of the Kings Mountain shear zone, Milton (1980) reported a cataclastic zone along the southeast side of the Inner Piedmont that trends northeast to the Davie County, N. C., Triassic-Jurassic basin (Fig. 2).

Appreciation is expressed to Villard Griffin who first showed me exposures of deformed rocks in the Kings Mountain belt and adjoining areas.

DEFORMATION IN THE LOWNDESVILLE SHEAR ZONE

Rocks in the shear zone have been polydeformed and show a wide variety of deformed fabrics and structures, which range from mesoscopic to microscopic in size. They include folds, mylonitic foliation (fluxion structure), and cleavages as well as other features attributed to both ductile and brittle deformation. Figures 3-8 show the major kinds of deformed fabrics present in the sheared rocks. The textural nomenclature used herein follows that of Sibson (1977). Deformation intensity appears to vary widely within the zone. Mapping shows that locally some undeformed rock lenses are in a braided network of finely comminuted mylonite, but generally deformation intensity seems to grade from less deformed Inner Piedmont rocks, showing minor crush breccia zones, to the highly deformed phyllonites of the Kings Mountain belt. The shear-zone boundaries appear to be gradational.

Structural features

The regional metamorphic foliation (S_1) seems to parallel the mylonitic foliation (Sm) within the shear zone. The mylonitic foliation of the shear zone is complexly folded on a small scale. Some mylonitic bands are folded into small rootless isoclines, which suggests that either the mylonitic foliation was folded and transposed or that the primary compositional layering has been transposed into parallelism with the mylonitic foliation everywhere except near the hinges of small rootless isoclinal folds. The strike of a more pervasive cleavage (S_2) forms a low angle (20°-35°) with that of the older mylonitic foliation. This type of penetrative cleavage commonly forms in pelitic mylonites (White and others, 1980; Sibson, 1977; Platt, 1980) and is believed in some places to develop during the same deformation that formed the mylonites, but at a later time or stage (White and others, 1980). Whether or not this is true in the Lowndesville zone remains to be determined. Horton (1981) described a similar cleavage in the Kings Mountain shear zone and called it a semibrittle feature. The S_2

Figure 3. Photomicrograph of protomylonite showing inosculating mylonitic foliation; large grains are more resistant feldspar. Crossed polars.

Figure 4. Photomicrograph of ultramylonite showing faint kinked mylonitic foliation. Crossed polars.

Figure 5. Photomicrograph of blastomylonite showing that average grain size of newly crystallized grains is larger than that of typical mylonites and that the grains are unstrained. Trend of mylonitic foliation (Sm). Crossed polars.

Figure 6. Photomicrograph of phyllonite showing mylonitic foliation and layering folded into late fold, and faint S_3 cleavage and minor kinking (K) in mica (in lower part of photo) which parallels S_3. Crossed polars.

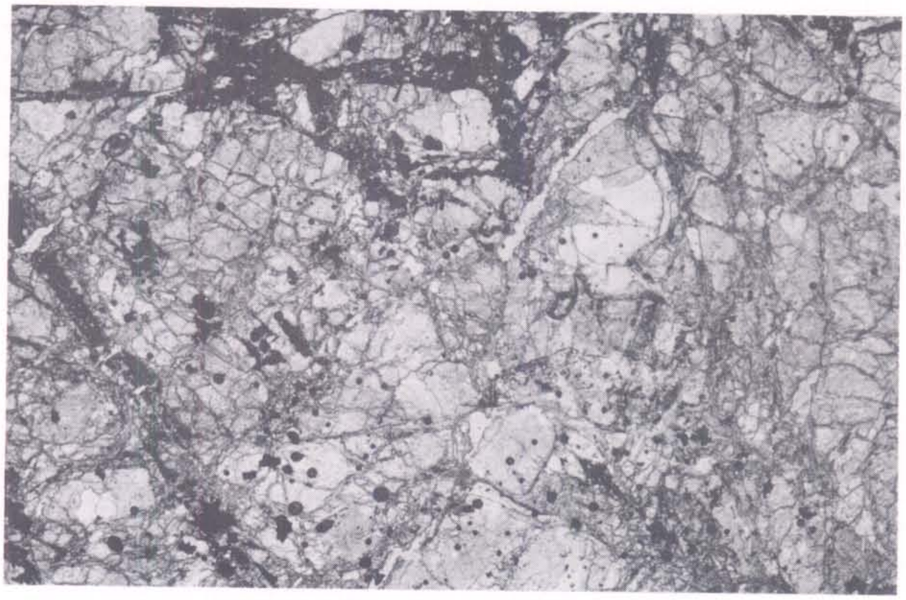

Figure 7. Photomicrograph showing extensive microfracturing, and faint crush zones in protocataclasite. Plane light.

Figure 8. Photomicrograph of protocataclasite showing faint veinlets of quartz; no mylonitic foliation. Crossed polars.

cleavage is well defined within the shear zone but is weak elsewhere. The intersecting surfaces (Sm and S_2) form the button schists of the Lowndesville shear zone. In places, the mylonitic foliation (Sm) is also folded into later more open small north-northeast-trending upright to northwest-verging asymmetric folds. An ill-defined slip cleavage (S_3) appears to be axial planar to these later folds; this cleavage, however, is not easily seen. The S_2 cleavage appears to have been displaced by the ill-defined S_3 cleavage.

Mylonitic fabrics

Protomylonite, mylonite, ultramylonite, blastomylonite, and phyllonite fabrics are present in the rocks that deformed ductilely (Figs. 3, 4, 5, and 6). Except for the ultramylonites, which are very fine grained, the mylonitic rocks typically have the following features: The quartz megacrysts are variably strained and have undulatory extinction and deformation bands, and the deformed bands have serrated borders. In addition, some of the deformation bands are polygonized to subgrains (Bell and Etheridge, 1973). Undulatory extinction seems to grade to discrete subgrains. Newly crystallized unstrained small quartz grains of different orientations commonly border the older deformed megacrysts. Also, the interstices between relatively large ellipsoidal feldspar grains contain newly crystallized grains. The matrixes of mylonites are usually mixtures of deformed and new unstrained grains. Generally the blastomylonites consist of recrystallized unstrained grains; only rarely are they strained. The strained fabrics in blastomylonites may indicate that a later episode of strain followed recrystallization or, more likely, that recrystallization was a dynamic (syntectonic) process rather than being posttectonic.

The above textures and fabrics show that the rocks had recovered from mechanical deformation (Bell and Etheridge, 1973). Furthermore, the presence of both deformed (strained) quartz megacrysts and new mostly unstrained grains in the matrix suggests that recrystallization was dynamic or syntectonic (White, 1977) and that the grain-size reduction in the mylonites was caused largely by recovery and recrystallization (White and others, 1980). Some feldspar megacrysts in the mylonitic rocks are fractured, but these fractures do not penetrate the matrix material. These fractures probably represent fracturing of hard material (megacrysts) in a soft ductile matrix because of unequal stress conditions. White and others (1980) reported similar features in mylonites. These features imply that brittle deformation locally accompanied ductile deformation and that it was also partly responsible for grain-size reduction during mylonite formation.

Cataclastic fabrics

Some rocks in the shear zone have deformation features that probably formed under brittle conditions. These rocks include protocataclasites and crush breccias (Figs 7, 8). The protocataclasites differ from protomylonites in that they do not have a mylonitic foliation or well-defined strain-recovery features. Two features, however, suggest that these rocks grade into protomylonites: (1) Some protocataclasites contain some polygonized quartz grains and (2) locally, parts of thin sections show a very ill-defined mylonitic foliation.

Fracturing and microfracturing have affected both the ductilely and brittlely deformed rocks. The microfractures penetrate both the matrix and megacrysts. At least two episodes of fracturing appear to have taken place; the earlier set of fractures is veined with quartz. Rare tiny branching veinlets of dark, very fine grained material that is not optically resolvable (pseudotachylite) penetrates some protocataclasites. In addition, some ultramylonites have been brecciated.

CONDITIONS FOR DUCTILE AND BRITTLE DEFORMATION

Sibson (1977) reported on the physical conditions for the formation of various rock fabrics within major fault zones. He showed that mylonitic fabrics begin to form in a zone near the lower temperature boundary of greenschist-facies conditions, and that cataclastic fabrics form in the lower part of the zone and at lower temperatures. The presence of both mylonitic and cataclastic fabrics in close proximity within the Lowndesville shear zone presents a problem. Did these fabrics form at the same time under approximately similar conditions or did they form at different times under different conditions? The mylonitic fabrics could have formed first during earlier deformation at deeper levels and higher temperatures. Then later, after uplift and erosion, the cataclastic fabrics could have formed at lesser depths and lower temperatures during later deformation. Alternatively, because greenschist-facies rocks underlie a part of the Kings Mountain belt deformed by the Lowndesville shear zone, the shear zone may have been at or near the lower temperature boundary level of greenschist-facies conditions during deformation. This level would then probably have been in the transition zone where the deformation mode changed from brittle to ductile; therefore, slight temperature changes within the actively deforming shear zone could have caused a change from dominantly mylonitic to cataclastic deformation. Tentatively, the latter interpretation is preferred for the formation of the mylonitic and cataclastic fabrics in the Lowndesville shear zone because my current field studies show that cataclastic fabrics are confined to rocks of the greenschist facies.

Sibson (1977) indicated that shear displacements across an active fault in the upper crust take place either by intermittent seismic failure or by aseismic fault creep. Seismic displacement takes place in a few tens of seconds and is believed to produce pseudotachylites. Aseismic displacements may be quasicontinuous or episodic and take place in the brittle- or ductile-deformation regimes, but if displacements takes place in the ductile zone, they tend to be obliterated by continuous shearing.

AGE AND SEQUENCE OF DEFORMATION IN THE SHEAR ZONE

Evidence from the Kings Mountain shear zone in North Carolina (Horton, 1981) indicates that the minimum age for mylonite formation is approximately 350 m.y. (Late Devonian). The minimum age for deformation in the Middleton-Lowndesville fault zone is also approximately 350 m.y. (Davis, 1980). Ductile and possibly some brittle deformation probably started near the end of the regional metamorphic peak, which according to Fullagar (1971) was 380-420 m.y ago. The fracturing postdates the mylonitization; the rocks may have been fractured during the Alleghanian deformation and during the Triassic and Jurassic Periods as well.

The cataclastic to mylonitic fabrics seen in rocks of the Lowndesville shear zone suggest the following deformational history:

1) Ductile deformation dominant in most of the shear zone; localized concomitant brittle deformation.
2) Possible folding of the mylonitic foliation to form the rootless isoclinal folds.
3) Late-stage ductile deformation when penetrative S_2 cleavage formed.
4) A stage of folding that produced the late north-northeast trending folds and associated slip cleavage S_3.
5) One or more periods of fracturing during or after the mylonite formation as well as possible seismic faulting to form the minor pseudotachylites (Sibson, 1977).

REGIONAL IMPLICATIONS

Regional relations suggest that the Lowndesville shear zone continues southwestward to the Towaliga fault zone in Georgia and northeastward to the Triassic-Jurassic basin in Davie County, N.C., via the Kings Mountain shear zone (Davis, 1980; Horton, 1981). As such, it is part of a major fault zone in the southern Piedmont.

The Lowndesville shear zone closely follows a major gravity gradient that trends northeast across the eastern United States (A.G.U. 1964; Bouger gravity map compiled from data on file at the Defense Mapping Agency). The significance of this gravity gradient and what bearing it has on the Lowndesville shear zone are unknown. The gravity data probably reflect a major change in the deeply buried basement,--from continental basement under the Inner Piedmont to oceanic crust to the southeast (Hatcher and Zietz 1980).

Similarities in lithology and ages suggest that the terrane southeast of the Lowndesville shear zone probably is the southern extension of the Avalonian terrane in New England and Newfoundland. If this is so, the Lowndesville shear zone probably has the same tectonic significance as the Bloody Bluff fault in eastern Massachusetts, for which Nelson (1976) has shown a similar history. The Bloody Bluff fault zone separates Avalonian terrane to the southeast from North American terrane to the west and northwest.

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Geology and mining history of the Kings Mountain belt in the Carolinas — A summary and status report

J. Wright Horton, Jr., U.S. Geological Survey, Reston, VA 22092 and J. Robert Butler, Department of Geology, University of North Carolina, Chapel Hill, NC 27514

INTRODUCTION

This paper summarizes the geology and mining history of the Kings Mountain belt in the central Piedmont of the Carolinas and reports on the status of geological studies.

The Kings Mountain belt was defined by King (1955, p. 350-352) to include distinctive metasedimentary rocks such as quartzite, conglomerate and marble, and mica schists that are partly volcanic in origin. He stated that the belt began near the Catawba River in North Carolina and extended southwest for about 80 km through the Gaffney area of South Carolina, noting the existence of marble occurrences along strike southwest of Gaffney. Overstreet and Bell (1965a, 1965b) extended the Kings Mountain belt across South Carolina to the Savannah River near Lowndesville, mainly using the presence of sericite schist and amphibolite to define the belt. Kesler (1972) questioned the correlation of rocks in the Lowndesville area with the Kings Mountain belt and introduced the name, Lowndesville belt. The Lowndesville belt is not continuous with the Kings Montain belt in the type area (Fig. 1), but Griffin (this volume) and Nelson (this volume) argue strongly for correlating the two because of similar lithologies and tectonic positions.

The Kings Mountain and Lowndesville belts are bounded on the northwest by the Inner Piedmont belt and on the southeast by the Charlotte belt (Fig. 1). The Inner Piedmont belt is described by Goldsmith (this volume) as a terrane of gneisses, schists, and granitoid rocks, considered to be allochthonous and characterized by low to moderate dip angles and inclined to recumbent folds. The Charlotte belt is composed of numerous intrusions, which range widely in age and composition, and a smaller component of metavolcanic and metasedimentary rocks. Wilson (this volume) interprets part of the Charlotte belt in Mecklenburg County, N.C., as a composite batholith. Both he and Rozen (this volume) emphasize the abundance of mafic plutons in the Charlotte belt.

Horton and Butler (1977) reviewed previous investigations in the Kings Mountain belt. Since that report, King's (1955) type area of the belt has been entirely mapped in reconnaissance by Horton (this volume)

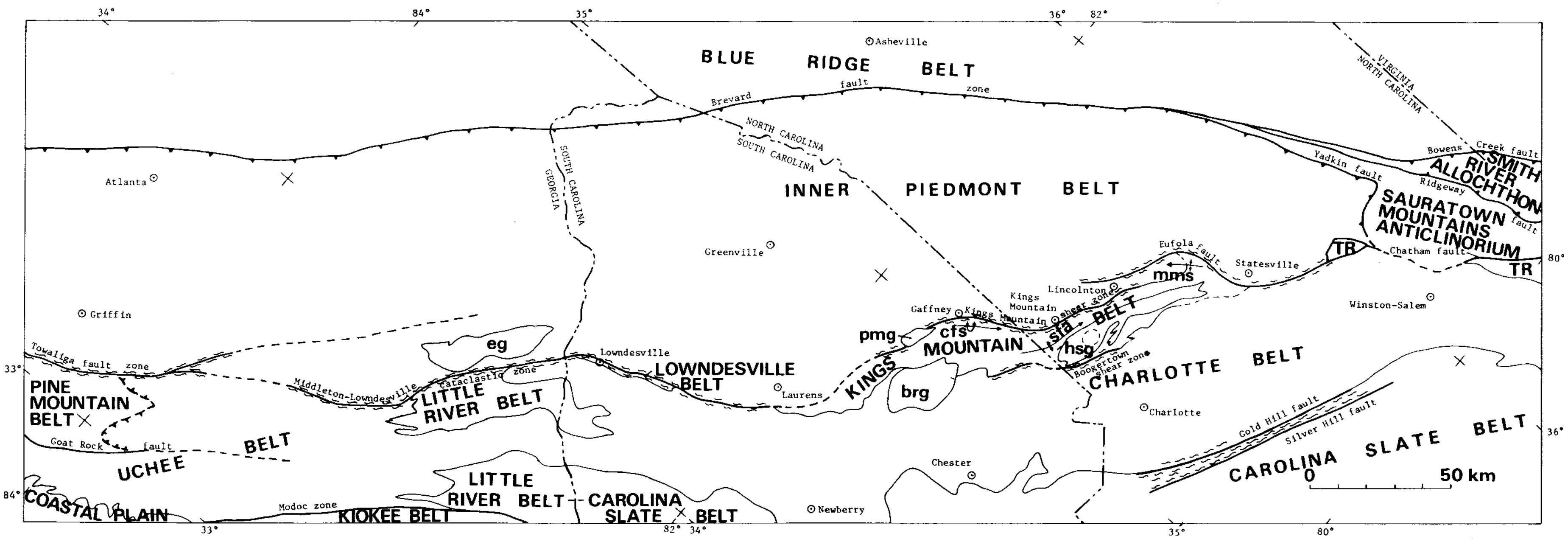

Figure 1. Generalized geologic map of the Kings Mountain belt region. hsg = "High Shoals" granitic gneiss; pmg = "Pacolet Mills" granite; brg = "Bald Rock" granite; eg = Elberton Granite; mms = Murrays Mill synform; cfs = Cherokee Falls synform; sfa = South Fork antiform. TR = sediments filling basins of Triassic age. All other units are Paleozoic and/or Precambrian in age. Geology modified from Overstreet and Bell (1965b) Espenshade and others (1975), Georgia Geological Survey (1976), Whitney and others (1978), Williams (1978), Whitney and Wenner (1980), and papers in this volume.

and Milton (this volume). Most of the belt between Kings Mountain, N.C., and Pacolet Mills, S.C., has been mapped at a scale of 1:24,000 (Wagener and Price, 1976; Godfrey, 1981; Butler, this volume; Murphy, this volume; Horton, unpub. data). Recent topical studies on mineralogy (White, this volume), petrology (France and Brown, this volume), structure (Schaeffer, this volume; Hatcher and Morgan, this volume), metamorphism (Gregory, this volume), and economic geology (Moss, this volume; Sharp and Hornig, this volume; Posey, this volume) are concentrated in the region of detailed geologic map coverage. The southwestern part of the belt between Pacolet Mills and Laurens, S.C., remains poorly known.

HISTORY OF MINING

The Kings Mountain belt is probably best known for its mineral wealth and its unusual variety of mineral deposits. Mining strongly influenced the early development of the region (Moss, this volume), and it continues to play an important role in the regional economy.

The area of the Carolina Geological Society field trip in the central Kings Mountain belt (Horton and others, this volume) had almost no permanent residents before 1750. The drainage of Doolittle Creek southeast of the present location of Blacksburg, S.C., was a buffer zone between the Cherokee Indians to the west and the Catawba Indians to the east, who were traditional enemies (Moss, 1972). A heavy influx of white settlers began in the 1750's after the region was opened to settlement by agreement with the Indians. B. G. Moss (this volume) describes the rapid development and subsequent history of "the Old Iron District" around Blacksburg. Settlers from Pennsylvania had experience in iron mining and manufacture, which they quickly put to use. The strong Pennsylvania influence is shown in place names, as the towns and counties of York, Chester, and Lancaster in South Carolina are named after localities in southeastern Pennsylvania.

Iron deposits in the Kings Mountain belt occur mainly around the Cherokee Falls synform (Fig. 1) and in a zone that extends about 85 km from Gaffney, S.C., almost to the Catawba River in North Carolina. Iron mining began along this belt before the Revolutionary War, and the mining history of the North Carolina part of the belt closely parallels that of the Blacksburg region in South Carolina (Moss, this volume). Bessemer City and Lincolnton in North Carolina became the main centers of iron manufacture. By 1860, there were seven iron works in Lincoln County, four in Cleveland County, and two in Catawba County (Stuckey, 1965). The iron industry in these counties made a major contribution to the Confederate effort during the Civil War. Kerr (1875, p. 251) noted that the belt of deposits in North Carolina "has been the principal source of our domestic supply of iron for a hundred years." The iron industry in the belt declined rapidly in the late 1800's, partly because the shallow ores were depleted and partly because of competition from the huge iron deposits in the Lake Superior region and the developing iron industry around the Great Lakes. By the late 1890's, the iron industry in the Kings Mountain belt had ended.

Beds of the Gaffney Marble occur in an elongate belt west of the main iron-bearing horizons, from Gaffney, S.C., to eastern Catawba County in North Carolina. The marble was discovered at about the same time as the iron ore, and numerous pits were opened to obtain marble to use as a flux in the iron furnaces and to burn in kilns for lime. Ruins of lime kilns are scattered along the entire belt, but the greatest lime production was at the Limestone Springs quarries in Gaffney. Lime production on a large scale began in the 1880's when continuous-process kilns were built, and lasted until 1913 (Keith and Sterrett, 1931; Moss, 1972). In 1907, five kilns having a total capacity of 540 barrels of lime per day were operating at Limestone Springs (Sloan, 1908). The main quarry near Limestone Springs was reopened in 1933 (Moss, 1972). The old quarry, which was at least 25 m deep, is now a lake adjacent to the Limestone College campus in Gaffney. Campbell Limestone Company and later Vulcan Materials Company operated another large quarry 4 km northeast of Blacksburg from 1954 until 1979 (described as stop 4 by Horton and Butler, 1977). In 1979, operations shifted to a new site 1 km farther northeast (stop 2 of Horton and others, this volume). Large quantities of crushed stone have also been produced from the Martin-Marietta quarry in the Gaffney Marble just south of Kings Mountain, but that company now uses amphibolite waste from the Foote Mineral Company spodumene operations (stop 4 of Horton and others, this volume).

Development of a gold mining industry lagged behind the establishment of iron mining by almost 70 years. Gold was discovered in Cabarrus County, N.C., in 1799 and in the Greenville district of South Carolina before 1802 (Pardee and Park, 1948, p. 27). In the ensuing gold rush, deposits were discovered at numerous other localities in the Piedmont. No one knows when and where gold was first found in the Kings Mountain belt, but the Kings Mountain mine was opened in 1834 and production was reported from the Smyrna area by 1838 (Lieber, 1856; Keith and Sterrett, 1931).

About 75 inactive gold mines and prospects are in the Kings Mountain belt. The Smyrna district in South Carolina includes about 50 of the localities, but most were only prospects or mines having low production (Butler, 1981). Another 25 mines and prospects were located in the belt north of the Smyrna district. Probably the most productive gold mines were the Kings Mountain mine, 3.5 km south of the town of Kings Mountain, and the Shuford mine, 25 km northeast of Lincolnton. The Kings Mountain mine was worked intermittently from 1834 until 1895 and yielded $750,000 to $1,000,000 in gold (Graton, 1906; Pardee and Park, 1948). The open-pit Shuford mine produced 1,716 ounces of gold and 586 ounces of silver from 1902 until 1911 (Pardee and Park, 1948). The main periods of gold mining activity were 1834-1861, 1866-1917, and 1931-1943 (McCauley and Butler, 1966); no production has been reported since 1943.

The Cameron lead mine, 5 km southwest of Gaffney, produced several hundred tons of lead ore during the Civil War (Keith and Sterrett, 1931). The vein, as much as 1.5 km thick, contained galena carrying 60 ounces of silver to the ton in an unusual gangue rich in siderite and cerussite (Sloan, 1908). A smaller amount of lead and silver was produced along Silver Mine Ridge at Cherokee Falls (Moss, 1972).

Pyrite was produced at the Oliver mine, 11 km south of Lincolnton, during the Civil War and from about 1886 until 1912 (Stuckey, 1965). It was also produced as a byproduct of kyanite operations at Henry Knob in York County from 1962 until 1966 (Butler, 1966).

Barite was discovered in the belt in the 1880's, and the largest deposits at Kings Creek (stop 12; Sharp and Hornig, this volume) were worked nearly continuously from 1885 until 1969. Thirteen barite localities occur in a narrow belt about 40 km long (Van Horn and others, 1949). The main production has been from the following mines: Kings Creek, Lawton, Wyatt, and Sam's Place. Total production is about one million tons (Horton and Butler, 1977).

The Kings Mountain belt has large reserves of kyanite and much lower reserves of sillimanite (Espenshade and Potter, 1960). The only significant kyanite production has been from Henry Knob in South Carolina, which was worked in 1935 and from 1948 through 1966 (Butler, 1966). Production from Henry Knob made South Carolina the nation's second largest kyanite producer for several years in the 1960's.

Currently the most important resource in the vicinity of the Kings Mountain belt is lithium produced from pegmatites that contain spodumene and cassiterite. The cassiterite was first identified about 1883 from specimens found in the town of Kings Mountain (Stuckey, 1965), and thereafter the belt was prospected for tin. Small amounts were produced sporadically from 1903 until 1937, but no major industry was established. Kesler (1942) and others recognized that the spodumene in the pegmatites was potentially much more important than the cassiterite, and development of lithium mines began on a large scale in the mid-1940's. Spodumene is now produced from two large open pits, and the pegmatite belt constitutes one of the world's largest reserves of lithium; it contains tens of millions of tons of potential ore (Kesler, 1976; Kunasz, 1976). Foote Mineral Company became active in the area in 1950 (Stuckey, 1965) and now has a very large mine and processing plant 3 km southwest of Kings Mountain (stop 4 of Horton and others, this volume). The Lithium Corporation of America, which began production in the 1960's, operates a large open-pit mine 7 km northwest of Bessemer City and a processing plant at Bessemer City.

In addition to lithium, scrap mica, feldspar, silica, clay, and crushed stone are currently being produced from the Kings Mountain belt and adjacent Inner Piedmont. The Kings Mountain Mica Company and allied companies produce mica, feldspar, silica, and clay from saprolite and partly weathered granitic rocks from pits 5 km southwest of Kings Mountain (stop 3 of Horton and others, this volume). At the present time, Kings Mountain Mica Company and Huber Corporation are independently engaged in exploration and drilling programs for new deposits of this type.

Recent reconnaissance by the U.S. Geological Survey has resulted in the discovery of concentrations of the major tin ore cassiterite, which occurs in masses as much as 1 cm in diameter, in stream sediments within 10 km of Boiling Springs, N.C. (J. P. D'Agostino and J. W. Whitlow, personal commun., 1981). Cassiterite is not limited to the belt of spodumene pegmatites, so tin deposits may be more widespread in the Inner Piedmont belt than previously suspected.

STRATIGRAPHY

Formal rock-stratigraphic units within the Kings Mountain belt include the Bessemer Granite of Keith and Sterrett (1917), the Blacksburg Schist and Gaffney Marble of Loughlin and others (1921), the Kings Mountain Quartzite and its Draytonville Conglomerate Member, and the Battleground Schist of Keith and Sterrett (1931). These names have been avoided or used with discretion since the work of Kesler (1942, 1944, 1955) and Espenshade and Potter (1960), because of the problems pointed out by them and by subsequent investigators. Much of the Bessemer Granite of Keith and Sterrett (1917, 1931) is volcanic and epiclastic or sedimentary in origin, and the intrusive rocks within the unit are not granites (Espenshade and Potter, 1960; Horton and Butler, 1977). Quartzites and quartz-pebble metaconglomerates, which Keith and Sterrett (1931) mapped as the Kings Mountain Quartzite and its Draytonville Conglomerate Member, occur at several stratigraphic levels (Kesler, 1944; Horton and Butler, 1977). Quartzites which Keith and Sterrett (1931) mapped as Kings Mountain Quartzite are found within rocks that they mapped as Blacksburg Schist as well as within those that they mapped as Battleground Schist. France and Brown (this volume) discuss similarities and differences among some of the different metaconglomerate beds mapped as Draytonville by Keith and Sterrett (1931). Beds of marble, called Gaffney Marble by Loughlin and others (1921), apparently crop out at two stratigraphic levels (Horton, this volume, Plate 1) within the Blacksburg Schist. The formal terminology of rock-stratigraphic units within the Kings Mountain belt will have to be revised if it is to reflect the geology accurately and achieve widespread acceptance.

Our concept of stratigraphy within the Kings Mountain belt is essentially that proposed by Horton and Butler (1977) as discussed by Horton (this volume). It is regarded as tentative until more reliable data from primary sedimentary structures are available. The lowest units in this tentative stratigraphy are considered to be facies of a volcanic-intrusive complex. This complex consists of felsic-to-intermediate metavolcanic rocks interlayered with quartz-sericite schists and intruded by metatonalite similar in composition to the metavolcanic rocks (Horton, this volume; Murphy and Butler, this volume). Many of the metavolcanic rocks have textures that indicate a volcaniclastic origin. A Proterozoic Z age is tentatively inferred on the basis of preliminary U-Pb isotopic data on zircons from the metatonalite (J. W. Horton, Jr., and T. W. Stern, unpub. data).

The volcanic-intrusive complex grades upward into a sequence that is primarily sedimentary in origin, and that consists of quartz-sericite schist containing beds of quartzite, quartz-pebble metaconglomerate, high-alumina quartzite, and manganiferous schist. At least some of the quartzites, particularly those that grade laterally into quartz-pebble metaconglomerates, originated as clastic sediments. Others may be metamorphosed cherts as suggested by Posey (this volume). The high-alumina (kyanite and sillimanite) quartzites (stop 7 of Horton and others, this volume) may have originated from Al-rich clays (Espenshade and Potter, 1960) or by hydrothermal leaching associated with nearby volcanic activity. Posey (this volume) suggests that Al-rich clays were eroded from nearby soils of hydrothermally altered zones and redeposited. Calcareous metasedimentary rocks adjacent to the manganiferous schist in the Kings Creek quadrangle suggest a marine origin for that unit (Horton and others, this volume). The manganese and associated iron may have been concentrated by chemical weathering and leaching of volcanic glass or as a distal volcanic-exhalative deposit of submarine hydrothermal vents (Horton and others, this volume, stop 10).

Another suite of metasedimentary rocks crops out along the western side of the Kings Mountain belt. This suite, generally more calcareous and less quartz-rich than the rocks mentioned above, consists of sericite schist or phyllite (commonly graphitic) containing beds and lenses of dolomitic or calcitic marble, quartzite, amphibolite, and calcsilicate rocks. The carbonate layers suggest a marine origin. The stratigraphic relationship of these rocks to other rocks of the Kings Mountain belt is uncertain because of intervening faults and plutons (Horton, this volume).

Plutonic rocks, which intrude the metasedimentary and metavolcanic rocks of the Kings Mountain belt, are discussed by Horton (this volume) and van Gelder and McSween (this volume).

STRUCTURE

Within the Kings Mountain belt, the major structures are gently plunging, tight-to-isoclinal folds and faults generally subparallel to fold limbs. Movement along some of the faults took place under ductile conditions during folding and, therefore, the faults are tectonic slides (Butler, this volume). The two largest folds are the South Fork antiform and Cherokee Falls synform (Fig. 1), although several other folds have been mapped (Horton, this volume, Fig. 1). The South Fork antiform was originally interpreted as a D_1 structure (Horton and Butler, 1977), but Horton (this volume) has since mapped an older schistosity around the fold hinge, so it is now classified as a D_2 structure as is the Cherokee Falls synform. Isoclinal F_1 folds, typically occurring as isolated hinges having limbs disrupted by the S_2 schistosity, are common on the mesoscopic and microscopic scales, but macroscopic F_1 folds are well-documented in only two places (Horton, this volume). The Murrays Mill synform, F_3?, which apparently folds Kings Mountain and Inner Piedmont rocks as a single package (Milton, this volume), is a puzzling structure in need of additional study (Fig. 1).

At most good exposures in the Kings Mountain-Gaffney section of the belt, two conspicuous early foliations exist, although they may be difficult to distinguish. Both are axial planar to isoclinal folds. The foliations generally trend northeast and dip steeply, intersecting at acute angles that range from about 20° to nearly 0°. They are generally called S_1 and S_2 by workers in this part of the belt (Butler, this volume; Horton, this volume; Schaeffer, this volume). Where only a single steeply dipping schistosity can be seen in outcrop, it is generally impossible to distinguish S_1 from S_2. The two foliations may intersect at large angles in the hinge areas of large folds such as the Cherokee Falls synform, where the S_2 foliation axial planar to the synform clearly overprints the S_1 foliation that follows lithologic units (S_0) around the hinge.

A third cleavage, called S_3 in several papers (Horton, this volume; Horton and others, this volume, stops 4 and 6; Schaeffer, this volume), is conspicuous in retrogressive shear zones but is present only in scattered places elsewhere. It strikes northeast and dips steeply northwest or southeast.

Younger structural features such as crenulations and kink bands are widespread but sporadic, and they have little effect on the map pattern. Logical and consistent sequences of four or five deformational episodes can be constructed on the basis of overprint criteria in relatively small areas (Horton and Butler, 1977; Horton, 1977; Horton and others, this volume; Schaeffer, this volume), but scattered distribution of the youngest structures makes these difficult to correlate on a regional scale without dangerous dependence on structural style and orientation.

METAMORPHISM

The metamorphic grade of the Kings Mountain belt is generally considered to be lower that of the adjacent belts. The metamorphic isograds of Gregory (this volume) and Horton (this volume) show an area of greenschist-facies and/or epidote-amphibolite-facies metamorphism in the Kings Mountain belt that is not present in nearby parts of the Inner Piedmont and Charlotte belts. The metamorphic grade is not low everywhere in the Kings Mountain belt, however, and parts of the belt have been metamorphosed to the sillimanite zone or upper amphibolite facies (Horton, this volume). Metamorphic textures in the Kings Mountain area suggest that a single progressive metamorphic event overlapped the two major deformation events, D_1 and D_2, with a thermal peak after the major D_2 deformation, and that all are related to a single orogenic episode (Horton, 1977, 1978). Whether this orogenic episode was Taconic or Acadian is an important unanswered question; we hope it will be resolved by isotope geochronology studies now in progress. Greenschist-facies retrogressive metamorphism is widespread, but it is most common in the vicinity of late shear zones (Horton, 1981).

Metamorphic isograds (Gregory, this volume; Horton, this volume) transect stratigraphic units and structures produced by D_1 and D_2. This transection eliminates the possibility that low-grade rocks of the Kings Mountain belt represent a simple structural window rimmed by higher grade rocks. Another possible interpretation, that the Kings Mountain belt is generally a synformal structure with down-folded isograds, is incompatible with structural observations (Horton, this volume) and can also be eliminated. A third possibility, that a major part of the belt is an overturned antiform with inverted isograds, is also incompatible with the structural data (Horton, this volume). A fourth interpretation, which we favor, is that isogradic surfaces had an original pseudo-synformal shape caused by thermal highs along the flanks of the belt, around the "High Shoals" granitic gneiss (Horton, this volume), and around the "Bald Rock" granite (van Gelder and McSween, this volume) during and/or after the peak of regional progressive metamorphism. A fifth interpretation, which does not necessarily exclude the others, is that the isograds were produced by a combination of two or more metamorphic fronts, perhaps even produced at different times.

Estimates of the time of metamorphism based on extrapolations from the Inner Piedmont and Charlotte belts (Horton, 1977, 1978) are no longer considered valid. Extrapolations from the Inner Piedmont and Blue Ridge are particularly suspect because the Kings Mountain shear zone of Horton (1981) was found to be a metamorphic boundary as well as a structural one (Butler, this volume; Horton, this volume).

Mineral ages at the Cherokee Nuclear Plant site are 271 m.y. to 302 m.y., and one date on phlogopite from the Gaffney Marble is 321 m.y. ± 11 m.y. (Fullagar and Kish, this volume). All the dated minerals are from rocks metamorphosed to staurolite-kyanite grade, and the mineral dates represent times when the rocks cooled to temperatures typical of middle to lowermost greenschist facies, so the mineral dates are reliable minimum ages for regional metamorphism.

The "Bald Rock" granite is synmetamorphic or postmetamorphic according to van Gelder and McSween (this volume), and its Rb-Sr mineral-and-whole-rock isochron age of 388 m.y. ± 5 m.y. (Fullagar and Kish, this volume) is interpreted as a minimum age for the peak of regional metamorphism. Some of the major D_2 folds trend southwest across the Blacksburg South and Gaffney quadrangles into the Pacolet Mills quadrangle, where they appear to be truncated by the "Pacolet Mills" granitic pluton (Wagener and Price, 1976). The date of 415 m.y. ± 40 m.y. for this pluton (Fullagar and Kish, this volume) is also considered to be a minimum age for D_1-M_1-D_2.

KINGS MOUNTAIN-LOWNDESVILLE-TOWALIGA SHEAR ZONES

Several retrogressive shear zones are recognized in the field trip area (Horton, 1980, 1981, this volume): along each boundary of the Kings Mountain belt (Kings Mountain zone on the west and Boogertown zone on the east) and within it (Blacksburg, Kings Creek, and Long Creek zones). The Kings Mountain shear zone is the most profound break. Only a few rock types occur on both sides of the Kings Mountain shear zone and the stratigraphic sequences are very different across it. Structural blocks separated by shear zones within the Kings Mountain belt or between the Kings Mountain and Charlotte belts all have common stratigraphic features, and their differences can be explained as facies changes (Horton, this volume; Milton, this volume).

The Kings Mountain shear zone was named by Horton (1981), who traced it for 60 km and suggested that it was part of a fault system more than 550 km long. Griffin (1970) recognized the cataclastic-mylonitic nature of the Lowndesville belt, especially along the contacts, and speculated that the zone of deformation continued southwestward to join the Towaliga fault. Papers in this volume by Butler, Griffin, Horton, Nelson, and Rozen emphasize the significance of the Kings Mountain shear zone and related zones along strike. Nelson (this volume) suggests that the shear zones are the boundary between different crustal blocks, analogous to the Bloody Bluff system in Massachusetts, which is the northwestern boundary of the Avalonian terrane.

The Geologic Map of Georgia (Georgia Geological Survey, 1976) shows an inferred extension of the Towaliga fault along an aeromagnetic lineament to the Hartwell area northwest of the batholith of Elberton Granite (Elberton Granite of Chayes (1952) and Crickmay (1952) herein adopted for U.S. Geological Survey usage) where it would not join the Lowndesville zone (Fig. 1). Mapping by Griffin (1970), Rozen (1978), and Davis (1980) indicated that the Middleton-Lowndesville zone passes southeast of the Elberton batholith. The inferred Hartwell extension of the Towaliga fault has no mylonitic or cataclastic fabric north of the Elberton Granite and its existence in that area is questionable, whereas the Middleton-Lowndesville shear zone is a deformed zone as much as 0.5 km wide containing mylonites affected by later brittle deformation (Whitney and Wenner, 1980). The fault zones bracketing the Elberton Granite join the Towaliga in central Georgia (Fig. 1).

At the northern end of the Kings Mountain belt, major mylonitic zones clearly continue along strike at least to an area west of Winston-Salem, and the southeastern boundary of the Inner Piedmont is typically a major fault zone (Espenshade and others, 1975; Milton, 1980; Horton, 1981), but many uncertainties remain. Distinctive lithologies such as marble, thick quartzite beds, and strata-bound iron deposits end in southwest-plunging folds in eastern Catawba County, N.C., which can be considered the northeastern termination of the Kings Mountain belt proper (Milton, this volume). Relationships in the area where the Kings Mountain shear zone, Murrays Mill synform, and Eufola fault converge are still poorly understood (Fig. 1; Milton, this volume).

Jonas (1932) postulated a major fault (Appomatox overthrust) that had an almost identical trace to the Kings Mountain-Lowndesville-Middleton-Towaliga zone discussed here. She proposed that the fault zone is overlain by Triassic rocks north of Winston-Salem but that southward it crosses the North Carolina Piedmont east of Hickory, passes just west of Gaffney, continues across South Carolina and ultimately joins the fault (now called the Towaliga) along the northern edge of the Pine Mountain region.

The "Pacolet Mills" granite is affected by ductile and brittle deformation along the Kings Mountain shear zone; consequently, the date of 415 m.y. ± 40 m.y. (Fullagar, this volume) for the granite is a maximum age for at least some of the major deformation along the zone. Spodumene pegmatite dikes near Kings Mountain have Rb-Sr whole-rock ages of 352 m.y. ± 10 m.y. (Kish, 1977) and are mostly located just west of the Kings Mountain shear zone. Some are affected by deformation along the shear zone, and Horton (1981) concluded that their age is approximately the same as the age of late-stage semibrittle deformation along the zone.

In northeastern Georgia, the Middleton-Lowndesville shear zone is cut by aplite dikes and a small granitic pluton most likely co-magmatic with the Elberton Granite batholith, which has a whole-rock Rb-Sr age of 350 m.y. ± 11 m.y. (Davis, 1980; Ellwood and others, 1980). The Elberton-like intrusions are younger than the mylonitic foliation but are locally offset by brittle faulting. The date is compatible with that of the spodumene pegmatite dikes in the Kings Mountain area and suggests that major ductile shearing all along the Kings Mountain-Lowndesville shear zone took place before about 350 m.y. ago. Undeformed and unmetamorphosed Mesozoic diabase dikes cut across the Kings Mountain shear zone and, therefore, are a younger bracket on significant movement along the zone, although diabase dikes are locally cut by minor faults having displacements of as much as 1.2 m (Horton and Butler, 1977). Diabase dikes near the Kings Mountain belt at Ora, 62 km southwest of Gaffney, have K-Ar whole-rock ages of 191 m.y. ± 7 m.y. and 186 m.y. ± 6 m.y. (Law Engineering and Testing Co., 1974; Fullagar and Kish, this volume).

GEOPHYSICS

The northeast-trending regional gradient between higher gravity on the northwest and lower gravity on the southeast passes through the Piedmont in the general vicinity of the Kings Mountain belt (Hatcher and Zietz, 1980). It is probably produced by deep crustal and/or upper mantle features and may represent the eastern edge of Grenville-age basement of the North American craton (Rankin, 1975; Hatcher and Zietz, 1980). This gradient is too broad, however, for one to confidently relate it to the Kings Mountain belt or either of its boundaries, and its relation to surface geology is obscure.

Hatcher and Zietz (1980) emphasized the contrast between the uniform broad-wavelength magnetic pattern of the Inner Piedmont belt, which reflects little of the surface geology, and the high-frequency magnetic pattern of the Charlotte and Carolina slate belts, which closely reflects the surface geology. Their proposed "central Piedmont suture" separates these terranes of different magnetic character (Hatcher and Zietz, 1980). Like the Charlotte belt, the Kings Mountain belt is characterized by a high-frequency magnetic pattern that closely reflects the surface geology (Daniels and Zietz, 1980). The pattern of linear north- to northeast-trending magnetic highs and lows in the Kings Mountain belt differs from the irregular pattern of the Charlotte belt, reflecting the distribution of rock units as shown on the geologic map (Horton, this volume, Plate 1). As one would expect from the geology (Horton, this volume), the transition between the magnetic patterns of the Kings Mountain and Charlotte belts is rather sharp in some places and gradational in others. The contrast beween the low-frequency pattern of the Inner Piedmont and the high-frequency pattern of lithotectonic belts to the southeast is a conspicuous feature of the aeromagnetic map (Daniels and Zietz, 1980). The transition between these low-frequency and high-frequency terranes is generally sharp, coinciding with the Kings Mountain shear zone as mapped by Horton (this volume, Plate 1). If the contrast in magnetic character represents a major crustal boundary such as the "central Piedmont suture," that boundary should coincide with the western margin of the Kings Mountain belt, not its eastern margin as proposed by Hatcher and Zietz (1980).

REGIONAL CORRELATIONS

Similarities in lithology (Griffin, this volume) and tectonic position (Nelson, this volume) strongly suggest that the Lowndesville belt is correlative with the Kings Mountain belt as proposed by Griffin (1970) and mapped earlier by Overstreet and Bell (1965a, 1965b). Rocks of the Lowndesville belt may also be correlative with similar lithologies to the east in the Carolina slate belt or Charlotte belt as suggested by Kesler (1972). Horton (this volume) and Milton (this volume) favor the idea that the Kings Mountain and Charlotte belts are dominantly sedimentary and volcanic-plutonic parts of the same terrane. Both point out similarities in lithology and the arbitrary nature of the belt boundary (except along the Boogertown shear zone). Milton (1980) also pointed out lithologic similarities between the Kings Mountain belt and the Carolina slate belt and suggested that the Charlotte belt may be a dominantly plutonic core of the same terrane. In the Carolinas, the stratigraphy in the Charlotte belt is too disrupted by plutons to be traced directly from the Kings Mountain belt to the Carolina slate belt. However, this continuous tracing may be possible in east-central Georgia where part of the Carolina slate belt, the Little River belt of Crickmay (1952), extends as far northwest as the Middleton-Lowndesville cataclastic zone (Fig. 1). In addition to lying along strike with the Kings Mountain and Lowndesville belts and being bounded on the northwest by the Middleton-Lowndesville zone, the northwestern part of the Little River belt contains Na-rich felsic metavolcanic rocks, sericite schists, and quartzites (Crickmay, 1952; Whitney and others, 1978; Whitney and Wenner, 1980) similar to rocks in the lower part of the Kings Mountain belt sequence. The kyanite quartzite at Graves Mountain in the southeastern part of the Little River belt, which merges with the Carolina slate belt to the northeast, is similar to those in the Kings Mountain belt (Espenshade and Potter, 1960).

Several authors of regional papers, such as Hatcher (1972) and Rankin and others (1973), have suggested that rocks of the Kings Mountain belt are correlative with a diverse sequence of similar metasedimentary rocks in the Pine Mountain (Wacoochee) belt of Georgia and Alabama (Fig. 1). This sequence, known as the Pine Mountain series (Crickmay, 1952), is a metasedimentary cover sequence that unconformably overlies an orthogneiss basement complex of Grenville age (Schamel and others, 1980). Quartzites and schists similar to those of the Pine Mountain and Kings Mountain belts also apparently overlie Grenville-age basement in the Sauratown Mountains to the northeast (Rankin, 1975). Grenville-age rocks have not been recognized in the Kings Mountain belt, however, and recent studies (this volume) have found no likely candidates exposed at the surface. Intervening units and structures make it impossible to trace stratigraphy directly from the Kings Mountain belt to the Pine Mountain belt or Sauratown Mountains anticlinorium, and any correlation inferred because of gross similarities in lithology is difficult to evaluate.

A correlation of the Kings Mountain belt with rocks of the Pine Mountain belt and Sauratown Mountains would imply deposition on Grenville-age crust of the North American plate. On the other hand, Nelson (this volume) proposes that the terrane southeast of the Kings Mountain and Lowndesville shear zones is an extension of the Avalonian terrane (a former microcontinent?) in New England and Newfoundland.

TECTONIC MODELS

The Kings Mountain belt necessarily plays a major role in regional tectonic models. As recently as 4 1/2 years ago, the belt was so poorly known that few limits could be put on the models (Horton and Butler, 1977). The rapid accumulation of new data and ideas, as illustrated in this volume, will have the scientifically healthy effect of stimulating more controversy and thereby motivating further research. In this section, we summarize and evaluate some aspects of proposed models, though we realize that the authors may have already modified their models on the basis of new information.

Hatcher and Zietz (1980) recognized two major crustal boundaries in the exposed southern Appalachians, the "central Blue Ridge suture" in the Blue Ridge Province west of the Brevard zone and the "central Piedmont suture" along the southeastern boundary of the Kings Mountain belt. The "central Piedmont suture" is the Lowndesville belt in western South Carolina and the Middleton-Lowndesville zone in eastern Georgia, but it does not follow the Towaliga fault. The proposed suture cuts across regional strike in central Georgia to pass south of the Pine Mountain belt, which has billion-year-old Grenville basement linking it to the North American plate (Hatcher and Zietz, 1980; Hatcher, 1980). In Hatcher's (1972, 1980) models, the Kings Mountain belt is a closely appressed synclinal zone associated with the root zone of westward-transported Inner Piedmont nappes.

We believe that the Kings Mountain shear zone is more likely to be a major crustal boundary than shear zones along the southeastern boundary of the Kings Mountain belt because the older stratigraphy in the Kings Mountain belt has more affinities with the Charlotte and Carolina slate belts than with the Inner Piedmont. If the Inner Piedmont belt is a complex of westward-transported nappes, the nappes must be rooted either on the southeastern edge of the Inner Piedmont (Hatcher, 1972; 1980; Williams, 1978) or somewhere to the southeast (Rankin, 1975). The eastern part of the Inner Piedmont just west of the Kings Mountain shear zone is not a good candidate for a root zone. Dip angles are low to moderate, axial surfaces of the most conspicuous folds are highly variable, and there is no zone of steeply dipping, highly appressed structures typical of root zones elsewhere. Inner Piedmont structures are truncated by the Kings Mountain shear zone and are probably detached from their root zone (Horton, 1981).

Griffin (1978, this volume) proposed a stockwork model for the Inner Piedmont and adjacent belts, in which the Inner Piedmont is the infrastructure and adjacent lower grade belts are the suprastructure. The Lowndesville belt is interpreted to be a detachment zone between the lower and upper levels. This model implies that the Inner Piedmont and the belts southeast of it are part of the same crustal block, although there may be considerable displacement along the detachment. Nelson (this volume) proposes an alternative view, that the Lowndesville zone and related features are the boundary between major crustal blocks, and implies that the blocks on opposite sides of the Lowndesville had a separate history until joined along the zone. If major movement took place on the Kings Mountain and Lowndesville shear zones after regional metamorphism in the adjacent blocks, then the terranes on opposite sides may or may not be part of the same infrastructure-suprastructure tectonic package.

Seismic-reflection profiles across the southern Appalachians are the basis of radical new ideas on large-scale Appalachian structure (Cook and others, 1979; Harris and Bayer, 1979). The COCORP seismic profile in eastern Georgia crosses structures discussed here. This profile shows strong reflectors at a depth of 6 to 15 km from the Valley and Ridge Province to the vicinity of the Elberton Granite batholith and Middleton-Lowndesville cataclastic zone, a distance of about 250 km. These reflectors are interpreted to be a sole thrust beneath an allochthonous upper block, and the Brevard zone is interpreted to be a splay fault (Cook and others, 1979, 1980). Horizontal reflectors below the Elberton Granite batholith led Cook and others (1979) to conclude that the batholith was transported. In an opposing view, Ellwood and others (1980) interpreted paleomagnetic data and geological relationships to indicate that the Elberton Granite was emplaced after major thrusting and that the age of 350 m.y. ± 11 m.y. for the granite is a younger limit on the time of thrusting. Just east of the Elberton Granite batholith and Middleton-Lowndesville cataclastic zone, the layered reflectors have an eastward dip and their thickness increases (Cook and others, 1979). Dipping reflectors southeast of the batholith led Hatcher and Zietz (1980) to conclude that the area was the root zone of the main sole thrust. Cook and others (1979) preferred the interpretation that the change in attitude and thickness marked the transition to a thicker sedimentary section and that the sole thrust continued southeastward beneath the Charlotte and Carolina slate belts.

These controversies cannot be resolved without more information. Discoveries in the past few years have only clarified the correct questions to be asked. They now point to the critical areas that still need to be mapped in detail and types of new studies that need to be conducted to clarify the geologic history of the Kings Mountain belt.

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Field guide to the geology of the Kings Mountain belt between Gaffney, South Carolina, and Lincolnton, North Carolina

J. Wright Horton, Jr., U.S. Geological Survey, Reston, VA 22092; J. Robert Butler, Department of Geology, University of North Carolina, Chapel Hill, NC 27514; Malcolm F. Schaeffer, Duke Power Company, P. O. Box 33189, Charlotte, NC 28242; Cynthia F. Murphy, Department of Geology, University of Georgia, Athens, GA 30602; John M. Connor, Kings Mountain Mica Co., P.O Box 709, Kings Mountain, NC 28086; Daniel J. Milton, U.S. Geological Survey, Reston, VA 22092; and Willard E. Sharp, Department of Geology, University of South Carolina, Columbia, SC 29208

INTRODUCTION

The field trips on both Saturday, October 24, and Sunday, October 25, 1981, will assemble at the Holiday Inn, intersection of SC-11 and I-85, Gaffney, S.C. Both trips are by bus only. Participants should reach the assembly point in time to depart at 8:00 a.m. on both days.

The Saturday trip consists of six and possibly seven stops between Gaffney, S.C. and Lincolnton, N.C. (Figs. 1 and 2). Our objective is to provide a regional overview of the central and northern portions of the Kings Mountain belt and adjacent areas along its northwestern flank. The emphasis is on the regional structure, distinctive lithologies, and economic geology. Stops 2, 3, and 4 are in active mines. The operators have been very cooperative in allowing us to make these stops, but neither they nor we can be responsible for personal injuries. You are expected to wear a hard hat and safety glasses and to observe normal precautions. Avoid dangerous overhangs and loose material in the walls.

The Sunday morning trip consists of five stops (Fig. 2), primarily to look at typical Kings Mountain belt lithologies in north-central South Carolina between Gaffney and Kings Creek. This is the widest segment of the Kings Mountain belt, and studies recently completed (this volume) and in progress make it one of the best known.

The diligent field tripper should read the regional geology paper by Horton (this volume) and the synthesis paper by Horton and Butler (this volume) before reading any of the stop descriptions. The quadrangle that includes stops 1 and 9 is discussed in detail by Butler (this volume) and the area that includes stops 10, 11, and 12 is covered in similar detail by Murphy and Butler (this volume). The paper by White (this volume) deals exclusively with stop 4 and the one by Sharp and Hornig (this volume) does the same with stop 12. The papers by Hatcher and Morgan (this volume) and by France and Brown (this volume) are extremely pertinent to stop 9. Field trippers interested in a more detailed discussion of mesoscopic structures should read the article by Schaeffer (this volume). All stop locations are shown on Horton's regional geologic map (this volume, Plate 1).

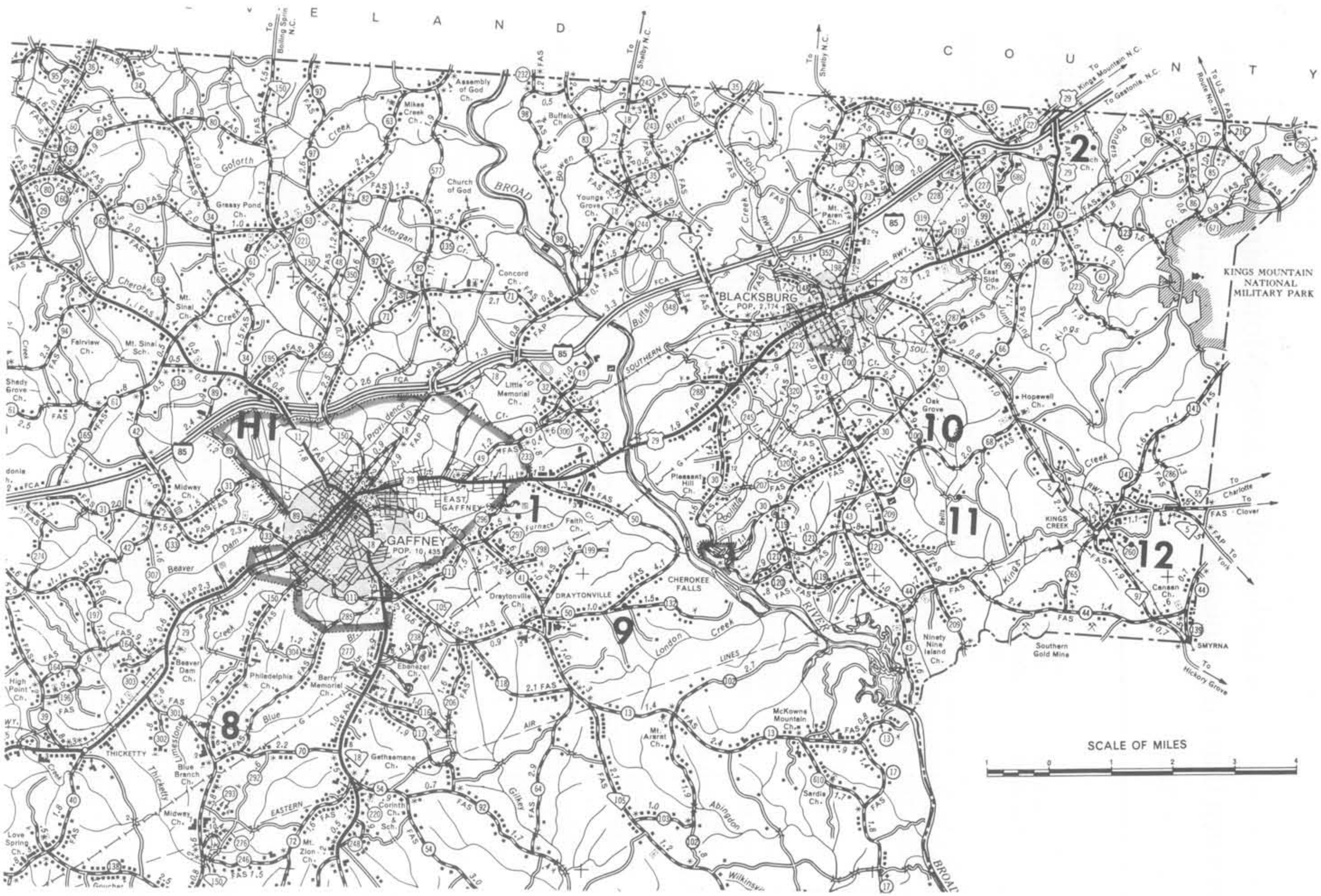

Figure 1. Highway map of the Gaffney-Blacksburg area, South Carolina, showing location of field-trip stops. HI is the location of Holiday Inn-Gaffney, headquarters for the 1981 Carolina Geological Society annual meeting.

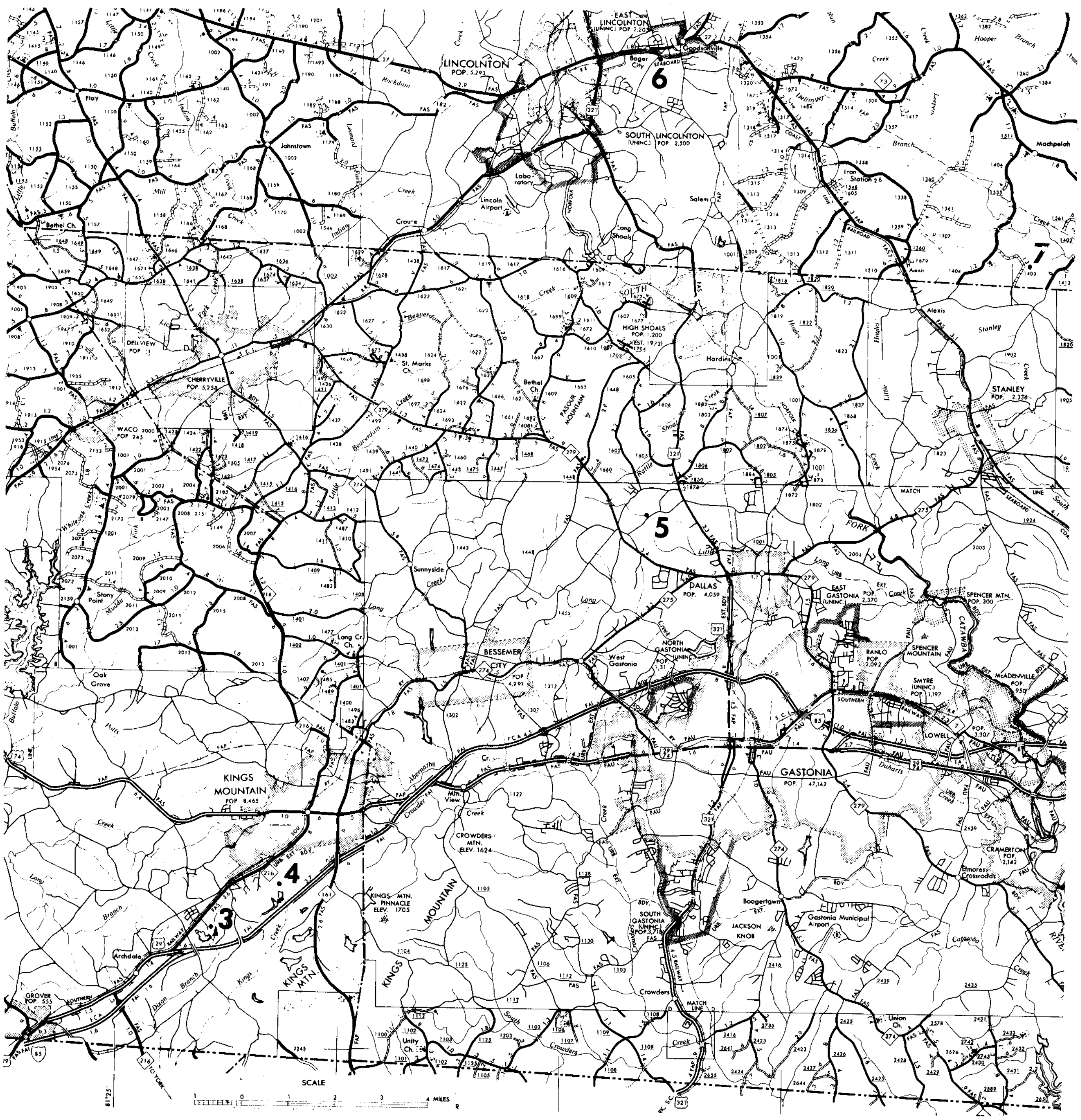

Figure 2. Highway map of the Kings Mountain-Lincolnton area, North Carolina, showing location of field-trip stops.

ROAD LOG - SATURDAY TRIP

Mileage	Itinerary
0.0	Buses leave Holiday Inn parking lot, proceeding left on the frontage road.
0.1	Turn right on frontage road.
0.15	Turn left on frontage road.
0.3	Turn right onto SC-11 (Floyd Baker Blvd.) and proceed southeast across bridge over I-85.
0.8	Bear left on West Frederick Street at traffic light and continue on SC-11.
1.3	Turn left onto SC-18 (North Logan Street).
1.4	Turn right onto West Robinson Street.
1.45	Turn left onto US-29 (North Granard Street).
1.5	Bear right on US-29.
1.6	Proceed straight across SC-18 on Cherokee Avenue.
2.7	Turn right onto S-11-167 at Sav-A-Ton service station.
3.1	Railroad crossing.
3.6	Turn left onto S-11-41.
4.1	Bear left around bend at hill top.
4.3	Turn left onto S-11-296.
4.4	Quartzite outcrop on right.
5.0	Leave buses and walk about 400 m east to a large cut on the Duke Power Company railroad at Peoples Creek.

STOP 1: Muscovite-biotite-chlorite schist with quartzose layers along the Duke Power Company railroad spur to Cherokee Nuclear Station (Blacksburg South 7.5′ quadrangle)

Leaders: Malcolm Schaeffer and Robert Butler.
Maps in this volume: Figure 1; Butler (Fig.1); Horton (Plate 1).
References: Schaeffer (this volume); Butler (this volume).

This cut is an unusually good exposure of a unit that generally weathers deeply. The rocks are in a subsidiary isoclinal fold on the northwest limb of the larger Cherokee Falls synform (Butler, this volume, Fig. 1). The Kings Mountain shear zone (Inner Piedmont boundary) lies about 1.3 km to the northwest (Horton, this volume, Plate 1) This exposure is in the staurolite or kyanite zone, but the isograd positions have not been more precisely defined. The rocks range from dark to light gray and are gradational in composition, having more biotite and chlorite in the darker layers and more quartz and feldspar in the lighter layers. Some of the light-gray layers may be metamorphosed tuffs.

In thin-section, the muscovite-biotite-chlorite schist exhibits lepidoblastic texture with muscovite, biotite, and chlorite representing 60 to 70 modal percent of the rock. The proportions of the micas vary, with muscovite or biotite dominating. Chlorite appears to be an alteration product of biotite. The remainder of the rock contains 20 to 30 modal percent plagioclase. The percentage of each is difficult to determine because of untwinned plagioclase. Accessory minerals are apatite, magnetite, pyrite, staurolite, and garnet. Minor kinking and flexure folding is visible in thin section and is defined by the bending of the micas.

The lighter colored schist layers contain subhedral to euhedral plagioclase crystals (20 to 30 modal percent) that are slightly altered. The very fine grained groundmass is mainly composed of small crystals of quartz and feldspar, including minor fine-grained microcline and untwinned plagioclase. Platy minerals (muscovite-sericite, biotite, and chlorite) are segregated into thin, subparallel planes that define the schistosity. Trace amounts of opaque minerals, apatite, and zircon(?) are present.

Several mesoscopic structures show better development in the more schistose lithologies. The main schistosity, probably S_2, has an average orientation of about N. 60° E. 48° SE. This schistosity overprints and transposes S_1 which is indicated by rare relict cleavage and disrupted compositional layering. Rare F_1 folds are preserved as small-scale (wavelength 1 to 3 cm), isoclinal, "S"- or "Z"-shaped or crescent-shaped fragments (Fig. 3A). The F_2 folds are isoclinal with S_2 representing the axial planar schistosity (Figs. 3B, 3C). Mineral elongation lineations, L_2, can be observed on S_2 planes and they are approximately parallel ("b" direction) to the F_2 fold axes (Fig. 3B). Fine crenulations, having axial surfaces about 1 mm apart with northeast strikes and steep northwesterly dips, may be related to the D_3 deformation of Schaeffer (this volume). F_4 folds are flexural-slip and kink folds which have steeply dipping axial surfaces (Fig. 3E). Crenulation lineations are related to a set of cleavages spaced about 1 cm apart which strike east and have steep northerly dips. In places, the crenulations fold the L_2 mineral elongation lineations. The crenulations (Fig. 3F) may be an expression of the D_5 deformation of Schaeffer (this volume).

Return to buses and continue.

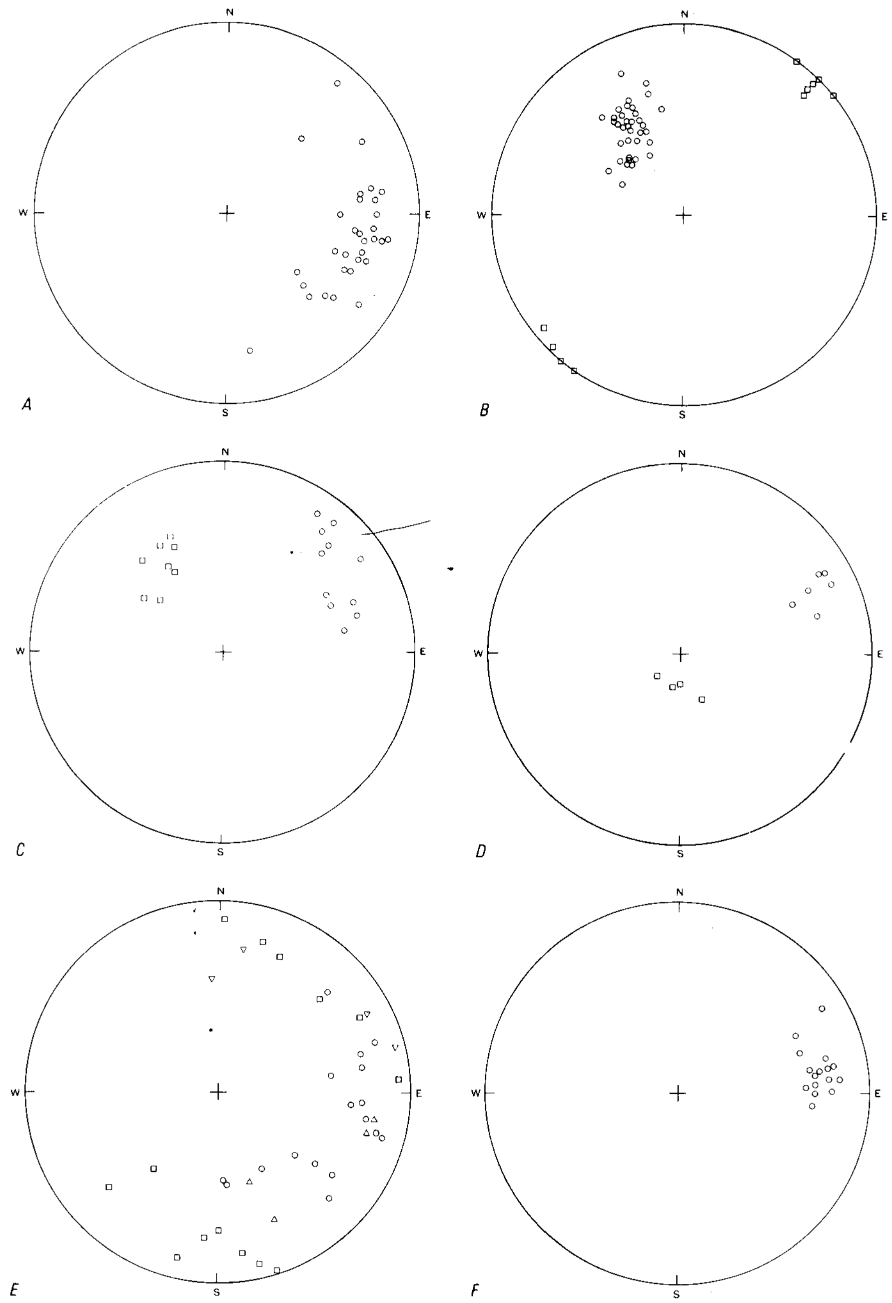

Figure 3. Lower hemisphere, equal-area projections of mesoscopic structures at stop 1: (A) 31 F_1 fold axes; (B) 36 poles to S_2 foliation planes (circles) and 10 L_2 mineral elongation lineations (squares); (C) 11 F_2 fold axes (circles) and 8 poles to F_2 axial planes (squares); (D) 6 F_4 fold axes (circles) and 4 poles to F_4 axial planes (squares); (E) 17 F_5 fold axes (circles), 4 F_5 kink axes (triangles), 14 poles to F_5 axial planes (squares), and 4 poles to F_5 kink planes (inverted triangles); (F) 16 crinkle lineations (L_5?).

5.4 Turn right onto US-29.

6.5 Outcrop of thinly interlayered dirty quartzite and hornblende schist.

7.0 Cross bridge over Cherokee Creek.

7.25 Cross intersection with new road S-11-32.

7.3 Cross bridge over Broad River.

9.6 Outcrop of Blacksburg Schist (phyllite) on right.

10.7 Enter Blacksburg, S.C. city limits. Blacksburg's traditional name, "The Iron City," is a reminder of the importance of iron mining to the early development of the region (Moss, this volume).

11.5 Pass intersection with SC-5. Iron City Pharmacy on right.

11.9 Cross railroad bridge.

12.3 Continue straight on US-29, passing another SC-5 intersection.

14.8 Continue straight on US-29, passing S-11-21 turnoff to Kings Mountain National Military Park, the site of the defeat of colonial loyalist troops by a rebel force of backwoodsmen on Oct. 7, 1780, one of the major Revolutionary War battles in the South.

16.1 View of inactive (since 1979) Vulcan Materials marble quarry on the left. This quarry was stop 4 on the 1977 G.S.A. field trip (Horton and Butler, 1977). The lower levels are now filled with water.

16.6 Turn right onto frontage road.

16.8 Bear right and continue along frontage road parallel to I-85.

17.3 Right bend in road.

17.9 Leave buses and enter new Vulcan Materials marble quarry.

STOP 2: Marble at The Vulcan Materials Grover quarry (Grover 7.5′ quadrangle)

Leader: Wright Horton. Possible comments by Horace Whelchel.
Maps in this volume: Figure 1; Horton (Plate 1).
Reference: Horton (this volume).

This medium light-gray to medium dark-gray banded dolomitic marble is part of the Gaffney Marble as defined by Loughlin and others (1921). It is generally typical of marble in the Kings Mountain belt, but appears more Mg-rich and more graphitic than average. The following chemical analysis in weight percent (sample #2278, 2/29/80) was provided by Vulcan Materials Co.: 50.4% $CaCO_3$, 31.7% $MgCO_3$, 2.3% Fe and Al oxides, and 15.6% acid insoluble material. This analysis is representative of the commercial product which may include minor amounts of amphibolite mixed with the marble. The stone quarried here is used as agricultural lime and crushed stone.

The true thickness of the marble at this locality is about 100 m. The compositional layering and parallel foliation are oriented about N. 73° E. 45° NW. A mineral lineation plunging about 30° N. 50° E. was also noted. Needles of white tremolite are locally concentrated along foliation planes in random mats and radial sunbursts. Lenses of amphibolite and calc-silicate rock occur locally within the marble. Contacts between the marble and Blacksburg Schist (medium gray biotite-sericite schist) on either side are characterized by interfingering. Staurolite has not yet been found in the vicinity of the quarry but the metamorphic grade is inferred to be lower amphibolite facies (staurolite zone) on the basis of isograds from Horton (this volume, Fig. 2).

Vulcan Materials Co. shifted its operation from the Blacksburg quarry to this site in April, 1979, following exploratory drilling and preliminary excavations during 1978. The present open pit encompasses the site of the old Whisonant quarry (Keith and Sterrett, 1931) and an elongate pit, 2 to 3 m wide with vertical walls supported by timbers, was uncovered in 1978 during the early stages of excavation. Old tools and other relics were reportedly recovered by mine employees (Horace Whelchel, personal commun.). An old kiln was also removed from the site.

Return to buses and head back to US-29 along the frontage road.

19.1 At end of frontage road, turn right and proceed on US-29.

19.5 Cross North Carolina State line at Grover and continue northeast on US-29.

21.3 Railroad crossing.

21.4 Pass Kings Mountain Brick, Inc. on left. The unusual white brick is made from clay produced at Stop 3.

21.7 Pass Military Park Service Station and intersection with NC-216.

22.2 On a clear day, Cherry Mountain and the South Mountains are visible on the left (about 30 miles northwest). Kings Mountain can be seen on the right.

23.0 Turn left onto NC-216 and continue to the northeast.

23.75 Cross CR-2245 (county road) intersection and proceed northeast on NC-216.

23.9 Turn right at entrance to Kings Mountain Mica Company. John Connor, the company's Chief Geologist, will lead us into the mine.

STOP 3: The Moss mine of Kings Mountain Mica Co., Inc. (Grover 7.5' quadrangle)

Leaders: John Connor and Wright Horton.
Maps in this volume: Figure 2; Horton (Plate 1).
Reference: Horton (this volume).

Kings Mountain Mica Company, Inc. mines a coarse-grained phase of the Cherryville Quartz Monzonite for mica, feldspar, quartz, and kaolin. Mining is generally restricted to the weathered horizon which ranges 6-42 m in depth. Overburden, material that is off color or does not meet chemical specifications, may be as thick as 6 m, but averages about 3 m in depth. The coarse-grained granite is gradational into pegmatite and is also cut by pegmatite dikes. Locally, the pegmatitic granite displays graphic intergrowths of feldspar and quartz. Schist, which occurs as screens and xenoliths throughout the ore body, is usually recognizable at the surface and avoidable in mine planning; however, xenoliths are also found "floating" within the ore body. Efforts are made to avoid any schist during the course of mining to minimize discoloration of mica and clay. Primary ore minerals are muscovite, feldspar, and quartz. Secondary kaolin is also considered an ore mineral. Accessory minerals are garnet, biotite, vermiculite and halloysite. Irregular weathering causes the quality of ore to vary considerably. As the kaolin is a product of the weathering of feldspar, the proportion of feldspar to clay increases with depth. The ore also displays lateral changes in quality, dependent upon the degree of weathering, which is related to the local density of fractures within the body. Mica and quartz percentages are quite constant. The company produces potassium feldspar as a by-product of its mica operations. Current specifications for feldspar are 10% K_2O (wt. %). In relatively unweathered rock, feldspar may constitute as much as 40% (wt. %) of the total rock, but K_2O may be only 6 to 7 percent (wt. %) of the feldspar. In the more weathered upper horizons, feldspar containing more than 13% (wt. %) K_2O may constitute less than 2% (wt. %) of the total ore.

Because of the great differences in the quality and quantity of feldspar, ore is blended to assure a constant headfeed to the plant for processing. Although ores from different parts of the mine may be chemically similar, they do not respond similarly to the separation process. To insure a uniform headfeed to the plant, mine planning based upon detailed drill hole analysis is necessary. Drill hole patterns are usually on a 30.5 m (100 foot) grid. In areas of erratic ore quality, closer spaced drilling may be necessary to evaluate and properly utilize all the ore body. The quality of the feldspar in the ore dictates the mining strategy and equipment used in the mining process. In areas of consistently soft ore of reasonably uniform quality, scraper pans may be used. In areas where ore quality is erratic, backhoes and trucks are used. Mined ore is crushed and sized to pass a 1-inch screen, then fed to the plant by means of front loaders. The clay is hydraulically removed and processed into a semi-dry material for the manufacture of structural clay products. The other minerals are subjected to rod milling followed by separation of coarse mica by Humphrey spirals. Separation of fine mica, feldspar and quartz is accomplished by flotation. Subsequent drying, grinding, and sizing prepare these concentrates for shipment.

The materials produced by Kings Mountain Mica Company, Inc. find varied industrial applications. Mica is used as a reinforcing agent in paints, plastics, wallboard, and caulking compounds. Potash feldspar is used in ceramics when the ability to withstand electrical and thermal shock is neccessary (e.g. electrical insulators and television picture tubes). The quartz sand is used as a melt in the production of glass containers. A subsidiary company, Kings Mountain Brick, Inc., produces white brick from the clay.

The schistosity, S_1, in schist at the mine is oriented about N. 38° E. 70° NW. with some variation. A superimposed crenulation cleavage, S_3, is oriented about N.70° E. 65° SE. and crenulations (F_3) produced by the intersection of this cleavage with S_1 plunge about 33° S. 41° W. (Horton and Butler, 1977, Fig. 11).

The Cherryville Quartz Monzonite is locally discordant to S_1 in the adjacent schist at this mine and elsewhere and, therefore, is younger than D_1, the earliest deformation event. Furthermore, the Cherryville is not involved in the tight to isoclinal recumbent to inclined F_2 folds of the Inner Piedmont and, therefore, is younger than D_2 as well (J. W. Horton, unpub. data; Richard Goldsmith, this volume, and personal commun.). However, the Cherryville is deformed by mesoscopic and macroscopic upright open folds and crenulations (F_3) which trend northeast along the southeastern flank of the Inner Piedmont belt. These relationships, the absence of a contact aureole (other than greisen), and the relationships of deformational events to regional metamorphism (Horton, this volume) suggest that the Cherryville may have been emplaced during the waning stages of regional metamorphism. Kish (1977) reported Rb-Sr whole-rock ages of 341±11 m.y. for the Cherryville and 343±14 m.y. for the related quartz monzonite pegmatites. The closeness of the Rb-Sr biotite (375 m.y.) and muscovite (350 m.y.) ages of Davis and others (1962) to the whole-rock age suggests rapid cooling and uplift after crystallization.

Relatively late ductile shear zones as thick as 30 cm cut the Cherryville and related pegmatites. They are nearly vertical and strike N. 30-40° W. at this locality. Two diabase dikes of probable Mesozoic age cut other rocks in the mine and one bifurcates within the mine.

Return to US-29 and <u>proceed</u> northwest (right) toward Kings Mountain, N.C.

25.4 U.S. Gypsum plant on the right.

25.6 Railroad crossing. Crenulated muscovite schist of the Inner

Piedmont belt is well exposed in the railroad cut on our left.

25.9 Turn right onto CR-2291 at the Foote Mineral Company sign just beyond Macedonia Baptist Church.

26.2 Bear left on paved fork in road.

26.3 Bear left again.

26.4 Saprolite exposure of Cherryville Quartz Monzonite in ditch.

26.5 Gate house at entrance to Foote mine. Advance permission is required to proceed beyond this point.

26.8 Foote Mineral Company mine office and parking lot. Bill Champa, the mine geologist, will accompany us from here.

STOP 4 (LUNCH): Spodumene pegmatite at the Foote mine (Kings Mountain 7.5' quadrangle)

Leader: Wright Horton. Possible comments by Bill Champa and John White.
Maps in this volume: Figure 2, Figure 4; Horton (Plate 1).
References: White (this volume); Horton (this volume).

The Foote mine lies within a narrow, 40 km long belt of spodumene pegmatites known as the Carolina tin-spodumene belt. This belt contains one of the world's largest reserves of lithium, according to Kesler (1976) and Kunasz (1976). The spodumene-pegmatite dikes of the Carolina tin-spodumene belt are present only in the Kings Mountain shear zone or within 300 m northwest of it (Horton, 1981). The fine-grained phyllonitic schist on the southeast side of the mine lies within the Kings Mountain shear zone, which marks the boundary between the Kings Mountain and Inner Piedmont belts in this area.

This mine, operated by Foote Mineral Company, is one of two large open pit mines in the spodumene pegmatites. The ore is crushed and spodumene, the main product, is separated by flotation. Feldspar and mica are recovered as by-products. Some of the amphibolite "waste" material is processed by Martin Marietta Corp. for crushed stone. Lithium Corporation of America has a similar operation 7 km northwest of Bessemer City, N.C.

Most of the spodumene pegmatites in the mine are intruded into thin-layered amphibolite, but some are also intruded into fine-grained phyllonitic schist on the southeast side of the mine (Fig. 4). The amphibolite consists mainly of green hornblende, plagioclase, and quartz with small amounts of sphene, epidote, and other accessory minerals. It also includes light-colored layers of calc-silicate minerals and calcite and schistose layers of biotite and chlorite. Holmquistite, a lithium amphibole, and biotite are abundant in

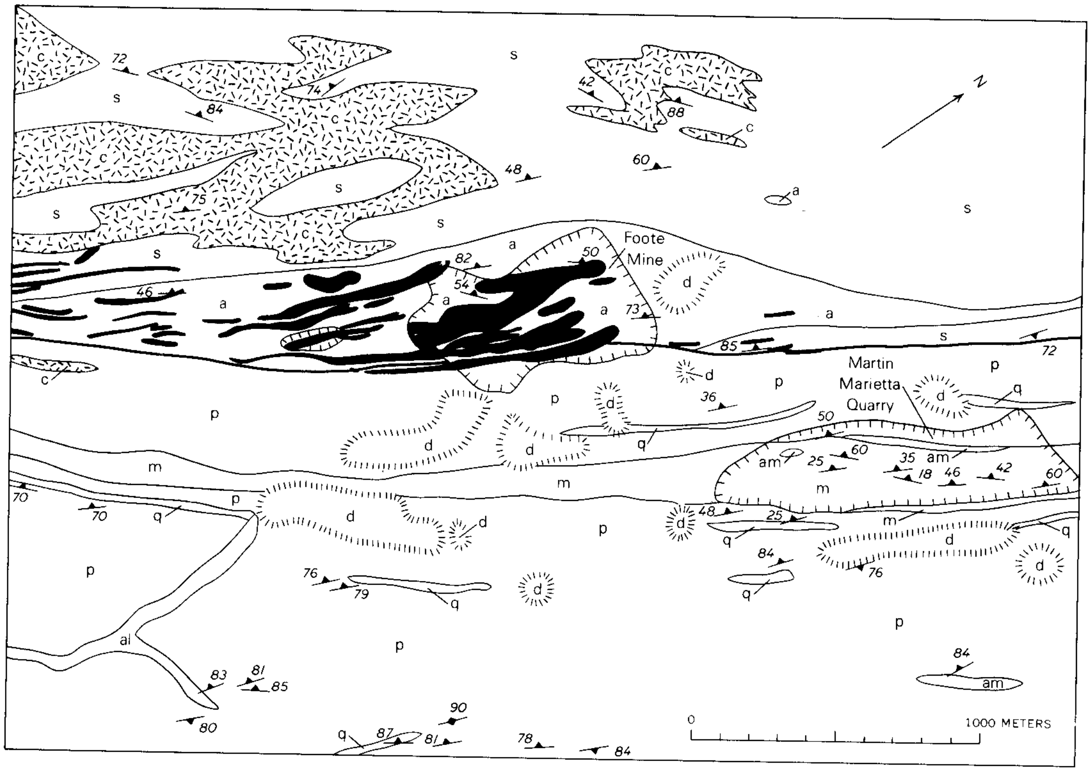

Figure 4. Geologic map of the Foote mine and vicinity (Kings Mountain 7.5′ quadrangle). Map units: d=mine dump; al=alluvium; (blackened areas)=spodumene pegmatite; C=Cherryville Quartz Monzonite; a=amphibolite of the Inner Piedmont belt (IP); s=white mica schist (IP); am= amphibolite of the Kings Mountain belt (KM); m=marble (KM); q= quartzite (KM); p=phyllitic metasiltstone (KM).

hydrothermally altered amphibolite adjacent to the pegmatite contacts. The phyllonitic schist in the mine consists mainly of muscovite, biotite, plagioclase, and quartz, with garnet, staurolite, andalusite, tourmaline, and chlorite as accessory minerals.

Kesler (1961) reported that the spodumene pegmatite has an average mineral composition by weight of 20% spodumene, 32% quartz, 27% albite, 14% microcline, 6% muscovite, and 1% trace minerals (these percentages were based on long-term observations of the milling of crude ore from the mine). Primary trace minerals include zircon, beryl, cassiterite, and columbite-tantalite. Only two minerals, spodumene and microcline, have the coarse sizes usually associated with pegmatites, and these are seldom longer than 30 cm. Compositional zoning occurs only on a very small scale in the pegmatites. White (this volume) has recognized four stages of mineral crystallization at the Foote mine, noting that each of the nearly 100 minerals recognized so far can be assigned to one of these stages. The Rb-Sr whole-rock age of the pegmatite, 352 ± 10 m.y. (Kish, 1977), is very close to that of the nearby Cherryville Quartz Monzonite, supporting other arguments (Kesler, 1961) that they are related.

Norton (1973), Kesler (1976), and Stewart (1978) have proposed models for the origin of the Kings Mountain spodumene pegmatite by anatexis of lithium-bearing sediments. Norton (1973) noted that these pegmatites have the same composition as the liquid with the minimum melting temperature in the feldspar-quartz-spodumene system. Stewart (1978) showed experimentally that magma of this composition could form by partial melting of Li-bearing rock at temperatures 75°C or more below the minimum melting temperature of granite at the same partial pressure of H_2O. He proposed that the Li-rich pegmatite magma formed first and that related granite magma, in this case the Cherryville, formed slightly later as a result of further heating in the source area. Stewart considers fractional crystallization unlikely because of mechanical problems required by the great volume of parent magma necessary to produce even a small fraction of restite liquid. White (this volume) asserts that hydrous phases such as muscovite are rare, thus indicating that the magma was exceptionally dry. Kesler (1961), however, stated that the average pegmatite at the mine contains 6% muscovite (wt. %). White (this volume) also presents evidence suggesting that the magma was almost, if not completely, crystallized at the time of emplacement.

Two generations of aplite dikes are present in the Foote mine. Both are composed primarily of albite and quartz and contain small variable amounts of microcline and other accessories (Luster, 1976). The younger aplites differ from the older ones in that they contain trace amounts of spodumene, have chilled margins, and are surrounded by zones of biotite alteration in the adjacent amphibolite (Gordon Luster, 1976, unpublished manuscript, Pennsylvania State University, furnished by Foote Mineral Company). The older aplite dikes are seldom thicker than 3 cm whereas the younger ones may be as much as 15 cm thick.

Five generations of folding and related deformation have been recognized at the Foote mine. The earliest folds, F_1, are rare. Where present they are isoclinal intrafolial folds with an axial-planar foliation. They are most easily recognized where calc-silicate and carbonate layers provide well-developed compositional layering in the amphibolite. F_2 folds are tight to isoclinal with axes plunging gently to moderately southwest and northeast.

Their axial planar schistosity, S_2, has an average orientation of N. 34 E. 58° NW. S_2 and S_1 are sub-parallel and their intersection produces thin wedges and crenulations in the schist. Relationships where F_1 folds are refolded by F_2 folds indicate that S_2 is the dominant foliation in the amphibolite as well as in the schist.

A steep northwest-dipping slip cleavage, S_3, similar to the one that cuts the mylonitic foliation in many parts of the Kings Mountain shear zone, cuts the older S_2 foliation in phyllonitic schist here. Crenulation axes, F_3, plunge gently southwest where the surfaces intersect. These crenulations are not present in the amphibolite, but a few mineral lineations have the same orientation. Spodumene pegmatite dikes which also discordantly cut S_2 are commonly parallel to the S_3 cleavage, indicating that they were emplaced during or after the deformation that produced the cleavage. Amphibolite, which does not show the cleavage, is commonly brecciated adjacent to the pegmatite contacts, as shown by Kesler (1961, Fig. 4). Some spodumene pegmatite dikes appear highly deformed and have an augen gneiss texture. Their foliation is parallel to the dike contacts and to the S_3 slip cleavage in phyllonitic schist adjacent to the contacts. Other spodumene pegmatite dikes, however, show no evidence of deformation. Horton (1981) interpreted the Late Devonian Rb-Sr whole rock age of spodumene pegmatite as a minimum age for deformation in the Kings Mountain shear zone and argued that pegmatites were emplaced during the latest stages of deformation in that zone. Several tight-to-isoclinal folds in the pegmatites have northeast-plunging axes and axial surfaces parallel to the foliation (S_3?) in the foliated pegmatites. They appear to be deformation features but do not deform the contacts with the adjacent wallrock and may be related to forceful emplacement of the pegmatites.

Mesoscopic open folds and kinks, F_4, have axes plunging gently northeast and southwest and axial surfaces that dip gently eastward. The best place to see them is in phyllonitic schist along the east wall of the pit. F_5 is characterized by gentle crenulations which deform S_2 and plunge 55° N. 56° W. An open cross-fold in a schist layer in the amphibolite has an axis plunging 75° N. 53° W. Northwest-plunging, down-dip lineations are commonly developed in the amphibolite, but seldom in the schist. They appear as the hinges of small open crenulations and sometimes as elongation lineations of parallel hornblende crystals. These lineations plunge 50-60° N. 56° W. Overprint criteria to establish the relative timing of F_4 and F_5 have not been observed at the Foote mine but these folds are similar in orientation and style to F_4 and F_5 of Schaeffer (this volume).

Fault planes are nearly vertical and cluster in two groups, one striking about N. 15° E. and another striking about N. 85° W. (Horton and Butler, 1977, Fig. 6F). Offsets are no greater than a few meters. The faults striking N. 15° E. appear to be parallel to the pegmatite contacts. The pegmatites may have been emplaced along earlier or contemporaneous planes of weakness of this orientation. Pegmatite is slightly offset by one of these northeast-trending faults, indicating some movement after emplacement of the pegmatites. Along faults striking N. 85° W., both the pegmatite and amphibolite are brecciated, indicating that these faults post-date the initial pegmatite intrusions. Faults of this orientation have been observed nowhere else in the region, however, suggesting that these younger faults at the Foote mine might be related in some way to stresses associated with the pegmatite intrusions. The largest of these faults, exposed on the north wall of the mine, has a zone of cohesive breccia about 30 cm thick, along which amphibolite is chloritized. Many interesting secondary minerals have been reported in the nearly vertical east-west fractures which cut the pegmatites (White, this volume).

After boarding the buses, we will return to NC-216, the way we came in.

27.0	Pass gatehouse.
27.1	Bear right at stop sign.
27.5	Turn right and proceed northeast on N.C. 216.
27.9	Pass Foote's open pit and waste piles on the right.
28.3	Pass the entrance to Martin Marietta's marble quarry on the right. The quarry is inactive and its lower levels are filled with water. Amphibolite "waste" from the Foote mine is processed here and sold as crushed stone.
29.1	Turn right onto US-74 (King Street) in Kings Mountain, N.C.
29.6	Turn left on NC-161 at Hardee's.
30.2	Pass under new bridge of US-74 Bypass.
31.4	Cross county line from Cleveland County into Gaston County.
32.9	Lithium Corporation of America chemical plant on the right. The L.C.A. open pit spodumene mine 6.8 km (4.2 miles) north of here is similar to the Foote mine (stop 4).
33.1	Enter the city limits of Bessemer City.
33.8	Micaceous quartzite with thin layers of gray phyllite in the road cut. This quartzite bed continues northeast and underlies Pasour Mountain north of Bessemer City.
34.45	Follow NC-161 to the left and beneath the railroad overpass.
34.5	Turn right on NC-274 (Virginia Avenue) at traffic light.
34.7	Pass traffic light in downtown Bessemer City and continue straight on NC-274.

35.8 — Turn left onto CR-1452 (Costner Road) at The Pantry convenience store.

37.8 — View of Pasour Mountain ahead, one of the prominent quartzite ridges in the Kings Mountain belt.

39.8 — Turn right at stop sign onto NC-279.

39.85 — Turn left onto CR-1600.

40.1 — Turn left onto CR-1601 in front of Costner Elementary School.

40.7 — Bridge over Little Long Creek. Leave buses and walk upstream.

STOP 5. "High Shoals" granitic gneiss at Little Long Creek (Gastonia North 7.5' quadrangle)

Leaders: Wright Horton and Robert Butler.
Maps in this volume: Figure 2; Horton (Plate 1).
References: Horton (this volume); Milton (this volume).

The "High Shoals" granitic gneiss (Horton and Butler, 1977) is a pluton of batholithic size that divides the northern end of the Kings Mountain belt into two prongs (Horton, this volume). The very light gray, coarse-grained, porphyritic, gneissic biotite granite or granitic gneiss at this exposure is typical of the "High Shoals". It consists of oligoclase and albite (35%), microcline (25%), quartz (22%), brown biotite (13%), myrmekite (3%), sphene (1%), and trace amounts of epidote, allanite, zircon, and apatite (Horton and Butler, 1977, p. 137). White, euhedral to subhedral phenocrysts of microperthitic microcline average about 1.5 cm in length but locally are as long as 5 cm. Oligoclase (An_{24-30}) forms zoned euhedral to subhedral crystals 1 to 5 mm long. Sodic oligoclase or albite forms small grains, some of which are myrmekitic, and rims around larger oligoclase crystals.

Field relationships indicate that the "High Shoals" was emplaced during the late stages of F_2 folding, close in time to the thermal peak of amphibolite facies metamorphism (Horton, this volume). At this locality, the "High Shoals" contains schlieren of biotite schist and gneiss, and xenoliths of amphibolite. The amphibolite xenoliths contain an old foliation, S_1, which is locally discordant with the younger foliation in the "High Shoals".

Subtle layering, defined by variation in the abundance of microcline phenocrysts, is warped around xenoliths in places and is interpreted as primary igneous flow banding. Microcline phenocrysts, tabular along (010), are preferentially oriented and define a foliation that typically strikes N. 14-33° E. and dips almost vertically. The phenocryst foliation is locally parallel to the igneous flow banding and schlieren and may be, in part, a primary igneous texture similar to that reported by van Gelder and McSween (this volume) in the "Bald Rock" granite. The phenocryst foliation is at least partly metamorphic in origin and it locally transects the schlieren and flow layering. It is generally parallel to the dominant S_2 foliation in rocks adjacent to the pluton and is sufficiently strong in some areas to produce an augen gneiss texture. In many parts of this exposure, biotite is oriented parallel to the phenocryst foliation, S_2. In other parts, the biotite defines a weaker subvertical foliation (S_3?) which typically strikes N. 31-51° E., noticeably east of the phenocryst foliation (N. 14-33° E.) on which it is overprinted. We have not determined how this second biotite foliation fits into the regional structural chronology.

Both foliated and non-foliated aplite dikes are nearly vertical. The foliated aplite dikes generally strike N. 0-20° E. The non-foliated dikes also strike north to northeast but have more variation.

A prominent set of subvertical joints strikes N. 72-79° W. and controls the steps of small waterfalls at this exposure.

The small drill holes at this locality represent samples taken for paleomagnetic determinations. Pole positions from several widely spaced outcrops in the "High Shoals" are highly consistent and they cluster with other Paleozoic poles from North America (L. Brown, 1981, personal commun.). This suggests that the "High Shoals" is Paleozoic in age and that the Kings Mountain belt was part of North America when the "High Shoals" cooled below the Curie temperature of magnetite.

	Return to buses and <u>continue</u> on CR-1601.
41.6	Turn left at stop sign onto US-321 toward Lincolnton.
41.65	"High Shoals" granitic gneiss is well exposed at the falls on Rattle Shoal Creek to the right.
42.0	Enter city limits of High Shoals.
45.9	Cross bridge over the South Fork Catawba River. Continue on US-321. The "High Shoals" granitic gneiss is well exposed at its type locality just east of (and below) the dam on our right.
46.8	Cross county line from Gaston County into Lincoln County.
47.1	Bear left and continue on US-321, passing CR-1307 intersection.
47.9	Outcrop of schistose quartz-pebble conglomerate.
49.2	Pisgah Church on left.
49.25	Quartzite outcrop on right.
50.3	Old bedrock workings in cassiterite-bearing greisen of the Ka-Mi-Tin mine are about 1 km to our right.

50.8 Turn right and continue north on US-321, passing NC-150 intersection.

51.1 Outcrops of Cherryville Quartz Monzonite.

51.6 Cross bridge over Lithia Branch.

51.8 Outcrop on the right of tourmaline-bearing muscovite schist of the Inner Piedmont.

52.0 Turn right onto CR-1262.

52.6 Spodumene-bearing pegmatite is exposed for several hundred feet along the edge of the Lincolnton Country Club golf course on our right.

52.8 Turn left onto CR-1294.

53.0 Kings Mountain shear zone. Outcrop of phyllonite of Kings Mountain belt affinity in front of Pentecostal Holiness Church.

53.8 Railroad crossing at Lowe's hardware store. Leave buses and walk east (right) along the tracks. This is a main line, so WATCH FOR TRAINS!

STOP 6: Kings Mountain shear zone at Boger City, N.C. (Lincolnton East 7.5' quadrangle)

Leader: Wright Horton.
Maps in this volume: Figure 2; Horton (Plate 1).
Reference: Horton (this volume).

The Kings Mountain shear zone marks the boundary between the Kings Mountain and Inner Piedmont belts in the region of today's field trip (Horton, 1981; Horton, this volume). The outcrop width of the zone is about 1 km in this area, and rocks of the shear zone are well exposed in railroad cuts at this locality.

The medium light-gray to dark-gray phyllonite here is derived from Kings Mountain belt metasedimentary rocks equivalent to those called Blacksburg Schist by Keith and Sterrett (1931) in the Gaffney-Kings Mountain area.

The dominant schistosity here is believed to be S_2. A pre-existing schistosity, S_1, is folded around the hinges of microscopic isoclinal F_2 folds. Two sets of crenulations and chevron folds, F_3 and F_4, and related crenulation cleavages, S_3 and S_4, are prominent here. S_3 is typically oriented about N. 35° E. 75° NW. F_3 crenulations and chevron folds plunge 16-35° NE. When viewed down-plunge, their asymmetry is consistently dextral, suggesting that the Inner Piedmont moved up relative to the Kings Mountain belt. Close examination with a hand lens reveals that F_4 crenulations deform those of F_3 at this locality. F_4 crenulations and fold axes plunge northeast at angles similar to those of F_3, but unlike F_3, their asymmetry viewed down-plunge to the northeast is consistently sinistral. S_4 dips gently northwest or southeast, in sharp contrast to the steep dips of S_3. S_4 also strikes northeast, but measured angles are more variable because of the gentle dips. Delicate needles of tourmaline and thin platy crystals of altered ilmenite, visible with a hand lens, cut across both sets of crenulations without evidence of deformation.

Brittle faults, which vary in orientation and sense of displacement, are another relatively late feature in these outcrops. Drag folds associated with these faults vary in orientation as do older structures which have been rotated. Faults striking N. 30-40° E., parallel to the mapped trace of the Kings Mountain shear zone, are probably first-order shears. Others, striking northwest, may be second-order and third-order shears. This is speculation, however, and additional work is necessary before such conclusions can be accepted.

Return to buses and continue north on CR-1294. (If time requires us to skip optional stop 7, we will return to US-321, follow it south to I-85, and continue south on I-85 to Gaffney.)

54.0 Turn right onto NC-27 in Boger City.

54.6 Bear right and continue on NC-27, passing NC-150 intersection.

55.3 Continue straight on NC-7, passing NC-73 intersection.

57.7 Soil indicative of "High Shoals" granitic gneiss. The large residual microcline phenocrysts may be visible from the bus.

58.8 Village of Iron Station, N.C. Notice the historic marker which says, "Many iron mines and forges were operated within a radius of ten miles of this point between 1790 and 1880."

60.7 View of Reese Mountain ahead on the left. The mountain is underlain by one of the sillimanite quartzite units of the Kings Mountain belt east of the "High Shoals" granitic gneiss.

62.0 Cross county line from Lincoln County back into Gaston County and continue on NC-27.

62.6 Turn left onto CR-1820 at traffic light in Alexis.

63.2 Bear right and continue on CR-1820, passing fork with CR-1900.

64.8 Road cut in kyanite-pyrophyllite schist at the south end of Clubb Mountain. This road cut has been popular with mineral collectors for many years and is now largely depleted. Kyanite, lazulite, rutile, and tourmaline have been found here.

64.9 Turn left onto CR-1901 (gravel road).

65.3 Cross county line back into Lincoln County.

65.8 Turn right onto gravel road just beyond powerline and park. Leave the buses and walk to the top of the hill.

STOP 7 (optional): Kyanite quartzite at Clubb Mountain (Lowesville 7.5' quadrangle)

Leaders: Daniel Milton and Wright Horton.
Maps in this volume: Figure 2; Horton (Plate 1).
Reference: Horton (this volume).

The kyanite quartzite at this locality is composed mostly of white quartz and pale blue kyanite, with minor white mica, red rutile, deep blue lazulite, magnetite, and oxidized pyrite. It crops out in steeply dipping lenses within quartz-rich white mica schist for about 2 km along the ridge of Clubb Mountain (Espenshade and Potter, 1960, Plate 9). Kyanite quartzite occurs at several localities in the Kings Mountain belt, one of which (Henry Knob, S.C.) was a major producer of kyanite between 1948 and 1970.

The aluminum silicate + quartz rocks of the Piedmont appear to be products of essentially isochemical metamorphism and their mineralogy (including the occurrence of the Al-silicate as pyrophyllite, kyanite, sillimanite, or andalusite) reflects the local metamorphic grade. The metamorphic grade, for example, is lower here than at Reese Mountain, 3.6 km to the west, which is underlain by sillimanite quartzite. The high-alumina protoliths could have been produced by weathering or by hydrothermal alteration. Espenshade and Potter (1960) found evidence for hydrothermal leaching of volcanic rocks at some deposits, particularly those in the Carolina slate belt, but for the Kings Mountain belt occurrences they favored a sedimentary origin, probably as clay-rich sands or silts. They pointed out that the conformable thin lenses are occasionally compositionally layered and are most easily interpreted as beds, and that the schists which generally enclose the lenses appear to be metasedimentary. On the other hand, the assemblage quartz + Al-silicate + rutile + Al-phosphate can be explained as a product of leaching of volcanic rocks by acid hydrothermal solutions (Wise, 1975), and the occurrence of rutile and Al-phosphate (lazulite) or pyrite, would be favored by hydrothermal alteration and not weathering processes.

The dominant foliation at this locality strikes north and dips steeply west. Local variations are partly a reflection of pinch-and-swell structure produced by ductility contrast between quartzite and schist.

Turn around and head back on CR-1901 the way we came in, under the powerline.

66.4 Turn left onto CR-1820 (paved road).

66.7 Turn right onto CR-1902.

69.4 Turn left onto NC-27.

69.5 Enter city limits of Stanley, N.C.

70.3 Turn right (west) onto NC-275.

73.7 Cross bridge over the South Fork Catawba River.

76.1 Turn right onto NC-279 (joins NC-275) in Dallas, N.C.

76.3 Railroad crossing.

77.2 Turn left onto US-321.

77.5 Pass Gaston College on the right.

78.4 Outcrops on the left of postmetamorphic "Gastonia" biotite granite.

78.7 Enter city limits of Gastonia, N.C.

79.4 Turn right on ramp and proceed south on I-85.

86.4 View of Crowders Mountain on left. Crowders Mountain is underlain by kyanite quartzite which is thickened and repeated by folding.

88.8 Pass junction with NC-161.

96.4 Cross State line back into South Carolina.

97.0 Pass US-29 intersection.

99.7 Continue south on I-85 passing South Carolina welcome center.

100.5 View of Whitaker Mountain on left. The southwest end of the micaceous quartzite layer that underlies this mountain appears to be truncated against the Kings Mountain shear zone (Horton, 1981).

104.8 Cross bridge over the Broad River.

110.4 Take Exit 92 marked SC-11.

110.5 Cross frontage road.

110.6 Turn left onto frontage road and return to the Holiday Inn.

110.7 Buses unload at Holiday Inn parking lot, I-85 and SC-11 at Gaffney, S.C.

END OF SATURDAY TRIP

ROAD LOG - SUNDAY TRIP

Mileage	Itinerary
0.0	From Holiday Inn parking lot, turn left onto frontage road.
0.1	Turn right onto frontage road.
0.15	Turn left onto frontage road.
0.3	Turn right onto SC-11 (Floyd Baker Blvd.) and proceed across bridge over I-85.
0.9	Continue straight through light on Floyd Baker Blvd.
2.4	Railroad crossing.
2.5	Turn right onto SC-150 (Limestone Street).
3.5	Bear left on SC-150 (O'Neil Street).
3.6	Bear right on SC-150 (Pacolet Road).
5.7	Pass outcrop of "Pacolet Mills" metagranite on the right. This is part of an outlying body of Pacolet Mills which is strongly foliated, epidotized and chloritized. It lies along the boundary between the Kings Mountain and Inner Piedmont belts and is flanked by shear zones on both sides.
6.7	Cross bridge over Limestone Creek.
7.3	Turn left onto S-11-70 at Blue Branch Baptist Church. Soapstone crops out on both sides of SC-150 just south of this turn.
7.8	Turn left onto S-11-285.

STOP 8: Rock exposures at Skelton Creek (Gaffney 7.5' quadrangle)

Leaders: Malcolm Schaeffer and Wright Horton.
Maps in this volume: Figure 1, Plate 1; Horton (Plate 1).
References: Horton (this volume); Schaeffer (this volume).

We are in the Kings Mountain belt approximately 600 m east of the projected trace of the Kings Mountain shear zone (Horton, this volume, Plate 1). In the roadcut just south of Skelton Creek, dark greenish-gray altered ultramafic rock is interlayered with a homogeneous white quartzofeldspathic rock of dacitic (or granodioritic) composition. The quartzofeldspathic rock, tentatively called metadacite for the purpose of this description, is composed primarily of partially sericitized plagioclase, quartz, microcline, and white mica. Dark minerals such as biotite and epidote typically occur only in trace amounts, except in thin layers and lenses where they are concentrated. The metadacite is fine grained to medium grained and rather homogeneous in appearance. Grains are typically about 0.05 to 0.1 mm in diameter but feldspar porphyroclasts as much as several mm in diameter occur locally. The fine, almost aphanitic, grain size suggests a shallow intrusive or possibly extrusive origin. Do you see any flow texture?

The altered ultramafic rocks are highly variable in composition. Mineral constituents include actinolite-tremolite, chlorite, talc, magnetite-ilmenite, cronstedtite(?), and locally relict pyroxene (augite?). The ultramafic rocks here are representative of several concordant lenticular bodies of ultramafic rock (metapyroxenite?) as much as 3 km long, which occur near the northwestern edge of the Kings Mountain belt. Locally, these bodies are altered to soapstone.

The roadcut at this locality is one of the best places to observe the contact between ultramafic layers and the metadacite. Contacts appear sheared parallel to the dominant foliation. No unequivocal evidence of one rock type being chilled against the other has been observed. In one part of the road cut, coarse clots of plagioclase were found in the ultramafic rock within about 15 cm of the contact with a metadacite layer. This suggests partial assimilation if the ultramafic rock is intrusive into the metadacite, or possibly a contact aureole if the metadacite(?) is actually intrusive into the ultramafic. Alternatively, it may be a result of regional metamorphism. The foliation in the roadcut has an average orientation of about N. 74° E. 62° NW.

The rock exposed in Skelton Creek for about 60 m east and west of the bridge is metadacite with thin layers of amphibolite and hornblende gneiss (metavolcanic?) and other layers rich in epidote and/or quartz. This layering may be additional evidence for a volcanic origin. Textures range from strongly foliated to almost massive. The foliation and gneissic texture become more prominent as we walk downstream toward the Kings Mountain shear zone. Locally, narrow zones parallel to the foliation appear almost mylonitic. The rocks are crosscut in places by numerous fractures filled with pale-green prehnite.

The plagioclase porphyroclasts in the metadacite(?) are angular, subhedral, and variable in size and shape (some almost round). Other minerals composing the gneissic metadacite in the creek are fine-grained polygonized quartz, white mica, chlorite, opaques and allanite. The plagioclase porphyroclasts (and plagioclase in the groundmass) are highly sericitized in places and some are partly recrystallized to fine-grained polygonal crystals. The last event to affect the rock seen in thin section is the development of undeformed prehnite in fractures that crosscut all other features of the rock. We have not yet determined if the foliation is S_1 or S_2 at this location. The orientation of the foliation is predominantly east-west (Fig. 5A), whereas in most of the belt it is northeast. It is folded by at least two sets of folds. The first set appears to be isoclinal with hinges plunging steeply northeast and axial surfaces subparallel to the foliation (Fig. 5B). Flexural-slip folds which plunge southeast are characteristic of

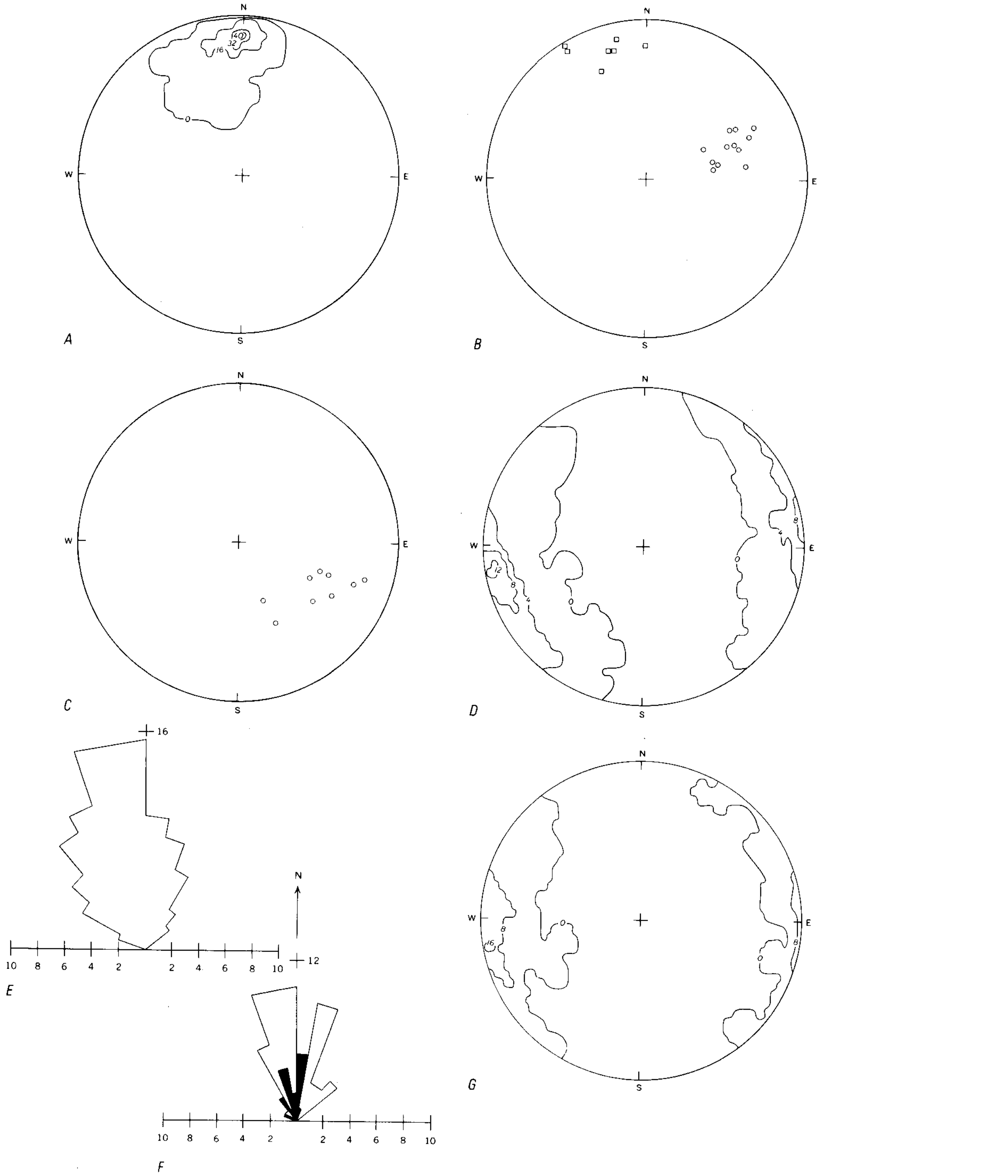

Figure 5. Lower hemisphere, equal area projections and rose diagrams of mesoscopic structures at stop 8: (A) 54 foliation planes; contours are 0, 16, 32 and 40% per 1% area; (B) 12 isoclinal fold axes (circles) and 7 axial planes (squares); (C) 9 flexural-slip fold axes; (D) 260 fracture planes; contours are 0, 4, 8 and 12% per 1% area; (E) rose diagram of 260 fractures, scale in percent; (F) rose diagram of 56 fracture planes with offsets; shaded area represents right-lateral offsets, blank area represents left-lateral offsets; scale in number of fracture planes; (G) 56 fractures with offsets; contours are 0, 8, and 16% per 1% area.

the second set (Fig. 5C). They refold the flanks of the older isoclinal folds. The flexural-slip folds are similar in style and orientation to the F_5 folds of Schaeffer (this volume). The isoclinal folds differ in orientation from those described east of here by Schaeffer. The difference in orientation of isoclinal folds and foliation may be related to the proximity of the Kings Mountain shear zone.

The rocks along Skelton Creek are cut by faults with as much as 15 cm of horizontal separation (Plate 1). Other fractures are related to the faults but have no offsets. The nature of the fracture planes, relationship of splays to main fracture planes, and mineralization in the planes suggest that they formed under semi-brittle to brittle conditions. Breccia zones approximately 1 cm wide are found along some fractures. One thin section shows the breccia matrix replaced or recrystallized by an overgrowth of undeformed muscovite, epidote and prehnite, indicating metamorphic conditions after deformation (H. S. Brown, personal commun.). The orientation of shear-related fractures is predominantly N. 0-20° W. but they range from N. 70° W. to N. 50° E. (Figs. 5D and 5E). The orientation of fractures with offset is similar (Figs. 5F and 5G). Figure 5F is a rose diagram showing the number of fracture planes with left separation and right separation. Vertical components could not be determined because of the nearly horizontal orientation of most exposures. Faults with left separation dominate and no clear conjugate sets are developed. Plate 1 (with accompanying photographs A, B, and C) is a detailed map showing fractures and faults in Skelton Creek approximately 25 m west of the bridge. No clear conjugate sets are present although the faults trending N. 45° E. with left separation may be conjugate to the set trending N. 0-10° E. with right separation. These faults may be related to semi-brittle deformation along the Kings Mountain shear zone.

8.1	Board buses at Skelton Creek.
9.0	Pass outcrop of phyllonitic Battleground Schist.
9.5	Pass outcrop of typical quartz-white mica phyllite of the Battleground Schist.
10.4	<u>Bear right</u> onto Thompson Street at Poole Jersey Farm dairy.
10.7	Turn left onto Cooper Street.
11.0	Turn right onto S-11-111 (O'Neil Street).
11.1	The lake on our left adjacent to the campus of Limestone College is the old Limestone Springs marble quarry. Large-scale lime production began here in the 1890's (Moss, 1972). The pit was reopened in 1933 and produced crushed stone and agricultural lime until 1953 (Moss, 1972).
11.6	<u>Continue</u> on S-11-111 across SC-18.

11.9 Turn right onto SC-105 (Wilkinsville Road).

14.2 Bear left onto S-11-50.

14.3 Outcrops of quartz-pebble metaconglomerate (Draytonville Conglomerate Member of Kings Mountain Quartzite of Keith and Sterrett, 1931) on the hilltop to our left.

14.5 Pass S-11-41 intersection at Draytonville, S.C. The quartz-pebble metaconglomerate at Draytonville Mountain on our right is discussed by Hatcher and Morgan (this volume).

14.8 More quartz-pebble metaconglomerate outcrops on the left.

15.5 Bear right on S-11-132.

15.65 Stop buses at hilltop.

STOP 9: Quartz-pebble metaconglomerate (Blacksburg South 7.5′ quadrangle)

Leader: Robert Butler. Possible comments by Wright Horton, Noelle France, and Robert Hatcher.
Maps in this volume: Figure 1; Butler (Fig.1); Horton (Plate 1).
References: Butler (this volume); Hatcher and Morgan (this volume); France and Brown (this volume).

Quartz-pebble metaconglomerate is exposed in low outcrops just north of the road. The metaconglomerate was named the Draytonville Conglomerate Member of the Kings Mountain Quartzite by Keith and Sterrett (1931) for exposures on and near Draytonville Mountain, the prominent hill 1.5 km west-southwest of this locality. A problem with this name is that it is used in the original reference for several conglomerate beds which occur at different stratigraphic levels (Horton, this volume; France and Brown, this volume). Where fresh, the metaconglomerate at this locality has pebbles of nearly pure, white quartz in a light to dark bluish-gray matrix of quartz, sericite, and opaque minerals, mainly hematite. In thin section, the pebbles are aggregates of fine quartz grains that are equant to slightly elongate, with no sign of a pre-depositional foliation. The metaconglomerate is here about 8 m thick and reaches a maximum thickness of about 20 m on Draytonville Mountain. The unit exposed here can be traced nearly continuously along strike for 2.5 km in each direction, from just northeast of Draytonville Mountain to the Broad River. The pebbles are triaxial ellipsoids which have one axis distinctly longer than the other two. The axis of elongation strikes east-northeast and plunges about 10° E., both here and on Draytonville Mountain (Hatcher and Morgan, this volume). The pebbles are mostly 1 to 4 cm long, but some patches of quartz appear to be pebbles several times longer. The most prominent foliation, which is unevenly developed, is a schistosity in mica-rich zones and a spaced cleavage in mica-poor zones. It strikes east-northeast and dips steeply south-southeast. The minimum axis of the pebbles is approximately perpendicular to the foliation, which is S_1 and/or S_2. A sporadically developed spaced cleavage (S_3?), generally without minerals oriented parallel to it, strikes northeast and dips 30-40° SE. Additional work is needed on the conglomerates to determine their depositional environment and mode of deposition, possible source areas for the clasts, and stratigraphic top and bottom criteria from primary sedimentary structures. A start has been made by France and Brown (this volume).

Return to buses and continue on S-11-132.

16.0 Turn left onto S-11-32 (new road).

16.3 Continue across Duke Power railroad and pass S-11-50 intersection.

16.5 Grassed roadcuts of sericite schist and thin quartzite.

16.7 Outcrop of schistose pyroclastic rock with coarse clasts across branch on right.

17.1 Cross bridge over Tom's Branch.

17.3 Cross northeast-trending line of old iron mines and prospects called the "River Ore Bank."

17.4 Pass S-11-199 intersection. Continue on S-11-32.

18.2 Cross bridge over Cherokee Creek.

18.4 Turn right onto US-29. Metatrondhjemite with minor amphibolite layers crops out at the intersection.

18.7 Cross bridge over the Broad River.

20.7 Pass outcrop of Blacksburg Schist.

21.9 Enter city limits of Blacksburg, S.C.

22.6 Turn right onto S-11-100 (Rutherford Street) at First Baptist Church.

22.7 Cross South Lime Street.

23.7 Cross old Blacksburg and Cherokee Falls Railroad bed.

23.75 Cross bridge over Doolittle Creek.

23.8 Outcrop of foliated metatrondhjemite on the left. This unit occupies the trough of the Cherokee Falls (F_2) synform.

24.4 Continue straight on S-11-100.

24.7 Pass S-11-30 intersection.

24.9 Outcrop of quartz-pebble metaconglomerate.

25.2 Stop buses.

STOP 10: Manganiferous schist (Kings Creek 7.5' quadrangle)

Leaders: Cindy Murphy, Wright Horton, and Robert Butler.
Maps in this volume: Figure 1; Murphy and Butler (Fig. 1).
Reference: Murphy and Butler (this volume).

This poor exposure of manganiferous schist was selected because of its easy accessibility along our field trip route. The manganiferous schist unit is about 48 m thick at this locality and is part of a thick sequence of metamorphosed siltstones and claystones, now mainly fine-grained sericite schist. Keith and Sterrett (1931) called this the manganese schist member of the Battleground Schist. The appearance here is typical of weathered exposures in the unit, which is nearly continuous for about 40 km along the northwest flank of the South Fork antiform. Chocolate brown to brownish-black pieces of weathered rock rich in oxides and hydroxides of manganese and iron are abundant on the surface. The manganese is present in minerals such as pyrolusite and psilomelane, derived by weathering from spessartine-almandine garnet and possibly other manganese silicates (White, 1944; O'Neill and Bauder, 1962). Thin sections and slabs from other exposures indicate that fine-grained equigranular garnet (50-70%) - quartz rock (coticule) is closely interlayered with quartz-rich sericite schist. Spessartine-almandine grains are typically round, about 0.1 mm in diameter, and, although widely disseminated, are concentrated in rhythmic bands generally less than 1 cm thick. In contrast to the relatively massive coticule, the quartz-rich sericite schist interlayered with it is strongly foliated. The schistosity at this outcrop strikes N. 73° E. and is nearly vertical (88° NW.).

The depositional environment of this unit is problematic, but its persistence as a single stratigraphic horizon is strong evidence for a sedimentary (and volcanogenic?) origin. The proximity to quartz-pebble metaconglomerate beds stratigraphically above and below it, and the fine grain size suggesting a relatively low energy depositional environment (in contrast with that of the metaconglomerates), are important considerations for evaluating possible depositional environments. Calcareous metasedimentary rocks adjacent to the manganiferous schist at another locality in this quadrangle indicate a marine origin. The manganese and iron may have been derived by chemical weathering and leaching of volcanic glass (Horton, 1977) or this may be a distal exhalative deposit of submarine hydrothermal vents.

Approximately 20 prospects and small inactive mines for manganese are known in the manganiferous schist (Keith and Sterrett, 1931; White, 1944). At present, several pits in the vicinity are intermittently worked for brown pigment used in brick manufacturing.

Return to buses and continue on S-11-100.

25.4 Pass S-11-68 intersection.

26.2 Very light gray phyllite (Battleground Schist). Barite occurs on the Childers' property near here.

26.4 Cross bridge over Bells Branch.

26.5 Road cut exposure on left of schistose pyroclastic rock cut by a diabase dike of probable Mesozoic age. This outcrop is very similar to stop 11.

26.65 Buses pull over on right.

STOP 11: Schistose pyroclastic rock (Kings Creek 7.5' quadrangle)

Leaders: Cindy Murphy, Robert Butler, and Wright Horton.
Maps in this volume: Figure 1; Murphy and Butler (Fig. 1).
Reference: Murphy and Butler (this volume).

Bluish-gray, fine-grained mottled sericite schist derived from pyroclastic rock is exposed on both sides of the road. These outcrops are within the crystal-lapilli metatuff unit of Murphy and Butler (this volume) and are located on Figure 1 of that paper. The rock is mainly medium bluish gray, but the clasts range from dark gray to nearly white. Foliations are well developed because of the high mica content.

The clasts are strongly flattened in the plane of schistosity and are mostly 0.5 to 2 cm in their longest dimension. At other localities in this unit, clasts more than 10 cm across have been noted. The dark clasts are composed mainly of iron-titanium oxides with minor quartz and white mica. The light clasts are mostly quartz, fine-grained white mica, and altered plagioclase. Plagioclase crystal clasts have been largely altered to white mica. Chloritoid is present in some thin sections and rocks with clusters of chloritoid are found elsewhere in this unit.

The groundmass is composed mainly of fine-grained white mica, quartz, and finely disseminated iron-titanium oxides. The oxides give the groundmass its characteristic bluish-gray color. Preliminary X-ray diffraction and microprobe data indicate that two white micas are present and they may be interlayered on the scale of a few microns or less. One white mica is essentially margarite and the other appears to be a paragonite-muscovite solid solution. An average of 10 microprobe analyses of interlayered white micas from this locality surprisingly gives Ca:Na:K molecular ratios of 6:3:1. See Murphy and Butler (this volume) for additional data and discussion.

This rock is part of a metavolcanic facies of the Battleground Schist which has an andesitic to dacitic composition. The schistose pyroclastic unit grades upward and laterally into a fine-grained phyllite without visible clasts or crystals, but with a similar bluish-gray appearance produced by finely disseminated iron-titanium oxides.

The main schistosity, S_1?, strikes northeast and dips 52°-60° SE. A second cleavage, S_2?, is nearly parallel to the older schistosity but has a slightly greater dip (about 65° SE.). This angular relationship is common along the west limb of the South Fork antiform. The schist breaks along the two cleavages into thin, wedge-shaped chips. A spaced cleavage, S_3?, that is visible in parts of the outcrops is somewhat variable in orientation, but generally trends northeast and is nearly vertical. Kink bands 1 to 3 cm wide trend east-northeast to northeast and dip 55°-65° NW.

An unmetamorphosed and undeformed diabase dike about 5 m thick of probable Mesozoic age is exposed in the eastern part of the roadcut and has an orientation of N. 17° W. 86° SW.

	Continue on S-11-100.
27.0	Turn left onto dirt road and continue.
27.8	Bear right on S-11-68 (paved road).
28.4	Turn right onto SC-5.
30.4	Cross bridge over Kings Creek.
30.6	Continue around curve to left, passing SC-97 junction.
30.8	Turn right immediately beyond railroad crossing.
31.95	Park buses at plant and walk into pits.

STOP 12: Barite mine at Kings Creek, S.C. (Kings Creek 7.5' quadrangle)

Leader: Ed Sharp. Possible comments by Cindy Murphy, Pam Godfrey, and Ed Wilson.
Maps in this volume: Figure 1; Sharp and Hornig (Fig. 1); Murphy and Butler (Fig. 1).
References: Sharp and Hornig (this volume); Murphy and Butler (this volume).

Barite was mined intermittently at Kings Creek from 1885 to 1966 (Sharp and Hornig, this volume). Since 1966, production has been limited to white saprolite for brick manufacturing. Mining has been concentrated in four pits: the very large east and west pits, and the smaller north and south pits.

The west pit has the best exposures of barite. A band of barite parallel to the foliation can be seen in the central (high) part of the east-west wall of the pit. With additional searching, however, you should be able to find layers of barite which are not parallel to the dominant foliation. Also look for examples of foliated and non-foliated barite, and for kinking of the barite bands. Notice the different color variations, such as gray, speckled, and pink, of the quartz-sericite phyllite. These are described in greater detail by Sharp and Hornig (this volume). The speckled variety is distinguished by the presence of chalcanthite (hydrous copper sulfate) formed by chemical weathering of chalcopyrite. The dip of the dominant foliation (S_1?) is unusually low (about 25° SE.), possibly suggesting later folding as discussed by Sharp and Hornig (this volume). A younger less intense foliation (S_2?) dips about 60° SE. On the south wall of the pit, it should be possible to observe crenulations whose axes plunge gently northeast. A short but thick gash vein of quartz at the northwest corner of the west pit contains abundant black tourmaline (schorl).

The barite cropping out at the north end of the north pit can be followed on the surface for about 60 m to the northeast. The weathered barite has a pitted surface texture similar to that of limestone but is readily distinguished by its extraordinary high density.

The best exposure of barite layers not parallel to the dominant foliation is at the south pit on the west side of a major bend in SC-97.

In the east pit, a thick zone of saprolite on the white sericite schist is now being mined for use in making bricks. The uppermost bench was stripped for use as fill to replace an old railroad trestle across Truth Branch. A large quartz vein cropping out at the southeast end of this bench is 12 m thick in places and at least 300 m long.

	NO MORE STOPS. The buses will return us to the assembly point where we will disband. Turn around and return to SC-5.
31.1	Turn left onto SC-5 at railroad tracks.
31.3	Continue on SC-5 around curve to right.
33.5	Pass Hopewell Church. Schistose pyroclastic rock is well exposed in railroad cuts behind the church.
35.2	Bridge over railroad. Outcrops of metatrondhjemite along railroad west of bridge.
35.6	Brick company on left.
36.7	Railroad crossing.
36.75	Turn left onto US-29.
37.1	Cross bridge over railroad.
37.2	Turn right onto SC-198.

37.35 Railroad crossing. View of Whitaker Mountain ahead on our right.

37.8 Cross micaceous quartzite at Whitaker Mountain.

38.4 Cross bridge over I-85.

38.5 Turn left on ramp and proceed south on I-85 to Gaffney.

48.3 Take exit 92 marked SC-11.

48.4 Cross frontage road.

48.5 Turn left onto frontage road and return to the Holiday Inn.

48.6 Buses unload at Holiday Inn parking lot, I-85 and SC-11 at Gaffney, S.C.

END OF SUNDAY TRIP

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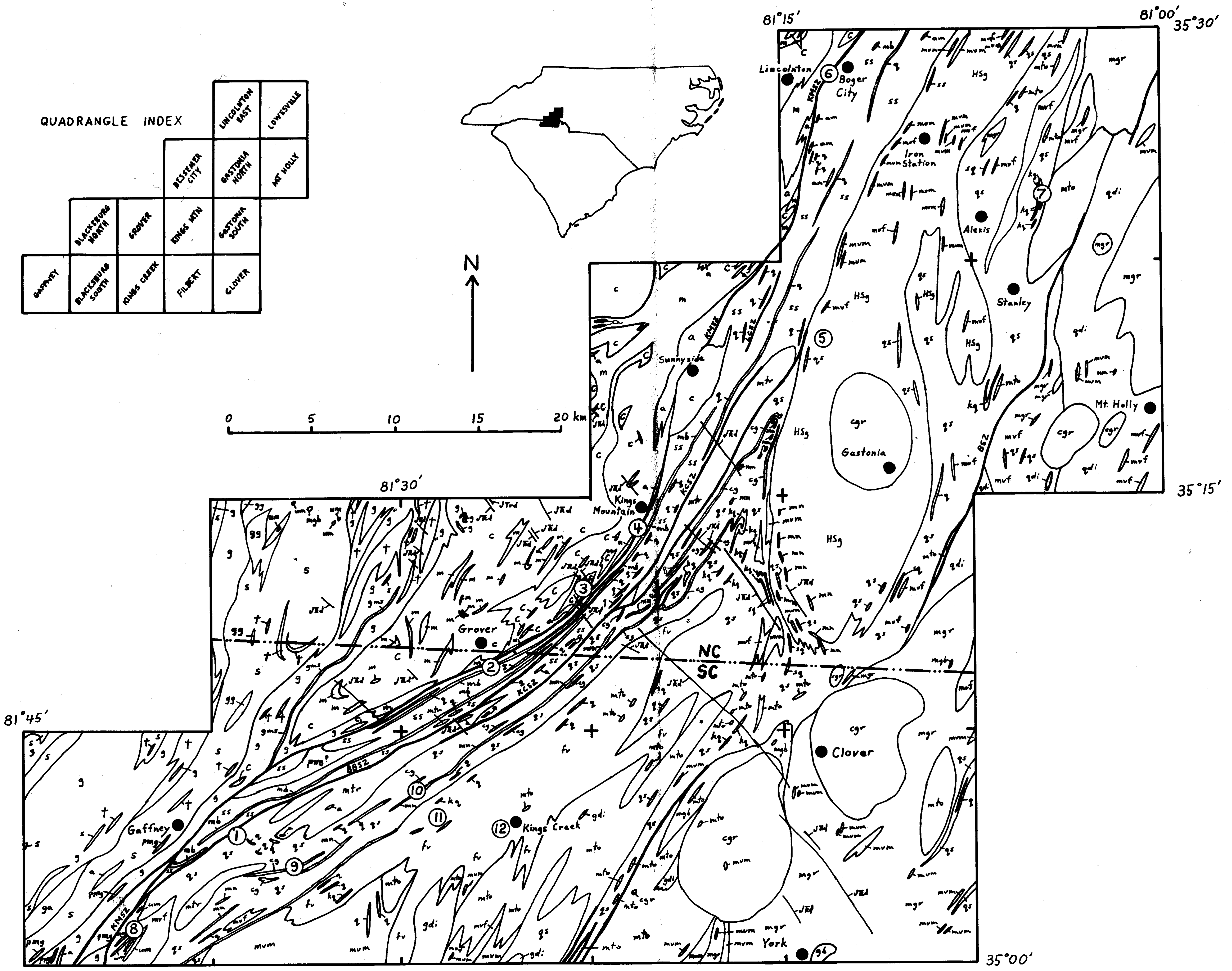


Plate 1. Preliminary bedrock map of the Kings Mountain belt between Gaffney, South Carolina, and Lincolnton, North Carolina. Geology by J. W. Horton, Jr., 1981.

ROCK UNITS

Kings Mountain belt

- JҜd - diabase dikes
- cgr - coarse biotite granite
- c - Cherryville Quartz Monzonite(?)
- pmg - "Pacolet Mills" granite(?)
- HSg - "High Shoals" granitic gneiss
- mtr - metatrondhjemite
- mto - biotite metatonalite
- gdi - metagabbro amd/or metadiorite
- um - ultramafic rocks
- am - amphibolite
- mb - marble
- ss - sericite schist (or phyllite)
- q - quartzite
- qs - quartz-sericite schist (or phyllite)
- mn - manganiferous schist
- cg - quartz-pebble metaconglomerate
- kq - kyanite quartzite
- sq - sillimanite quartzite
- fv - schistose felsic volcaniclastic rocks
- mvf - felsic metavolcanic rocks
- mvm - mafic metavolcanic rocks

Charlotte belt

- JҜd - diabase dikes
- cgr - coarse biotite granite
- gb - gabbro
- q - quartzite
- qs - quartz-sericite schist
- mvf - felsic metavolcanic rocks
- mvm - mafic metavolcanic rocks
- um - ultramafic rock
- mgr - metagranite or metagranodiorite
- mto - biotite metatonalite.
- qdi - meta-quartz-diorite

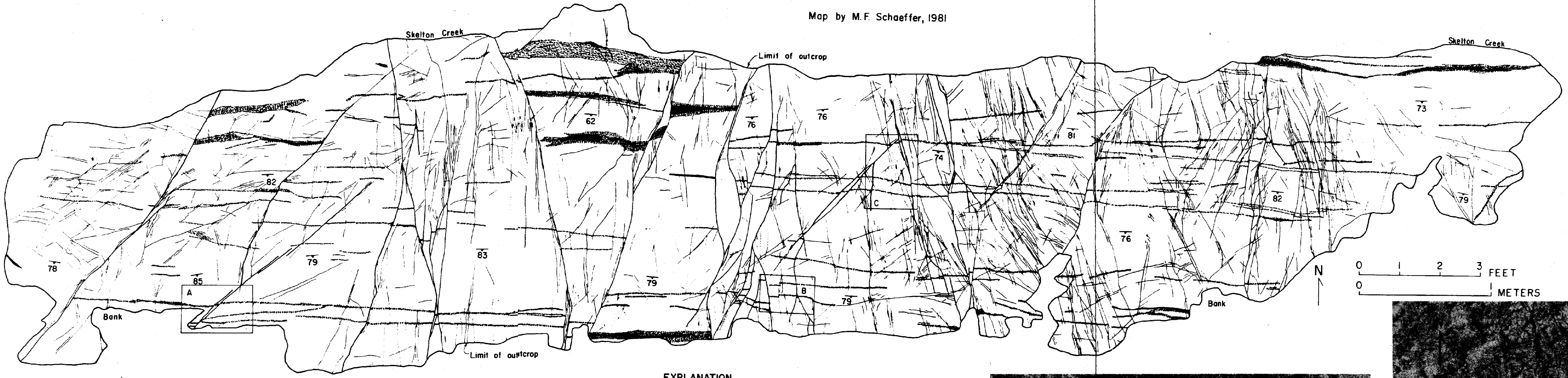
Inner Piedmont belt

- JҜd - diabase dikes
- c - Cherryville Quartz Monzonite
- pmg - "Pacolet Mills" granite
- T - Toluca Quartz Monzonite
- gg - layered granitoid gneiss
- mgb - metagabbro
- um - ultramafic rock
- a - amphibolite
- ga - interlayered amphibolite and biotite gneiss
- b - biotite gneiss
- m - white mica schist
- g - garnetiferous mica schist
- s - sillimanite-mica schist

SHEAR ZONES

- KMSZ - Kings Mountain shear zone
- BBSZ - Blacksburg shear zone
- KCSZ - Kings Creek shear zone
- LCSZ - Long Creek shear zone
- BSZ - Boogertown shear zone

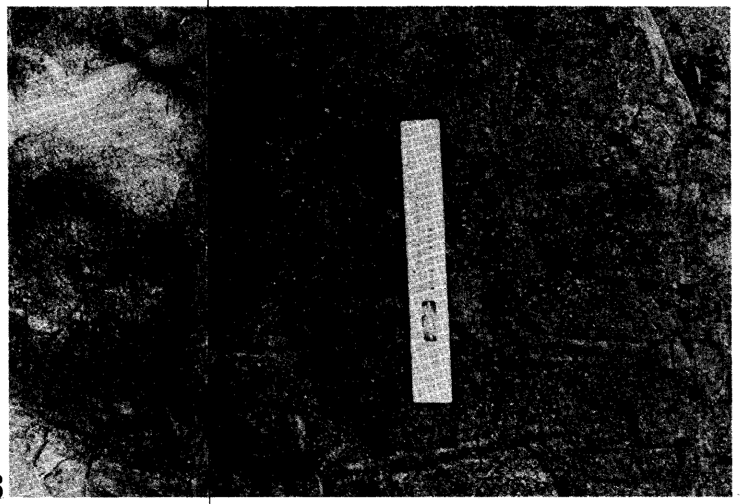
Circled numbers represent field trip stops of Horton and others (this volume).

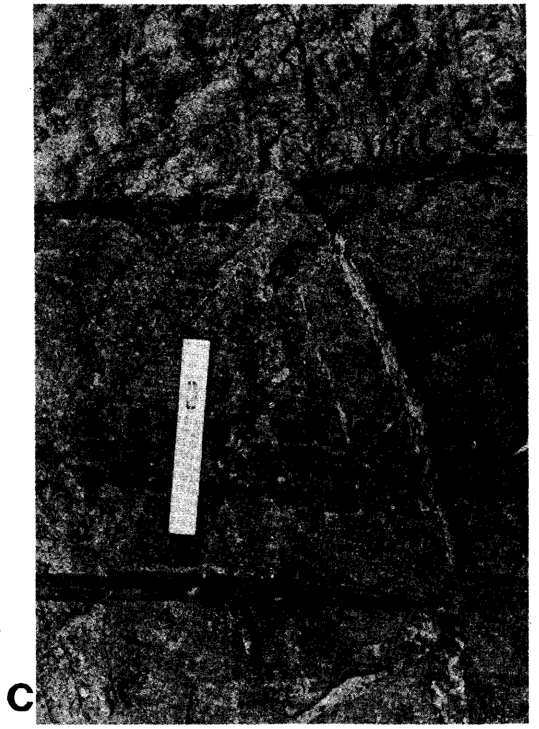


A

Plate 1. Sketch map of a small outcrop in Skelton Creek with photographs A, B, and C which show faults with strike separation. Locations of the photographs are shown on the sketch map.

B





C