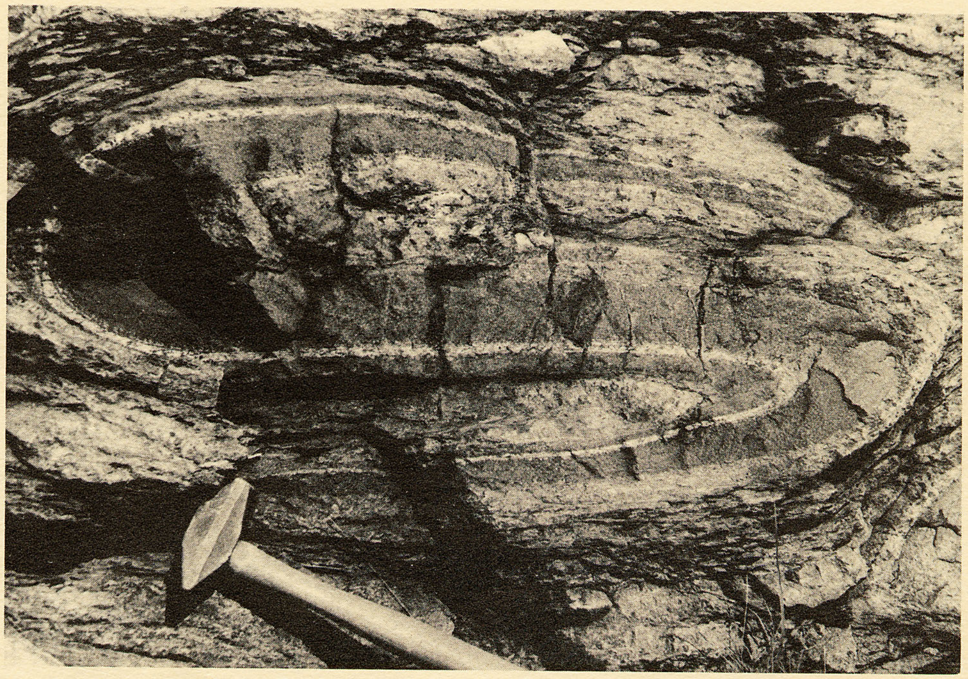
Geological investigations of the eastern Piedmont, southern Appalachians

(With a field trip guide on the bedrock geology of central South Carolina)

edited by

Arthur W. Snoke



CAROLINA GEOLOGICAL SOCIETY

Field Trip Guidebook 1978

October 7-8, 1978

West Columbia, South Carolina

Carolina Geological Society

Field Trip Guidebook

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Geological Investigations of the Eastern Piedmont, Southern Appalachians

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Front cover photograph: S-shaped fold of amphibolite in pelitic schist, Lake Murray spill-way, central South Carolina Piedmont

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FOREWORD

In 1973, Glover and Sinha described the southern Appalachian Piedmont as "the last large-scale modern frontier of extremely complex regional geology in the United States." These words, I think, reflect the excitement that many of us feel toward the region. We are all aware of the poor exposure, the complex structure, and the local intensity of metamorphism; but as Appalachian geologist along the length of the orogen are concluding— it is the metamorphic core terranes that will be the "proving grounds" for the multitude of regional tectonic models now available. Therefore, we, who are presently working in the internal zones of the southern Appalachians, are in a unique position to put major constraints on working hypotheses concerning the tectonic evolution of the region. It is truly an exciting time to be studying Piedmont geology, and as a field geologist, principally trained in the western United States, I feel fortunate to be able to participate in this "renaissance period" of southern Appalachian geology.

This is the philosophy from which this volume was spawned. It is basically a collection of progress reports on various aspects of the geology of the eastern Piedmont. It seems especially appropriate that such a volume be published in conjunction with the annual meeting of the Carolina Geological Society. For this event, outside of the annual meeting of the Southeastern section of the Geological Society, brings together more southern Appalachian geologists than any other activity in a normal year.

The articles in this volume are diverse in their subject matter as well as geographic distribution. Reports are included which essentially span the length of the eastern Piedmont throughout the Carolinas and in part overlap into adjacent Virginia and Georgia. The articles have been arranged in a basically north to south order, and Plate 1 is a location map which illustrates the geographic distribution of the various studies with regard to the regional geology of the southern Appalachian Piedmont.

Many people helped me in numerous ways to complete this project. Norman K. Olson, the state geologist of South Carolina, was enthusiastic from its inception and strongly supported the work until completion. My colleague, Donald T. Secor, Jr., gave me valuable advice on many aspects as well as continuous encouragement. Many individuals in the Department of Geology, University of South Carolina helped in the preparation of this publication: Diane Moses and Joyce Goodwin (manuscript typing), Burk Scheper (photography), Nanette Muzzy (Drafting). Finally, I wish to especially thank the many contributors to this volume; they were cooperative in every way, and the incorporation of their articles with the field guide tremendously enhances the usefulness of this publication.

Arthur W. Snoke

Columbia, South Carolina
August, 1978

KEY TO PLATE 1

1. John M. Parker, III, Structure of west flank of the Raleigh belt, North Carolina
2. E. F. Stoddard, V. V. Cavaroc, and R. D. McDaniel, Status of geologic research in the Raleigh belt and adjacent areas, eastern Piedmont of North Carolina
3. Van Price and R. Bruce Ferguson, The use of *NURE* regional geochemical data in geologic mapping
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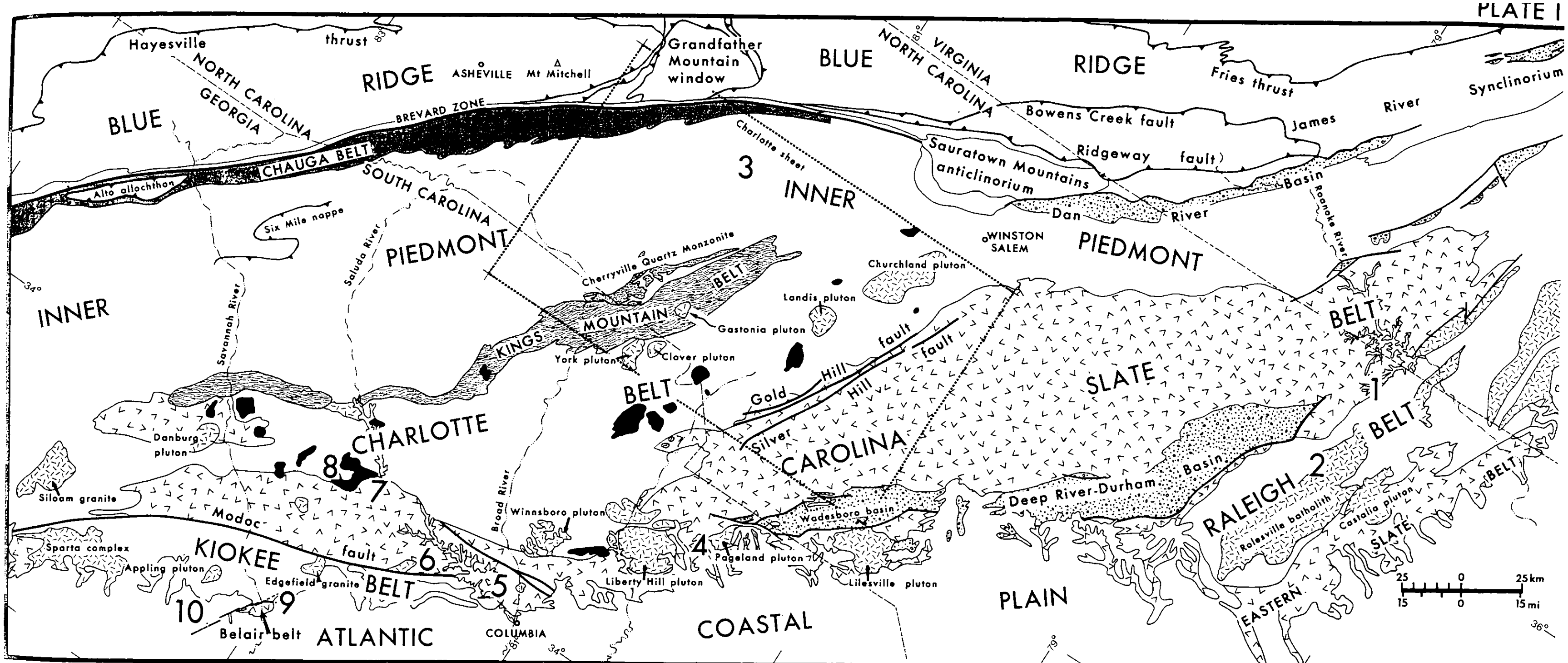
8. Richard G. Chalcraft, David P. Lawrence, and Carl A. Taylor, Jr., The petrology of the Greenwood pluton, Greenwood County, South Carolina: A preliminary report
9. Harmon D. Maher, Stratigraphy and structure of the Belair and Kiokee belts, near Augusta, Georgia
10. David C. Prowell, Distribution of crystalline rocks around Augusta, Georgia, and their relationship to the Belair fault zone

Not plotted:
Stephen A. Kish and Paul D. Fullagar, Summary of geochronological data for Late Paleozoic plutons from high grade metamorphic belts of the eastern Piedmont of North Carolina, South Carolina, and Virginia

PLATE I



Modified from Williams (1978) Tectonic lithofacies map of the Appalachian orogen (1,000,000)
Drafted by A.W. Snoke - August, 1978

Mafic rocks (chiefly gabbroic) Late Paleozoic (Hercynian) granitic rocks -- References: Fullagar (1971), Fullagar and Butler (in press) Kish and others (1978), Kish and Fullagar (this volume) Wright and others (1975)

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STRUCTURE OF WEST FLANK OF THE RALEIGH BELT, NORTH CAROLINA

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INTRODUCTION

The Raleigh belt in the northeastern Piedmont of North Carolina consists of metamorphic rocks of medium-to high-rank and is cored by an adamellite batholith and several stocks. It extends 80 miles southward from the Virginia state line and is some 30 miles wide. Bordering it on the west is the Carolina slate belt made up of low-rank metamorphosed volcanic and sedimentary rocks penetrated by many intrusions. Similar rocks on the south and east have been designated in the eastern slate belt. The area is a great uplift that has been named the Wake-Warren anticlinorium (Parker, 1968). The west flank of the uplift, west of the central adamellite intrusions, is a closely folded sequence of mica gneisses and schists with subsidiary amphibolite, totaling some 20,000 feet in thickness, intruded by many small igneous bodies varying in composition from felsic to ultramafic.

This paper summarizes the relations of the Raleigh belt to the Carolina slate belt, between the Virginia-North Carolina boundary and southern Wake County, and considers the major structures within its west flank. The discussion is based on the cited published and manuscript sources and on my recent (1977-1978) reconnaissance mapping.

CAROLINA SLATE-RALEIGH BELT BOUNDARY

The nature of the boundary between the Carolina slate and Raleigh belt varies from place to place. The variations are described below in segments extending from the North Carolina-Virginia line southward for a distance of nearly 80 miles (Fig. 1).

State line to upper Nutbush Creek

The easternmost rocks of the slate belt in this segment (about 10 miles) are sericite-chlorite phyllites which form a narrow strip along the east edge of a large albite granodiorite pluton (Parker, 1963). This strip ranges in width from about 450 to 700 feet but widens in Virginia to at least 3500 feet. To the east are various gneisses and schists which, near the boundary, interfinger with phyllite. Foliation and bedding in both groups of rocks strike north-northeast and dip steeply northwest. The structure here was interpreted (Parker, 1963) as homoclinal and the boundary as a gradation in metamorphic character across a conformable stratigraphic sequence. Recently, other workers (Hadley, 1973; Casadevall, 1977) have suggested that the phyllite stripe defines a major fault zones; this possibility will be discussed later/

Upper Nutbush Creek to Kittrell area

The phyllite strip appears to narrow and eventually disappear as a mappable entity along upper Nutbush Creek valley, about 6 miles north of Henderson; however, detailed geologic mapping is not available south of here (Parker, 1963). From this area to a point west of Kittrell (about 11 miles), albite granodiorite that intrudes slate belt rocks lies adjacent to mica gneiss and schist (Cook, 1968; Hadley, 1973,1974). Near the contact phyllitic rocks are interlayered with gneiss similar to the situation north, and suggesting that these parts of the boundary are much alike.

Kittrell area

West of Kittrell, the boundary, for about 6 miles, is a nearly straight line that parallels local structure. Numerous granodiorite sills occur along this belt, and phyllitic strips are interlayered with gneissic rock. The boundary here seems to be a gradational metamorphic change as in the segments farther north.

Tar River to Wake County

Near the Tar River, for about 5 miles an adamellite stock in the gneissic belt lies just east of the slate belt (Carpenter, 1970). Between then is a siliceous zone about 400 feet wide which may be a shear zone. Southwestward from the stock for 3 miles to a point 2.5 miles south of Wilton, the boundary extends in a nearly straight line parallel to local foliation but is terminated at a sharp bend in the Jonesboro fault, the eastern border of Triassic sedimentary rocks. This segment of the boundary may be a fault and an extension of the siliceous zone. Alternatively, however, the contact may be a change in metamorphic grade or an unconformity (Carpenter, 1970). For the next 4.5 miles almost to Wake County, slate belt rocks are absent as Triassic sediments are faulted against lower amphibolite grade schists and gneisses and an ultramafic lens.

Wake County segment

For 10 miles from the northern Wake County line a diorite-gabbro complex lies along the boundary between slate belt rocks and various gneisses of the Raleigh belt (Parker, 1978). Southward from this point across Wake County (about 28 miles) typical metavolcanic and metasedimentary

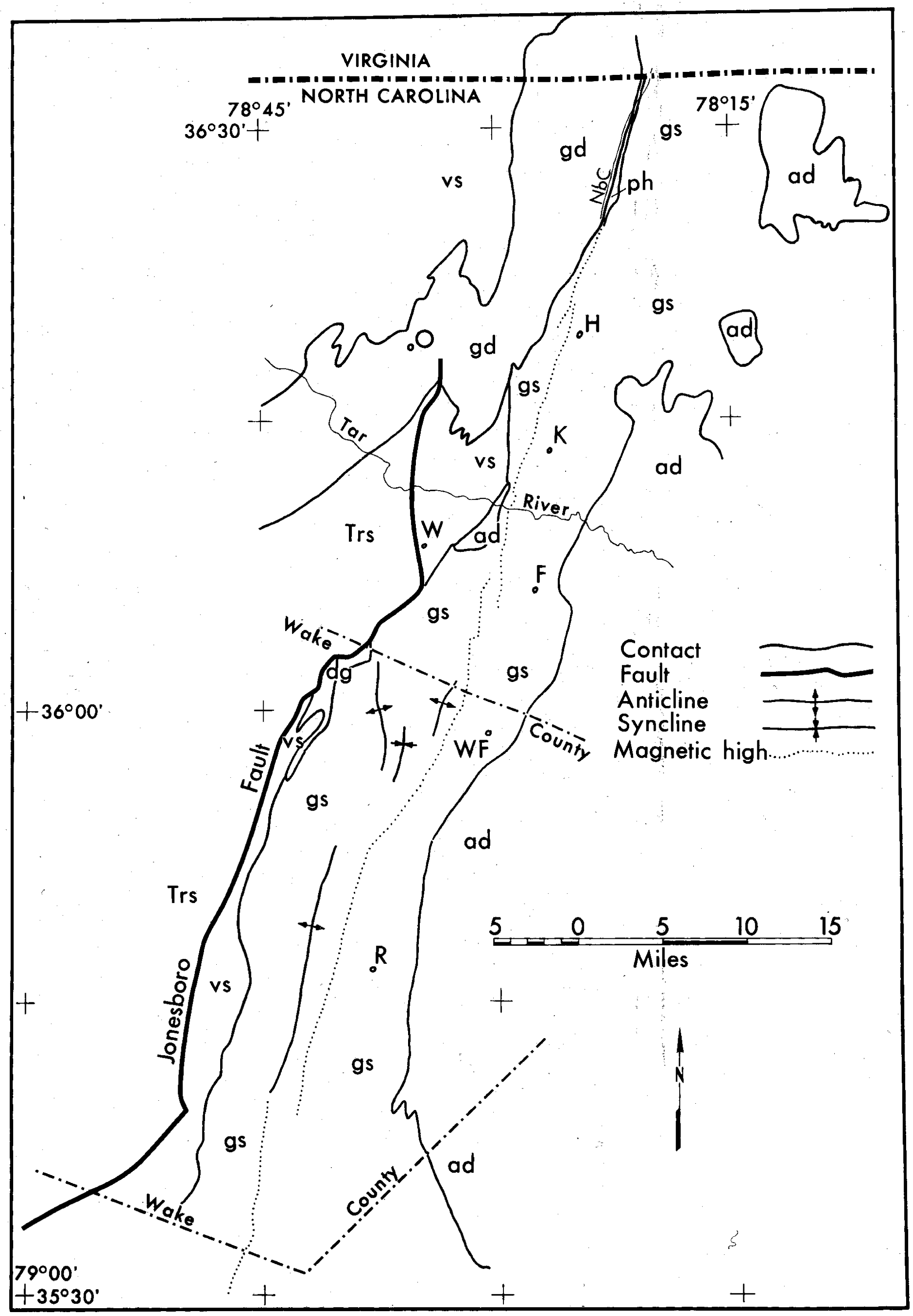

Figure 1. Geologic map of west flank of Raleigh belt, North Carolina. Symbols: gs-mica and hornblende gneisses and schists; vs-metavolcanic and metasedimentary rocks with intrusions (part of Carolina slate belt); ph-phyllite (phyllonite?); dg-diorite-gabbro complex; gd-granodiorite; ad-adamellite; Trs-Triassic sedimentary rocks. Places: F-Franklinton; H-Henderson; K-Kittrell; NbC-Nutbush Creek;)-Oxford; R-Raleigh; W-Wilton; WF-Wake Forest. Base from Army Map Service Greensboro and Raleigh sheets. Geology mapped and compiled by J.M. Parker, III; 1963-1978.

rocks of greenschist facies occupy an irregular belt 1 to 3 miles wide. They grade eastward into various older gneisses and schists of amphibolite facies. The whole sequence dips generally westward and seems to be conformable. The boundary, therefore, appears to be a metamorphic gradation.

Summary of boundary relations

The boundary between the Carolina slate belt and the west flank of the Raleigh belt is interpreted, for most localities, as a change in metamorphic rank in a conformable, westward-dipping series of rocks. The younger rocks to the west were largely volcanic, volcaniclastic, and sedimentary while those to the east were mostly sedimentary deposits of graywacke and associated types. Faulting and intrusion have locally complicated the boundary.

STRUCTURE

The west flank of the Raleigh belt consists chiefly of foliated and bedded metamorphic rocks striking north-northeast. In Wake County, these rocks dip generally westward in the west half of the belt but are essentially vertical in the eastern half (Parker, 1977, 1978). An anticlinal axis evidenced by structural and stratigraphic data passes through west Raleigh. An isoclinal synclinal axis is inferred to exist about 2 miles to the east; it is believed to coincide with a persistent belt of quartzitic gneiss characterized by a strong, pervasive horizontal lineation of mica streaks. This lineation is interpreted as having formed in a complex of tightly compressed and rotated folds (fold mullions). The lineated gneiss and the inferred synclinal structure coincide with a strong magnetic linear high.

In the area just south of the Virginia-North Carolina boundary, gneisses of the Raleigh belt are vertical or dip steeply to the west. Here the structure in the western part of the Raleigh belt also appears to be a west-dipping homocline (Parker, 1963). The areas farther to the east and the interval southward to Wake County have been examined only in reconnaissance, so locations of fold axes are not known.

REGIONAL FAULTING

Faults of regional significance have been postulated recently as extending through the west flank of the Raleigh belt. Hadley (1973, Fig. 1) plotted a fault through the phyllite strip along the east side of the granodiorite pluton, and Casadevall (1977) extended the fault far into Virginia and southward past Raleigh and beyond Wake County. Hatcher and others (1977a, 1977b) suggested an associated system of faults extends from Alabama to central Virginia. They extend the Modoc fault of South Carolina through Raleigh. The chief basis for these speculations is linear aeromagnetic anomalies.

Many linear magnetic anomalies occur along the west flank of the Raleigh belt where steeply dipping metamorphic rocks crop out in narrow strips. None of the anomalies extends unbroken through the area considered here, though commonly where one anomaly dies out another begins en echelon nearby. Most of these anomalies are readily correlated with surface geologic features, though the reasons for the anomalies are not always clear. The major linear magnetic highs along and near the postulated fault have been plotted on the accompanying map (Fig. 1).

The postulated fault near the Virginia line coincides with the strip of phyllitic rocks described above and also with an abrupt escarpment-like magnetic anomaly (lower to the east). Casadevall (1977) interpreted this strip as phyllonite but has not yet presented supporting data. His interpretation may prove to be correct though my mapping indicates otherwise/ It is not known whether phyllonite continues along this line south of upper Nutbush Creek. This magnetic anomaly dies out in western Henderson and another more ridge-like high begins half a mile to the east. This extends parallel to various gneisses and, west of Kittrell for 5 miles, it coincides with hornblende gneiss. Near the Tar River it follows lineated quartzitic gneiss until the anomaly dies out a little southwest of Franklinton. Here it is succeeded en echelon to the west by a linear high that continues southward along hornblende gneiss and lineated quartzitic gneiss to a point about 2 miles west of Wake Forest. From here it continues in strongly lineated quartzitic gneiss to a point 10 miles south of Raleigh; this segment is believed to be an isoclinal axis (Parker, 1978). Hatcher and others (1977b, Fig. 3) plot the Modoc fault along the west side of this high. Another high begins 2 miles to the west and extends southward beyond the area considered here; it probably marks an anticlinal axis. The Modoc fault is shown curving over to pass along its west side.

The suggested location of the Modoc fault in the Raleigh belt is thus seen to link up a series of unlike geologic features. No one can doubt that the belt is one of important tectonic movements but whether it includes a regional fault is dubious. Closely compressed folding with some dislocation seems to me a better concept in the present state of knowledge. Pending publication of information from careful field, petrographic, and perhaps other geophysical studies , the suggested extension of the Modoc fault through the Raleigh belt should remain a speculation.

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STATUS OF GEOLOGIC RESEARCH IN THE RALEIGH BELT AND ADJACENT AREAS, EASTERN PIEDMONT OF NORTH CAROLINA

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INTRODUCTION

In recent years, plate tectonists have commonly ignored the Raleigh belt in their promulgation of large-scale models for the Paleozoic tectonic development of the southern Appalachians. In fact, the role and position of the Raleigh belt in the geologic history of eastern North Carolina is not well understood. Research currently underway at North Carolina State University and at the State Geological Survey is directed at a variety of petrologic, structural, and depositional problems in eastern North Carolina. Our ultimate aim is to integrate results of our studies with existing information in order to provide a unified, coherent picture of the depositional, tectonic, magmatic, and metamorphic history of the Raleigh belt. We feel that such understanding will place significant constraints on plate tectonic models for the southern Appalachians.

GEOLOGIC SETTING

Pre-Mesozoic rocks in the region between the Inner Piedmont and Coastal Plain provinces of northeastern North Carolina may be divided into two types: 1) low grade (greenschist to epidote amphibolite facies) metavolcanic and interlayered volcanogenic metasedimentary rocks of the Carolina and eastern slate belts; and 2) higher grade (amphibolite facies) metasedimentary and probably metaplutonic rocks as well as younger unmetamorphosed plutonic rocks of the Raleigh belt. The metavolcanic rocks occur in tow belts separated by the Raleigh belt rocks, apparently the manifestation of a large scale anticlinorial structure (Fig. 1 and Parker, 1968).

RALEIGH BELT LITHOLOGIES

The Raleigh belt contains a great variety of rock types (Parker, in press). It is cored by felsic gneisses, some of which are granitic, but most of which indicate a probable sedimentary origin because they have bulk compositions of arkosic arenites and contain likely sedimentary structures and relic textures. Pelitic schists, some probably highly graphitic, and amphibolites and hornblende gneisses of problematic origin are less abundant but occur on the limbs of the large anticlinal structure. In addition, podiform ultramafic bodies occur in the Raleigh belt, northwest of the city of Raleigh. All these Raleigh belt lithologies have undergone relatively high pressure amphibolite facies metamorphism with the pelites locally containing garnet, kyanite, and staurolite.

Felsic plutonic rocks, most ranging from granite to quartz monzonite in composition, occur in the Raleigh belt. The two largest bodies (Fig. 1), the Rolesville batholith (Parker, in press) and the Castalia pluton (Julian, 1972), occur in eastern Wake and adjacent Franklin Counties, and are currently under investigation by Glover and co-workers at V.P.I. & S.U. (S. Farrar, personal communication). The Castalia pluton has been dated at 316 ± 6 m.y. (P.D. Fullagar, reported in Julian, 1972; Rb/Sr whole rock isochron $(Sr^{87}/Sr^{86})_0 = 0.7147 \pm 0.0022$). To our knowledge, no geochronologic study has been completed on the Rolesville body, but several lines of evidence suggest that it is older than the Castalia. First, it is almost uniformly concordant to the surrounding country rock, whereas the Castalia appears to be distinctly discordant, at least on its south side. Second, although the Rolesville is distinctly foliated in places, the Castalia is unfoliated. Third, the Rolesville appears to occupy the metamorphic culmination of the high pressure amphibolite facies metamorphism of the Raleigh belt (parker, 1978, and in press), its western boundary being highly veined with pegmatite and aplite and taking on a migmatitic character in places. The Castalia, on the other hand, probably possesses a low pressure thermal aureole (W.F. Wilson, reconnaissance mapping) and appears to cut regional metamorphic isograds (Julian,1972).

RALEIGH BELT-SLATE BELT RELATIONSHIPS

It appears quite probable that the sedimentary precursors of the Raleigh belt metamorphic rocks constituted at least in part a continental shelf assemblage of arkoses, local quartzites, shales, carbonaceous matter, and possibly muddy limestones. Subsequently metamorphosed to relatively high grade, Raleigh belt rocks thus present a striking contrast to the greenschist facies metavolcanics and volcanogenic metasediments of the adjacent slate belts, and indicate a distinctly different history.

The Raleigh belt may thus represent an exhumed portion of the continental basement (some possibly of Grenville age,

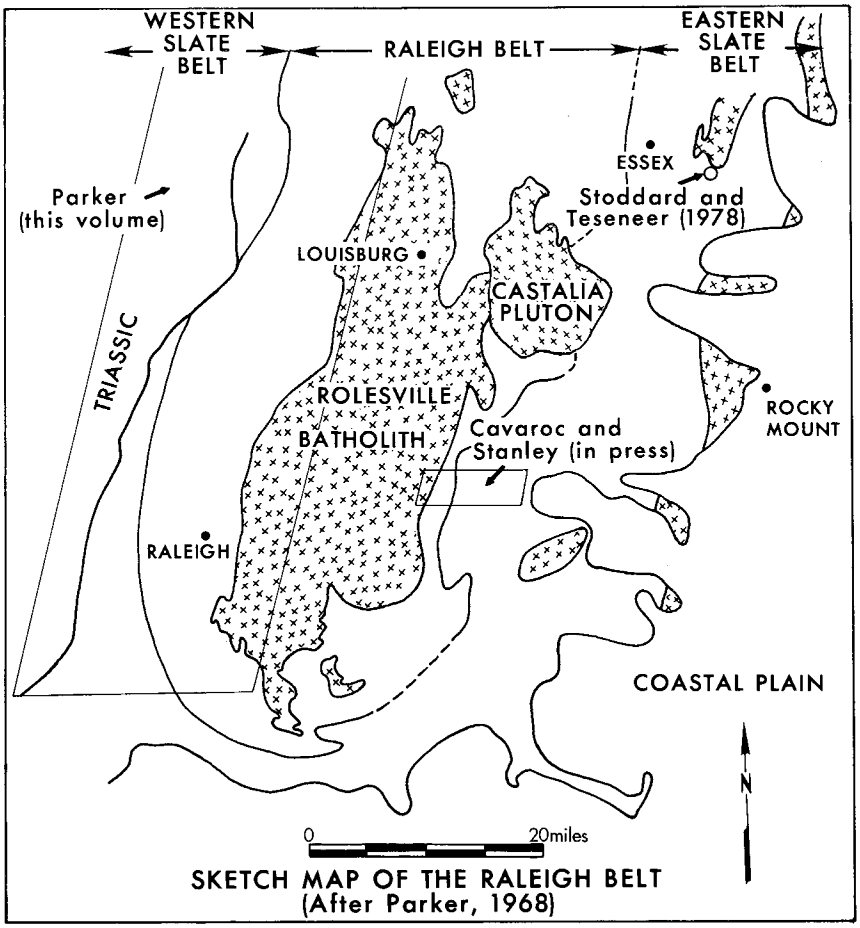

Figure 1.

cf. Glover and others, 1978) and shelf sediments upon which the slate belt volcanic arc was built up. If this is the case, then the contacts between the Raleigh belt and slate belt units might very well be gradational and conformable, and they must have shared a common tectonic and thermal history since the early Paleozoic. In fact, Parker has suggested such a stratigraphic relationship, and argues (this volume) that the Raleigh - slate belt boundary west of Raleigh is a continuous metamorphic gradient. However, others (Casadevall, 1977; Hatcher and others, 1977; S. Farrar, in Costain and others, 1978) have inferred the existence of a major fault zone in this area.

East of Raleigh, the Raleigh belt - eastern slate belt contact has also been interpreted by Parker (1968 and in press) as conformable, and a study by Cavaroc and Stanley (in press) supports Parker's conclusions (Fig. 1). However, farther east in the eastern slate belt, stratigraphic relationships are increasingly difficult to discern, as Coastal Plain cover predominates. The occurrence of possible oceanic lithosphere (Fig. 1; Stoddard and Teseneer, 1978) on strike with a linear aeromagnetic anomaly and a probable fault of regional extent (Hatcher and others, 1977) suggests the possibility of a major crustal discontinuity in that area.

Although it is probable that the Raleigh belt - slate belt boundary is a continuous metamorphic gradient in places, it has not been conclusively demonstrated to be so on all sides. Definitive answers must await the results of more detailed and comprehensive work/

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THE USE OF *NURE* REGIONAL GEOCHEMICAL DATA IN GEOLOGIC MAPPING[1]

Van Price, Jr. and R. Bruce Ferguson

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1.Work supported by USDOE Contract No. AT (07-2)-1. The Savannah River Laboratory is operated for DOE by E.I. du Pont de Nemours and Co. and has responsibility for a geochemical reconnaissance of the Eastern United States (Ferguson and Price, 1976).

INTRODUCTION

The objective of this paper is to point out the copious regional geochemical data available through the U.S. Department of Energy (DOE) National Uranium Resource Evaluation (NURE) Program and to demonstrate the potential of such data as a tool for geologic mapping in the southeastern Piedmont. For some years geologists have been limited to high altitude imagery and regional geophysical maps to aid in the extrapolation and regional interpretation of limited geologic field data. Geochemistry has been restricted to characterizing mapped rock units (such as a specific pluton) or to pinpointing ore deposits in areas which were preselected because of geologic criteria. The NURE program provides a massive data bank to assist geologists to prepare more meaningful and accurate geologic maps.

DISCUSSION

Sample Collection and Processing

In the southeastern Piedmont, -40 mesh stream sediment composite samples were taken from small streams every 5 square miles. Ground water was sampled at a 10 square mile spacing. At each stream and ground water site, measurements were made of alkalinity, pH, and conductivity of the

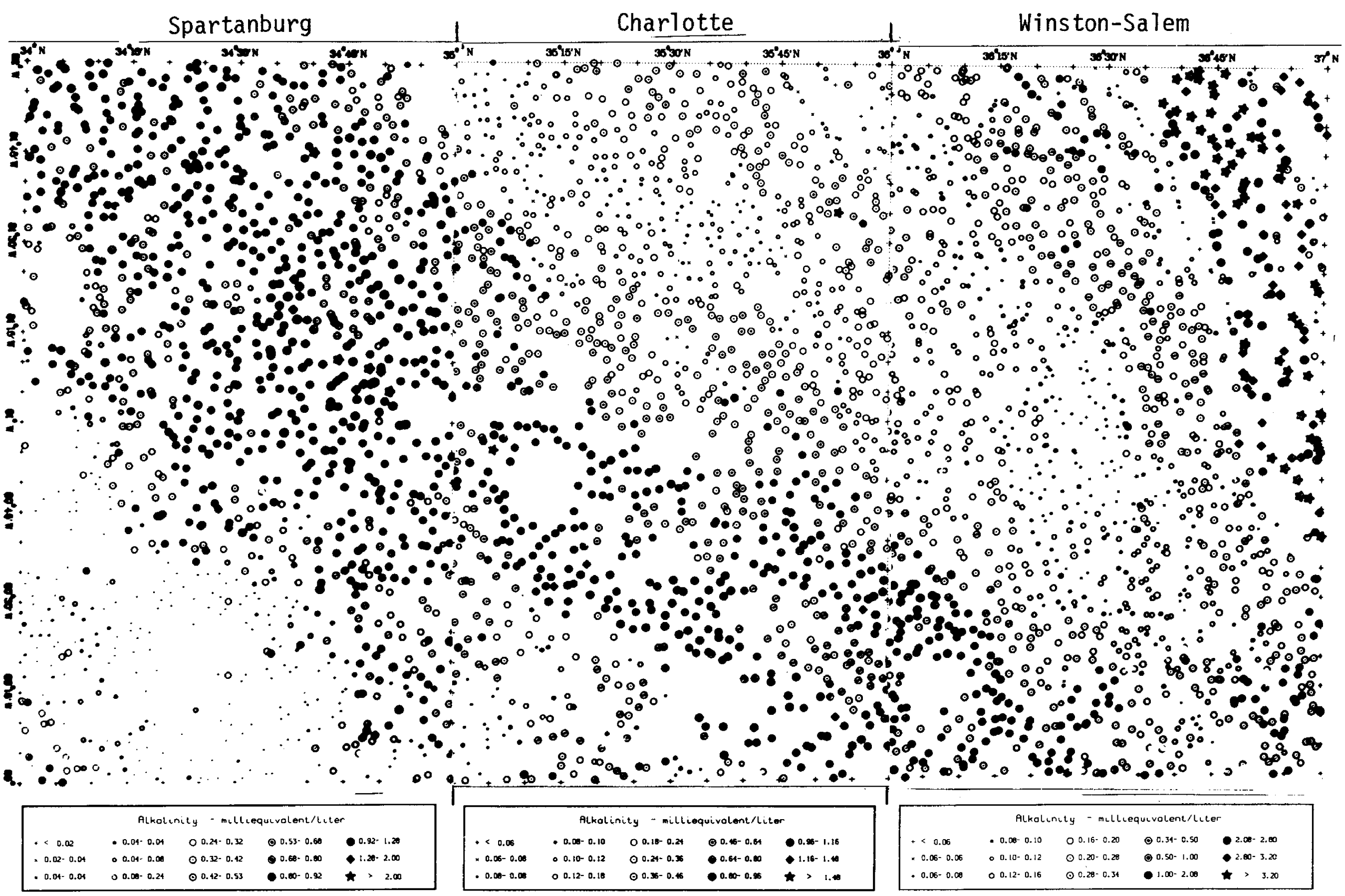

Figure 1. Areal Distribution of Stream Water Alkalinity Values for the Winston-Salem, Charlotte, and Spartanburg NTMS Quadrangle.

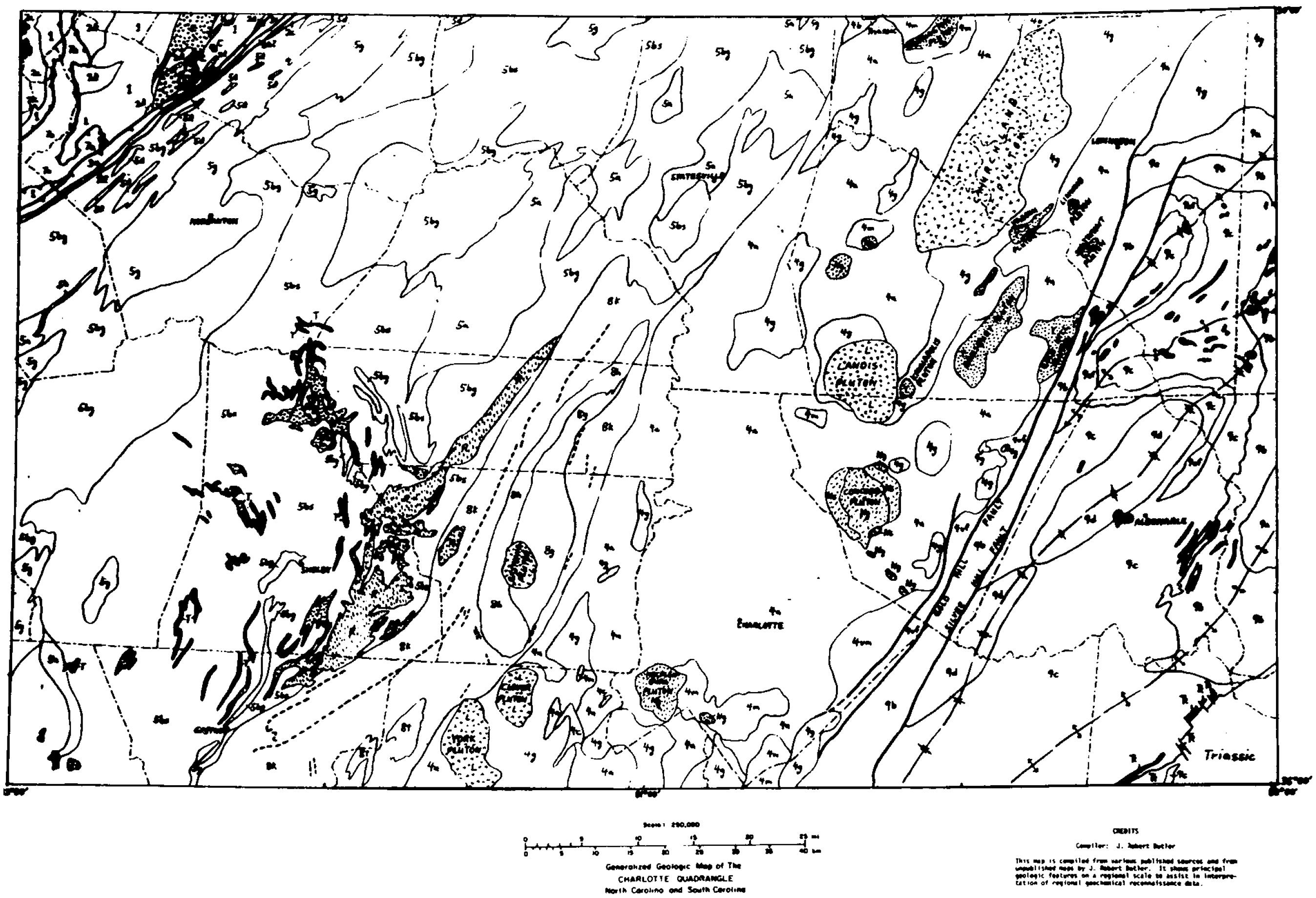

Figure 2. Geologic map of the Charlotte NTMS Quadrangle.

water. Sediments were sieved to -100 mesh in the laboratory and analyzed for a number of elements which can be clues to petrogenetic processes.

Data Interpretation

Throughout the following discussion, the reader is cautioned to recall that any interpretation of the data should include possible grain size variations because the analysis is of -100 mesh material. For example, if crystallization conditions caused ilmenite in one gabbro to be coarser than -100 mesh, our titanium distribution map might not show that gabbro.

WATER QUALITY

Figure 1 is a map pf the areal distribution of titratable alkalinity in small streams of the Spartanburg, Charlotte, and Winston-Salem quadrangles. Several regional features such as Valley and Ridge carbonate rocks, upper Coastal Plain sands, and Charlotte belt mafic rocks are obvious. For example, the Churchland pluton (80°20'W, 34°55'N) stands out as a low-alkalinity area within the Charlotte belt. Water quality data for small streams show strong geologic control and, through multivariate techniques such as cluster and discriminant analysis, can be used as a mapping aid even in detailed geologic studies (Ferguson and Price, 1976).

Uranium and Thorium in Sediments

Figure 2 is an outline geologic map of the Charlotte 1° by 2° quadrangle as compiled for the Savannah River Laboratory by J.R. Butler (Heffner and Ferguson, 1978). Figure 3 shows the distribution of uranium in 1249 stream sediment samples from the Charlotte quadrangle. Figure 4 shows the thorium distribution for the same area. Stream sediments from the monazite belt are high in uranium and thorium. Use of perspective views quickly reveals some regional patterns. For example, the high-rank metamorphic zones of the Inner Piedmont yield high values for uranium and thorium in stream sediments, except in areas intruded by plutons such as the Churchland pluton. Finer structure is evident in the data, but extended discussion is beyond the scope of this paper.

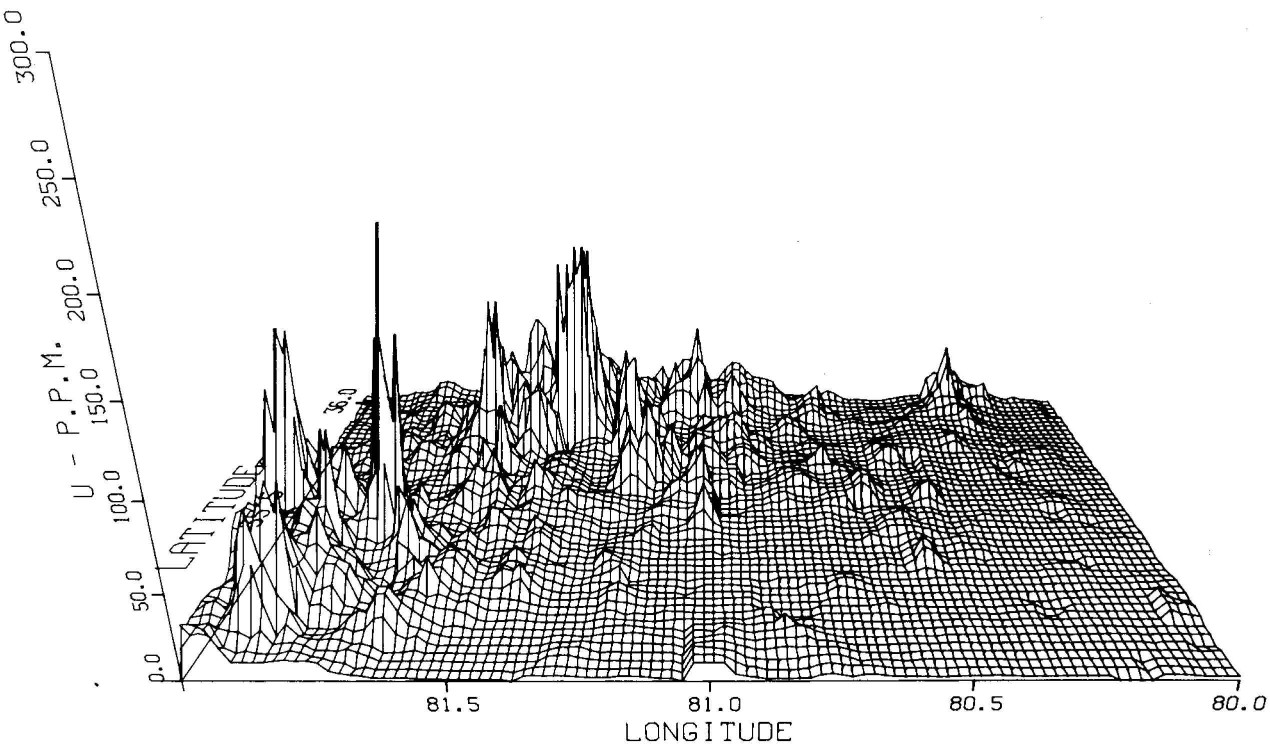

Figure 3. Distribution of Uranium in Stream Sediments in the Charlotte NTMS Quadrangle.

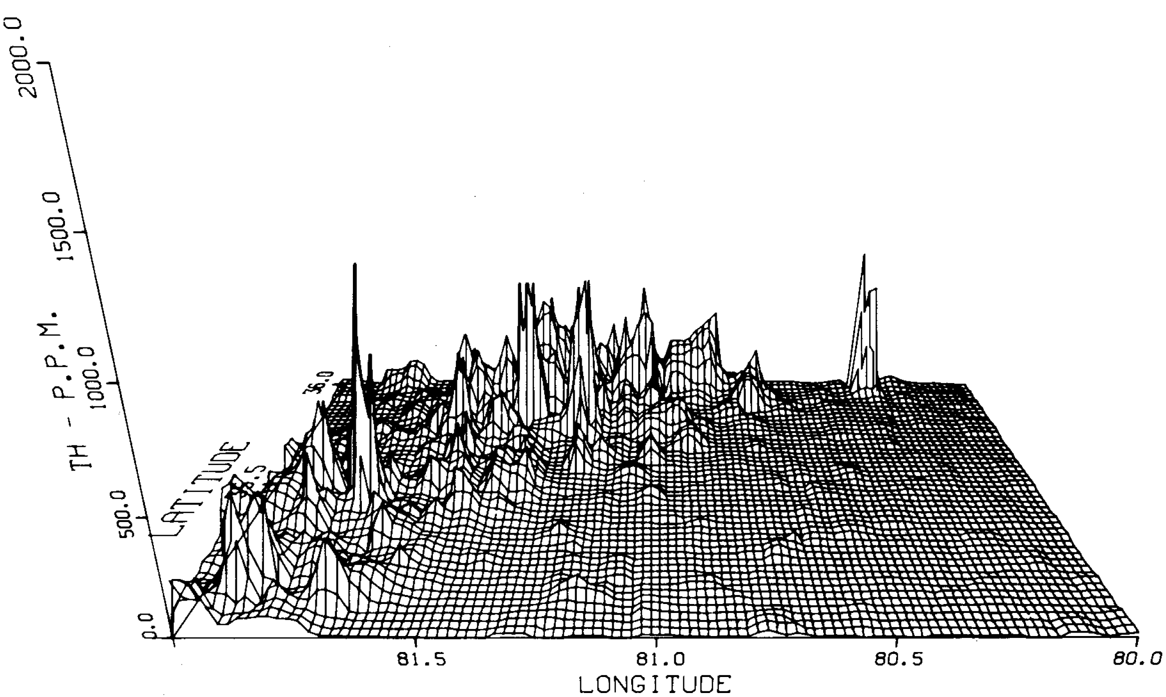

Figure 4. Distribution of Thorium in Stream Sediments in the Charlotte NTMS Quadrangle.

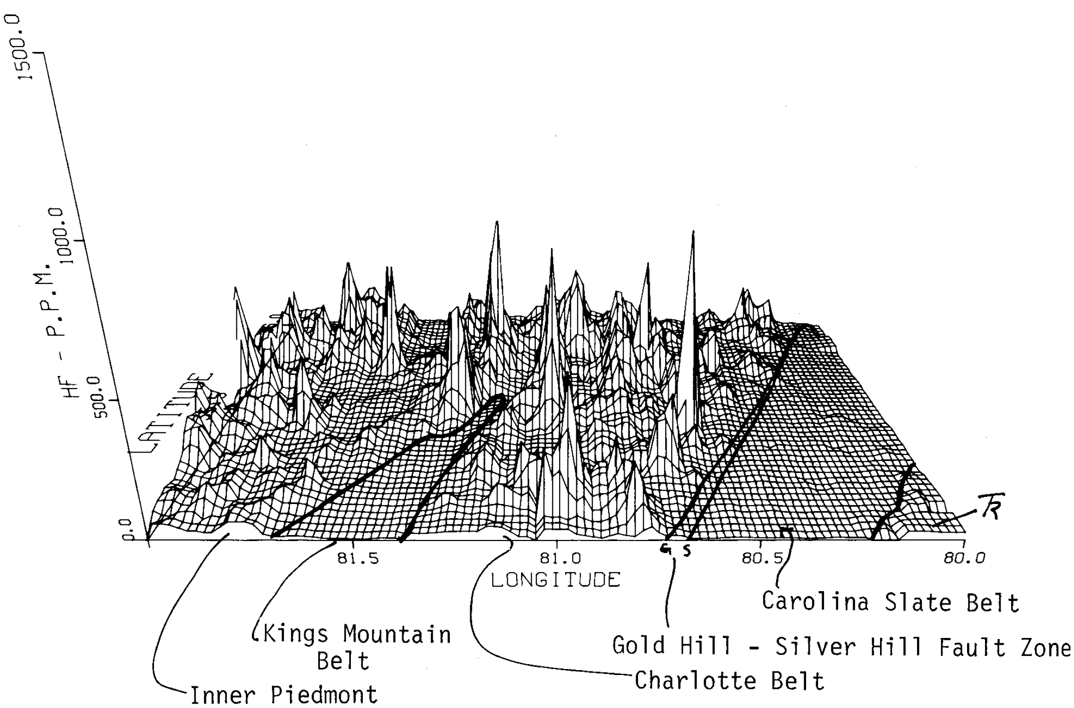

Figure 5. Distribution of Hafnium in Stream Sediments in the Charlotte NTMS Quadrangle.

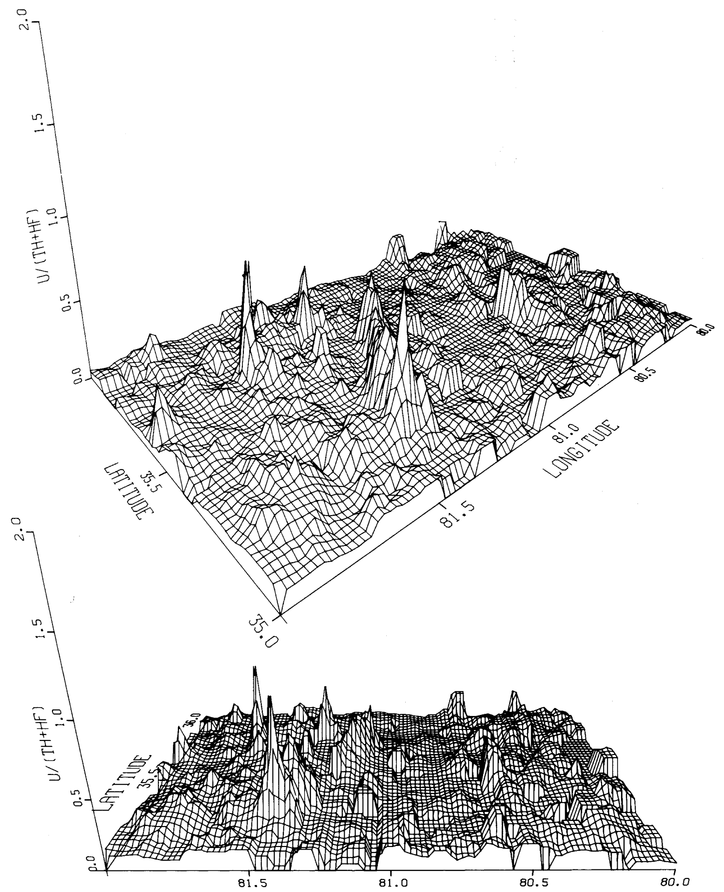

Figure 6. Plot of the Ratio U/(Th + Hf) for the Charlotte NTMS Quadrangle.

Distribution of Hafnium

Hafnium distribution is shown in Figure 5. The Gold Hill-Silver Hill fault is sharply defined as the boundary between the hafnium-rich Charlotte belt and the low hafnium Carolina slate belt. The Carolina slate belt and Kings Mountain belt are distinctly low in hafnium values- even lower than values reported in the Wadesboro Triassic basin.

Value of Elemental Ratio Maps

In addition to simple elemental maps, certain elemental ratio maps are extremely useful for geologic interpretation. For example, Figure 6 shows the ration U/(Th + Hf). This ratio tends to accentuate the presence of uranium in minerals other than monazite and zircon or to accentuate areas where zircon or monazite might be particularly high in uranium, The outcrop area of the Cherryville Quartz Monazite is seen to yield high values for this ratio.

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COMPARISON OF ANOMALIES DETECTED BY AIRBORNE AND TRUCK-MOUNTED MAGNETOMETERS IN THE HAILE-BREWER AREA, SOUTH CAROLINA

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Total-intensity aeromagnetic maps of large parts of South Carolina have been published or made available to the public by the U.S. Geological Survey. The data for these maps have been acquired by airborne magnetometer along flight traverses at various altitudes above ground and at spacings of either ½ or 1 mile (0.8 or 1.6 km). An aeromagnetic map of the Haile-Brewer area, South Carolina, is based on traverses about 122 m above ground and approximately 0.8 km apart (U.. S. Geological Survey, 1970). A small part of this map is shown in Figure 1.

The aeromagnetic map of the Haile-Brewer area shows numerous closely spaced linear positive anomalies of moderately high amplitude. Many of these anomalies are conspicuously alined in a northwest trend and have steep gradients that reflect sources having magnetic tops near the surface of the ground. The east-west flight lines are well oriented for revealing these narrow anomalies in the Haile-Brewer area. If the flight lines had been oriented in some other direction, recognition of the linear anomalies would have been more difficult.

The aeromagnetic anomalies are clearly related to diabase dikes of Triassic and Jurassic (?) age, but the aeromagnetic map pattern indicates that the total number of these dikes is very much larger than that previously known from outcrops. The widths of the northwest-trending linear magnetic anomalies seem to indicate tabular magnetic sources that are wider or less steeply dipping than are the diabase dikes known from field experience and reconnaissance mapping. In order to locate the magnetic anomalies as precisely as possible on the ground and to confirm that the anomalies overlie diabase dikes, as inferred, a ground-magnetometer survey was made using truck-mounted equipment. Traverses were made along roads that crossed the anomalies shown by the airborne survey. The equipment, described by Zablocki (1967), consists of an encapsulated flux-gate magnetometer suspended on a boom behind the vehicle from 3 to 4.6 m above the ground. Kane, Harwood, and Hatch (1971) used similar equipment in New England to test and map magnetic anomalies previously located by airborne surveys. The results of the ground traverses in South Carolina were similar to the results in New England, and indicated a correlation of the anomalies with diabase dikes known previously from geologic mapping. Several anomalies apparently are from diabase dikes not previously discovered. In addition, the ground traverses showed that a few broad anomalies are really many small anomalies not evident in the data from the airborne survey (Fig. 2). These small anomalies in the ground data are assumed to result from closely spaced thin dikes that are not seem as individual anomalies in the airborne-magnetometer survey. Because of the distance of the recording instruments above the magnetic sources, the data from the airborne survey are too attenuated to show small ground anomalies.

In order to test the assumption that the anomalies obtained by airborne and truck-mounted instruments could be related to known diabase dikes in the area, magnetic profiles were calculated using a small part of profile A-A' in Figure 2 as a model. The model, shown in Figure 3, consists of tabular bodies simulating diabase dikes ranging from 7.6 to 30.5 m in thickness, extending an infinite length perpendicular to the profile, dipping at 80° W. or 80° E., extending to an infinite depth, and having parallel contacts. The calculation of the profiles is based upon measurement of the magnetic susceptibility and remanent magnetization of many dikes in the Haile-Brewer area. Two profiles were calculated, at an assumed 4.6 m above ground and at 122 m, and were compared with the actual profiles obtained from the airborne and truck-mounted magnetometers.

The results illustrated in Figure 3 show calculated profiles that resemble closely the observed profiles and tend to confirm that closely spaced thin diabase dikes produce the observed anomalies. The results suggest that many other linear magnetic anomalies on aeromagnetic maps of the southeastern Piedmont that have been attributed to single diabase dikes (Fig. 1) may represent an unknown number of dikes of various thicknesses and spacings, all trending in nearly the same direction at any particular location.

The diabase is black to dark gray. In hand specimens, the dikes differ mainly in grain size and abundance of phenocrysts of olivine and feldspar. In general, the diabase dikes in the Haile-Brewer area have the strongly oriented trend of about N. 45° W., which is characteristic of diabase dikes in the southeastern Piedmont. Locally, individual dikes have strikes that differ from place to place, and a few dikes have a trend that differs from most others. The dip of the dikes commonly is vertical or nearly so. Diabase dikes seen in outcrop or interpreted from the aeromagnetic map are not uniformly distributed either in eastern North America or in the Haile-Brewer area. The dikes tend to be particularly abundant near Kershaw in Lancaster County and along the Wateree River near the boundary between Kershaw and Fairfield Counties. Commonly, they crop out in stream beds where dense unweathered diabase obstructs and diverts the stream. These obstructions and diversions produce topographic features

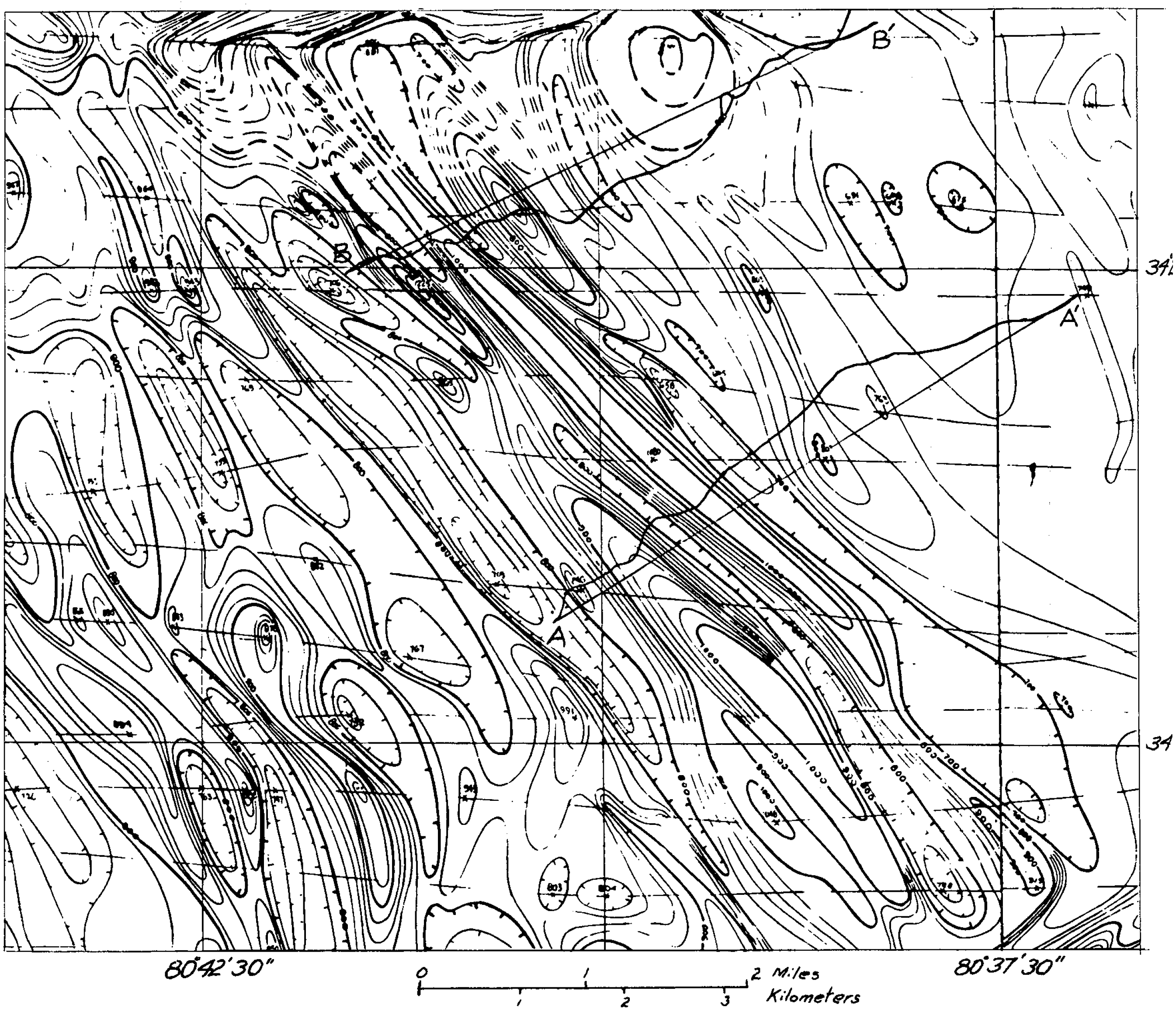
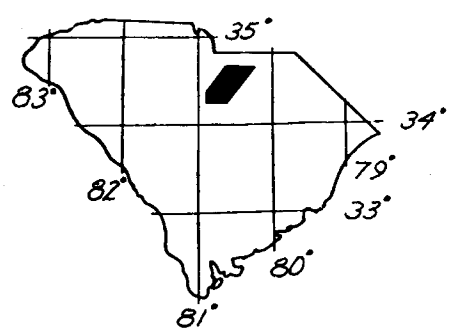


Figure 1. Part of the aeromagnetic map of the Camden-Kershaw area, north-central South Carolina (U.S. Geol. Survey, 1970) showing the location of magnetic profiles.



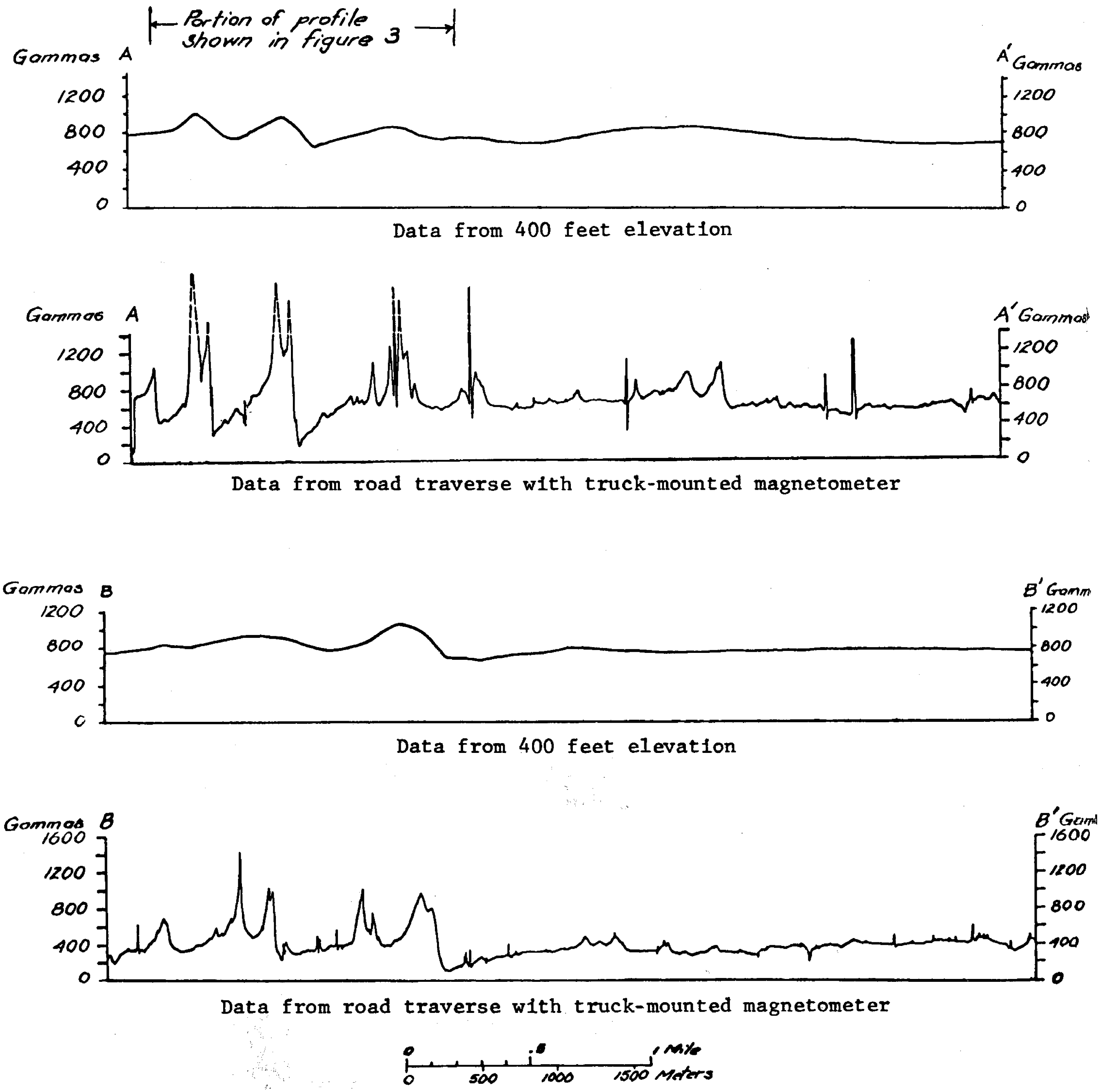


Figure 2. Comparison of profiles detected by airborne and truck-mounted magnetometers. Profile locations shown on figure 1.

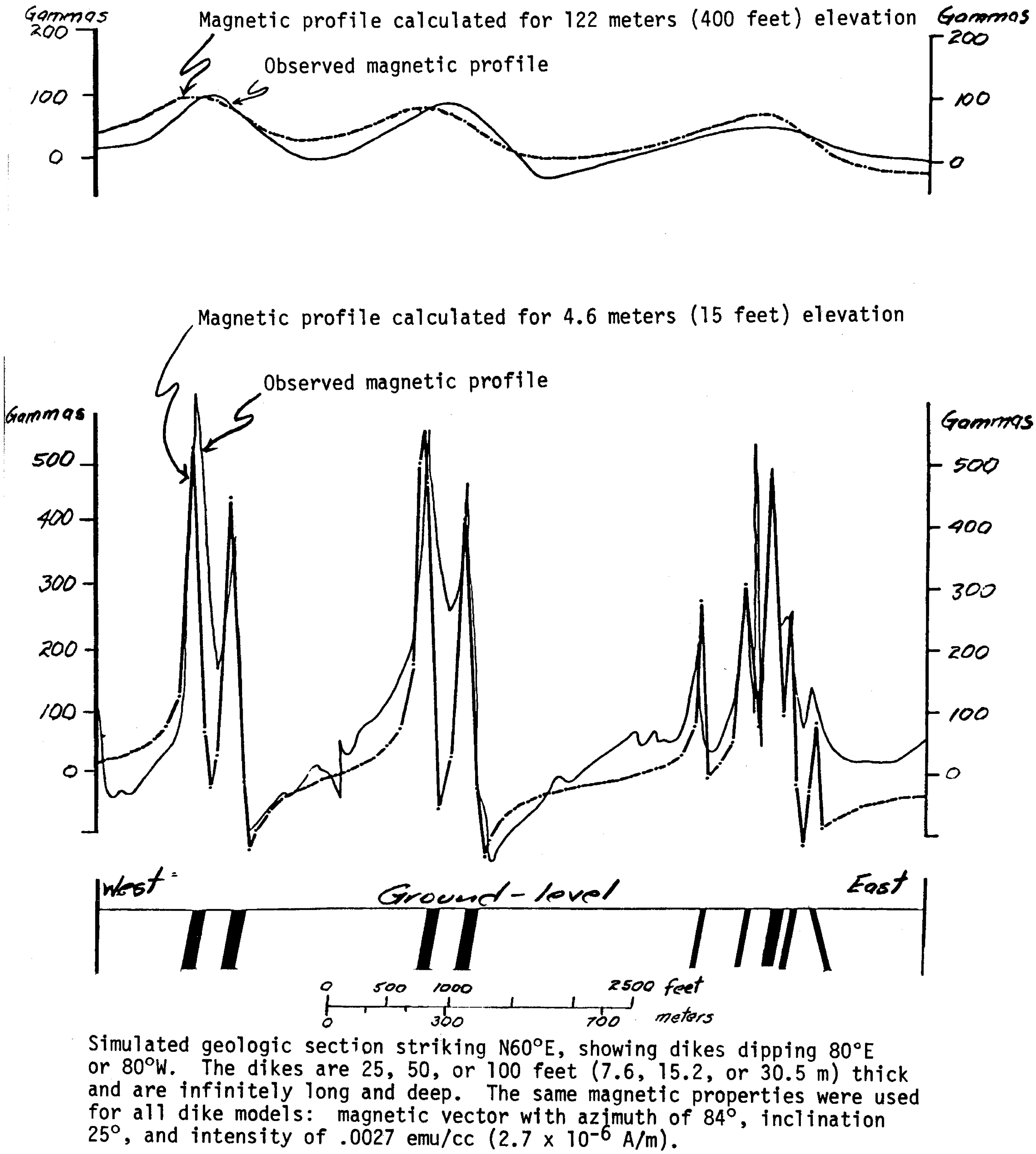


Figure 3. Magnetic profiles calculated for 4.6 m (15 feet) and 122 m (400 feet) in elevation over a two-dimensional model simulating a geologic section.

that locally reveal the trends of dikes, but dikes may be difficult to find on flat forested interfluves away from streams. The dikes weather spheroidally and commonly have a characteristic weathering rind of soft orange-brown residuum. Cores of such spheroids commonly are scattered as float on the ground surface below the dike outcrop. As a result, weathered dikes are often difficult to locate and measure. Systematic thickness measurements of diabase dikes in South Carolina have not been published; thus, neither average thicknesses nor the most common thickness is known. However, the thicknesses of dikes in the Haile-Brewer area were measured or estimated wherever the dike contacts could be at least approximately located; these thicknesses range from a few centimeters to more than 300 m. The most common thicknesses appear to be about 3 m and 15 m. The largest dike, carefully measured by Steele (1971) where it is exposed in a deep roadcut in Lancaster County, is 1,123 feet (342.3 m) thick. Such thick dikes appear to be very rare. In several roadcuts and other artificial exposures, perhaps as long as 100 m, as many as nine dikes crop out, ranging in width from less than 25 cm to as much as 22 m. Where several thin dikes are close together, correlation of specific dikes from outcrop to outcrop is complicated by the similarity in appearance of the dikes, their nearly parallel strike, and their apparently anastomosing character. In Meriwether County, Ga., a single linear magnetic anomaly detected by airborne methods proved to be as many as four distinct dikes when studied at ground level (Rothe and Long, 1975).

The presence of multiple dikes in Georgia and the experience in South Carolina of testing aeromagnetic anomalies with the truck-mounted magnetometers suggests that such groups of dikes are more common than previously thought. Tilford and Canady (1977, p. 41-45) found that using ground-magnetometer traverses to study diabase dikes and faulting associated with sedimentary rocks in the Triassic (?) Durham basin of North Carolina led to a better understanding of the geologic history of the area. We hope that further study of linear magnetic anomalies associated with diabase dikes may yield information pertinent to the structure and history of gold-bearing rocks and massive sulfide deposits in the Haile-Brewer area.

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STRUCTURAL CHRONOLOGY OF THE LAKE MURRAY SPILLWAY, CENTRAL SOUTH CAROLINA

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INTRODUCTION

The Lake Murray spillway is a spectacular exposure of polyphase-deformed rocks near the northeast terminus of the Kiokee belt, central South Carolina. Although the geology of the spillway has been studied by many geologists (Heron and Johnson, 1958; Kiff, 1963; Tewhey, 1968, 1977), detailed structural analysis has not been attempted. The purpose of this article is to summarize the structural chronology of the spillway as deduced from the analysis of mesoscopic deformation features. Over 2000 structural measurements were collected with a Brunton compass throughout the length of the spillway.

LITHOLOGIES

The main rock units exposed in the spillway can be broadly divided into two gneiss units and two schist units (See STOP 9--Secor and Snoke, this volume). The contacts between these units are sharp and straight and have all appearances of being conformable. The gneiss varies in composition from granodiorite to quartz monzonite. It is an even-grained, relatively homogeneous, light gray rock with a well-developed gneissosity. Large porphyroblasts (up to 5 or 6 mm in length) of white to pink microcline are conspicuous. A decrease in grain size and a corresponding increase in the development of mylonitic texture is apparent from west to east across the exposures. The schist unit is considerably less monotonous than the gneiss/ Silver-gray, garnetiferous quartz-muscovite schist is interlayered with quartzo-feldspathic gneiss and green to black amphibolite. Garnet porphyroblasts in the schist reach 2 cm in diameter and impart a knobby appearance on weathered surfaces.

Aplite, pegmatite, and mafic dikes intrude the above units. The mafic dikes are metamorphosed to biotite- and amphibole-rich schists. Lamprophyre and diabase dikes are late aspects of the igneous history of the area and do not display evidence of penetrative deformation and metamorphism.

Textural, compositional, isotopic, and mineralogical data indicate that the gneiss units were originally igneous rocks. A sedimentary origin is assumed for the compositionally-layered schist units. Therefore, prior to the main phase deformation, it is inferred that a granitic pluton (i.e., the protolith of the gneiss) intruded a heterogeneous sequence of sedimentary rocks. The mechanism of emplacement of the pluton is uncertain, but perhaps a diapiric intrusion of semi-crystalline magma is a viable hypothesis (see Tewhey, 1977).

STRUCTURAL FEATURES

Initial analysis, employing several domains based on lithology and geography, revealed that the structural chronology for both the gneiss and schist units was the same. Therefore, the spillway is considered a single, homogeneous domain with respect to the described deformational events.

All planar and linear features measurable within the spillway are on the mesoscopic scale. Structures range in size from minute crenulations, only a few millimeters in length, to folds having amplitudes and wavelengths of 5 to 6 meters. Four, possibly five, deformational phases are evident from comparison of the geometric relationships between individual structures. The mesoscopic structural elements as deciphered from the spillway are summarized in Tables 1 and 2.

D_1 phase[1]

The effect of the D_1 deformational event is manifested as the development of foliation in the gneiss and schist unites and in the early mafic dike (metamorphosed to biotite schist) in the gneiss. The gneissosity (S_1) is defined by the segregation of light and dark minerals in thin layers, only a few millimeters wide. Quartz, microcline, muscovite, and minor sodium plagioclase compose the light bands; whereas biotite flakes compose the dark bands. The schistosity (S_1) in the muscovite schist is parallel to compositional layering in the schist and is defined by the parallel alignment of muscovite flakes. The schistosity in the biotite schist is the result of the alignment of biotite plates.

F_1 folds were not observed in the gneiss or biotite schist (metadike), but scarce "refolded" folds were found in the schist unit. However, the S_1 foliation in all units is interpreted to have developed during an intense isoclinal folding event (F_1).

Subsequent to D_1, a mafic dike (altered to amphibole schist) intruded the gneiss. This dike along with many pegmatite intrusions appear to be pre-D_2 , for they are locally deformed by second generation structures.

1.Editor's note: Secor and Snoke (this volume) believe that the dominant synmetamorphic penetrative foliation in the Lake Murray gneiss is regional S_2; therefore, the numerical sequence used by Carr should be considered in a local sense rather than a regional.

TABLE 1. SUMMARY OF MESOSCOPIC STRUCTURES, LAKE MURRAY SPILLWAY

DEFORMATIONAL PHASE	D_1	D_2	D_3	D_4	D_5
FOLDS	F_1, isoclinal	F_2, open to isoclinal, some attenuated limbs, intrafolial, rootless folds, chevrons locally	F_3, open folds and crinkle folds	--	--
SURFACES FOLDED	S_0, bedding; and original igneous structures in the gneiss	S_0 and S_1, foliation	S_0, S_1, and S_2	S_0, S_1, S_2 and S_3 (?)	S_0, S_1, S_2, S_3 (?), S_4 (?)
PLANAR STRUCTURES	S_1, dominant metamorphic foliation	S_2, secondary foliation subparallel to S_1, locally dominant axial surface to F_2 folds	S_3, axial planar to F_3 open folds, crinkle folds	S_4 , local slip or fracture cleavage	S_5, axial surfaces of elongate wraps
LINEAR STRUCTURES	---	L_2, intersection lineation between S_1 and S_2	L_3, crenulation lineation	L_4, crenulation lineation	L_5, elongate linear ridges
ATTITUDE	overturned folds to SE, with present NE axial trend	overturned folds to SE, moderate to steeply plunging, NE axial trends	subhorizontal axial surface dipping slightly SE	subvertical axial surface, E-W trend	subvertical axial surface, NE trend

TABLE 2. ORIENTATION OF STRUCTURAL ELEMENTS, LAKE MURRAY SPILLWAY[1]

DEFORMATIONAL EVENTS AND RELATED STRUCTURES		WESTERN GNEISS	SCHIST (both units)	EASTERN GNEISS	BIOTITE SCHIST	AMPHIBOLE SCHIST	APLITE DIKES	PEGMATITE DIKES
D_1	F_1	--[2]	~65°, N43E presently	--	--	--	--	--
	S_1	N12W, 52NE	N48E, 68SE	N53E, 71SE	N48E, 58SE	--	--	--
D_2	F_2	52°, N78E	65°, N46E	60°, N54E	--	--	--	--
	S_2	N28E, 70SE	N42E, 62SE	N55E, 73SE	N20E, 54SE	N42E, 70SE	N32E, 47SE	N39E, 50SE
	L_2	49°, N51E	26°, N58E	31°, N46E	--	--	--	--
D_3	F_3	--	--	--	--	--	--	--
	S_3	N55E, 21SE	N65E, 24SE	--	N42E, 26SE			
	L_3	05°, N65E	26°, S72W	--	21°, N66E	--	--	--
D_4	S_4	N73E, 72SE	N88W, 74SE	N88W, 70SW				
	L_4	--	65°, S50E	--	--	--	--	--
D_5	S_5	--	--	--	--	--	--	--
	L_5	--	68°, N50E	--	--	--	--	--

[1] -- Values reflect statistical maxima or most representative orientation.
[2] -- The symbol "--" indicates that either no structure was present or it was not measurable.

D_2 phase

The second phase of deformation was by far the strongest and most pervasive. All lithologies show evidence of this deformation with the exception of the late lamprophyre and diabase dikes. Structural features associated with D_2 include F_2 folds, S_2 foliation (parallel to axial surfaces of F_2 folds) and L_2 lineations,

Folding associated with D_2 is quite consistent with respect to orientation, but quite variable with respect to style and scale. When plotted on a stereonet, F_2 fold axes cluster closely; the minor scatter is easily accounted for by effects of subsequent milder deformation episodes. The folds are consistently overturned to the southeast with moderately to steeply plunging axes. F_2 folds are widespread in the gneiss and schist units as well as the biotite schist metadike. Aplite and pegmatite dikes have locally also been deformed by F_3 structures.

Folding is commonly similar in style, some open, but mostly approaching isoclinal. Isoclinal, similar folding is the rule in the pelitic schist units. Numerous examples of isoclinal folds with highly attenuated limbs as well as rootless folds were observed. Almost perfectly concentric folds occur in the more competent gneiss units. F_2 chevron folds are locally present in both the muscovite schist and gneiss units as well as in the biotite schist metadike. F_2 folds also vary considerably in dimension. Folding generally is on a larger scale in the more competent gneiss units. Amplitudes and wavelengths range from several centimeters up to 6 meters or more. However, folds in the pelitic schist reach maximum amplitudes of only 1 to 1.5 meters and wavelengths usually do not exceed a meter.

S_2 is a closely spaced cleavage which parallels the axial surfaces of F_2 folds. Measurements of S_2 orientation were taken from the gneiss and schist units, the biotite and amphibole schist metadikes, and aplite and pegmatite intrusions. S_2 is subparallel to S_1. The two surfaces reach perfect parallelism in the easternmost gneiss unit, where shearing forces appear to have had their greatest effect. Pegmatites in the eastern gneiss also locally record an intense D_2 deformation. For example, at one locality K-feldspar augen were flattened in S_2 and elongated parallel to F_2 fold axes.

The axial surfaces of F_2 folds show minor differences in orientation form one unit to another. These variations are probably a function of the rheologic properties of the lithologies and their response to stresses as well as slight changes in the actual direction of shear during deformation.

L_2 lineations are chiefly the product of the intersection of S_1 and S_2. These lineations appear as streaks of stretched minerals, commonly micas, or as very faint ridges on S_1 surfaces. Lineations measured on or parallel to F_2 fold axes are also part of this group. The variations in orientation of L_2 structures and F_2 fold axes (see Table 2) could indicate a slight fanning of axial surfaces during deformation or simply a lack of sufficient structural measurements.

D_3 phase

Effects of the D_3 deformation phase are chiefly recorded in the pelitic schist units. Subhorizontal S_3 axial surfaces intersect S_1 foliations to produce L_3 lineations and F_3 folds. L_3 lineations are tiny subhorizontal crenulations (only several millimeters wide) which are pervasive throughout the muscovite schist. L_3 lineations are also present in the biotite schist metadike and in the gneiss. F_3 folds are represented as broad warps in F_2 fold axes by the S_3 axial surface. The axial surfaces of several F_3 folds were measured on the north wall of the spillway; however, inadequate exposure did not permit the measurement of actual fold axes.

D_4 phase

Structures associated with this episode appear to be the result of mainly brittle deformational processes. S_4 crenulation cleavage and fractures vary considerably in their spacing and degree of development, but are most penetrative in the muscovite schist unit. Cleavage refraction in individual members of the muscovite schist unit complicated the collection of accurate measurements; therefore, measurements were taken only from the schistose member to allow a greater degree of compatibility of results. Where closely spaced, the cleavage tends to enhance the "button" texture on the weathered surface of the schist. These "buttons" are, in many places, more apparent than real and are mainly the result of the schistosity wrapping around large garnet porphyroblasts in the schist. Some brittle fractures in the gneiss share the same orientation as S_4 and are, therefore, presumed to be developed in response to D_4 deformation. S_4 appears to offset lineations of the D_3 generations. L_4 crinkle lineations result from the intersection of S_4 with S_1 foliation. Their slightly variable orientation may result from the effects of cleavage refraction or possible later deformation.

D_5 phase

Warping of S_1 foliation by S_5 axial surfaces forms elongate linear ridges (L_5) in the muscovite schist unit. Designation of D_5 as a separate event, however is only tentative. The orientation of L_5 structures corresponds fairly closely to that of F_2 axes and may therefore be related to this event as subsidiary or drag folds on the limbs of F_2 folds.

CONCLUSIONS

The rocks exposed in the spillway have been polyphased deformed, and four, possibly five, distinct events are recognized. Rb-Sr geochronological data (S.A. Kish, personal communication, 1978) indicate that these deformation phases are post-Middle Carboniferous and therefore, are synchronous with the classic Alleghanian foreland fold-thrust belt. Post-dating these deformation phases, lamprophyre and diabase dikes intruded the area. These dikes are unmetamorphosed and perhaps are a manifestation of Mesozoic rifting.

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Detailed Structure and Post-kinematic Dikes in the Carolina Slate Belt, Greenwood and Saluda Counties, South Carolina

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Mapping at a scale of 1:1200 in active and recently-abandoned clay pits in Greenwood and Saluda Counties, South Carolina had allowed detailed study of Carolina slate belt rocks which are otherwise very poorly exposed (Ritchie and Fallaw, 1976). The clay pits, operated by the Southern Brick Co. of Dyson, South Carolina, are scattered over an area of some 30 km^2 (Fig. 1). Each of the seven largest pits studied provides between 1/4 and ½ km^2 of 50% to 75% exposure. These clay pits are recommended to any student of the Piedmont who wishes to see good outcrops of these typically poorly-exposed rocks. In addition, the pits provide excellent opportunities for field trips for classes in structural geology and igneous and metamorphic petrology.

The Carolina slate belt is a northeast-trending zone of gently deformed, low-rank metamorphosed sedimentary, volcaniclastic, and volcanic rocks within which metamorphic grade generally increases to the northwest. The study area lies on the northwest margin of the slate belt, only a few kilometers from its contact with the schists and gneisses intruded by a more complex sequence of igneous rocks (Overstreet and Bell, 1965). The nature of the contact between these two belts is unclear.

Metamorphic rocks in the study area include gently folded, very fine-grained argillite, tuffaceous argillite, and a few thin rhyolite flows. These lithologies have undergone greenschist facies regional metamorphism (chlorite zone) but locally contain posigrade garnet near intrusive plutonic masses. Compositional layering in the argillites parallels slaty cleavage and lies in a girdle maximum oriented N72°W, 85°NE containing a major point maximum oriented N16°E, 34°NW and a minor point maximum oriented N29° 21°SE (Fig. 2). A few intrafolial folds within the compositional layering indicate some transposition of original sedimentary layering. A spaced fracture cleavage trends N13°E, 60°NW and appears to be an axial plane cleavage to mesoscopic folds. If so, then axial surfaces are overturned slightly to the southeast. Open mesoscopic folds have axes which trend approximately N26°E and are subhorizontal with a slight tendency to plunge gently to the northeast (Fig. 2). These folds have amplitudes of a few centimeters to about 10 m and wavelengths of about 1 to 10 m. Wavelength-to-amplitude ratios range from about 5 to 1 to about 10 to 1.

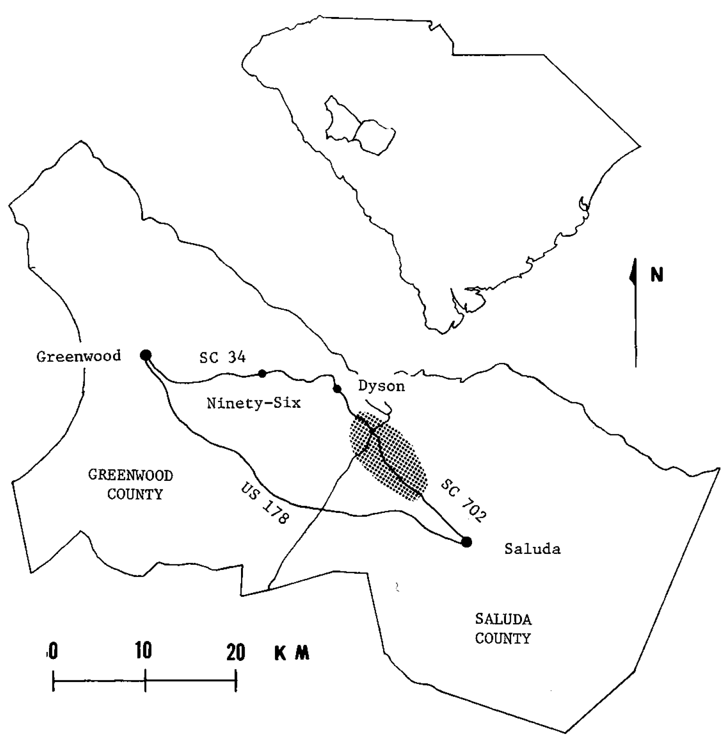

Figure 1. Location of Greenwood and Saluda counties in South Carolina and location of study area (shaded). Scale is for lower map.

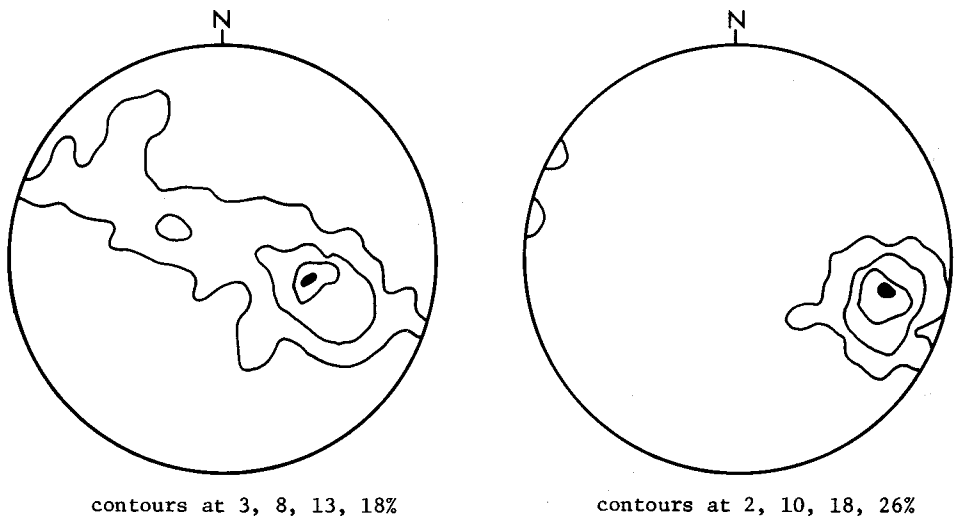

Figure 2. Lower-hemisphere equal-area plots of 188 poles to compositional layering and slaty cleavage (left) and 159 poles to fracture cleavage (right).

These metamorphic rocks are cut by three sets of post-kinematic dikes. The oldest dikes are relatively mafic and even in otherwise fresh exposures are completely weathered to dark tan or buff and brown saprolites. These mafic dikes are 10 cm to 18 m thick, dip steeply, and approximately parallel the regional northeast trend, although they do locally crosscut both foliations in the metamorphic rocks. Near these dikes, metamorphic foliations are in places disturbed and rotated. Some dike margins are slickensided and may be minor faults. One mafic dike retrained what appears to be a flow foliation near its margin.

The mafic dikes are cut by much fresher, more felsic dikes. These felsic dikes are rhyolites to quartz latites and are glomeroporphyritic with individual phenocrysts up to 2 mm. Phenocrysts of alkali feldspar (sanidine and albite) and B-quartz paramorphs are subhedral to euhedral, some with resorbed margins. The groundmass consists of a fine-grained aggregate of unoriented quartz and feldspar. These felsic dikes are 10 cm to 37 m thick and, like the mafic dikes, have steep dips, crudely parallel the regional northeast trend, and locally crosscut and disturb the foliations in the metamorphic rocks. Some felsic dikes have thin chill margins and thin baked or silicified zones in the metamorphic rocks they cut. One felsic dike pinches our vertically. These are shallow intrusions. The felsic dikes clearly crosscut the mafic dikes and are, in turn, cut by numerous small, steeply-dipping faults with normal separation.

The third set of dikes is poorly exposed and poorly represented in the study area. These dikes, although altered and weathered in most outcrops, are diabases which are probably representatives of the most numerous Triassic-Jurassic diabase dikes found elsewhere in the Piedmont. These dikes possess the spheroidal weathering with an orange rind characteristic of such dikes. In addition, these dikes are steeply-dipping, have sharp contacts, and clearly cross-cut the felsic dikes.

There are no radiometric ages on these dikes or on their host rocks, but perhaps the timing of the events responsible for the geology in this area can be approximated by comparison with other dated areas. The volcanic rocks of the slate belt were erupted over a considerable period of time up to about 520 m.y.b.p. (Black and Fullagar, 1976; Fullagar and Butler, 1976, Sinha, 1976). The principle Paleozoic Barrovian metamorphic event has been assigned a variety of ages, but appears to have had its peak between about 450 and 400 m.y.b.p. (Black and Fullagar, 1976; Fullagar and Butler, 1976, Sinha, 1976). The previously enumerated field relations indicate that the dikes in the study area must postdate this event. Gabbroic and syenitic plutons in the Charlotte belt, such as the Mt. Carmel complex were intruded about 400 to 380 m.y.b.p. (Fullagar and Butler, 1976). This mafic plutonic event may be responsible for the earliest, mafic dikes. Slate belt plutons, for the most part biotite adamellites such as the Lilesville and Pageland plutons, have been dated at 332 and 302 m.y.b.p., respectively (Butler and Fullagar, 1975). This Carboniferous igneous episode may have been responsible for the magmas which fed the felsic dikes in the study area. Finally, there are well-established 210 to 160 m.y.b.p. ages for diabase dikes associated with Triassic grabens in the Piedmont (Deininger and others, 1975; Sutter, 1976).

This area holds promise for continuing work in several areas. The dikes, which are well-exposed in the slate belt, may be traced along, and possibly across, the contact with the Charlotte belt, and may help to better define the nature of this boundary. Also, radiometric ages are needed on the dikes and the host rocks so that the timing of events responsible for the local geology and the relationship to the rapidlyemerging regional history can be worked out.

This paper was reviewed by Dr. Van Price, Jr.

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THE PETROLOGY OF THE GREENWOOD PLUTON, GREENWOOD COUNTY, SOUTH CAROLINA: A PRELIMINARY REPORT

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INTRODUCTION

The Greenwood pluton intrudes rocks of the Charlotte and Carolina slate belts just southeast of Greenwood, South Carolina. Diorite, gabbro, and olivine gabbro are the major rock types comprising this sixty square mile intrusive body. The Greenwood pluton is believed to be a younger post-metamorphic gabbro intrusion of Late Paleozoic age (Overstreet and Bell, 1965). About thirty separate post-metamorphic gabbro plutons form an arcuate belt extending from Farmington, North Carolina to Calhoun Falls, South Carolina (Butler and Ragland, 1969). Younger post-metamorphic gabbro plutons have been investigated by McCauley (1960), Hermes (1968), Medlin (1969), Chalcraft (1970, 1977), and McSween (1972).

This report represents the preliminary findings of a large-scale study of the Greenwood pluton and the adjacent country rocks. This investigation will include detailed geologic mapping of south-central Greenwood County, the production of a Bouger gravity anomaly map, and detailed mineralogical and geochemical data.

We would like to express our appreciation for the encouragement and financial aid provided by Norman K. Olson and Paul Nystrom of the Division of Geology, South Carolina State Board of Development and to members of the faculty research committee at the College of Charleston.

GEOLOGIC SETTING

The Greenwood pluton is a horseshoe-shaped intrusive body open to the west (Fig. 1). Exposures of the Greenwood pluton are found within the Kirksey, Ninety Six, Dyson, and Good Hope 7½ minute quadrangles of south-central Greenwood County. The pluton has been emplaced at the boundary between the Charlotte belt to the northwest and the Carolina slate belt to the southeast. The transition from greenschist facies rocks (chlorite zone) of the Carolina slate belt and the amphibolite facies rocks (garnet zone) of the Charlotte belt occurs within a one mile wide band in the study area.

LITHOLOGIES OF THE CAROLINA SLATE BELT

Light to dark green, fine-grained laminated argillite forms a wide north- to northeast-trending unit in the southeastern portion of the map area. Cleavage is well developed near the Charlotte belt boundary and often obscures bedding. Metarhyolite and poorly sorted volcaniclastic sandstone are interlayered with the argillites.

Near the boundary between the belts, metamorphosed mafic tuffs comprise a large portion of the section. Minor graphitic and iron-rich phyllites are also present. Phenocrysts may reach 0.5 inches in tuffs that are not intensely metamorphosed. Most exposures of the mafic tuff are dull green to black chloritic greenstone or actinolite amphibolite.

LITHOLOGIES OF THE CHARLOTTE BELT

Biotite gneiss is the most widely distributed unit in the Charlotte belt terrane of the map area. Metasandstone and amphibolite are coarsely interlayered with the biotite gneiss at a few outcrops. A crinkled muscovite schist commonly veined by granitic material is another recognizable unit. Diorite gneiss associated with small diorite intrusions may represent a marginal foliated facies of the plutonic diorite.

Peripheral to the Greenwood pluton are small coarse-grained diorite stocks which may be comagmatic differentiates. There appears to be little difference in composition and texture between these dioritic rocks and the more feldspathic and hornblende-rich phases of the Greenwood pluton.

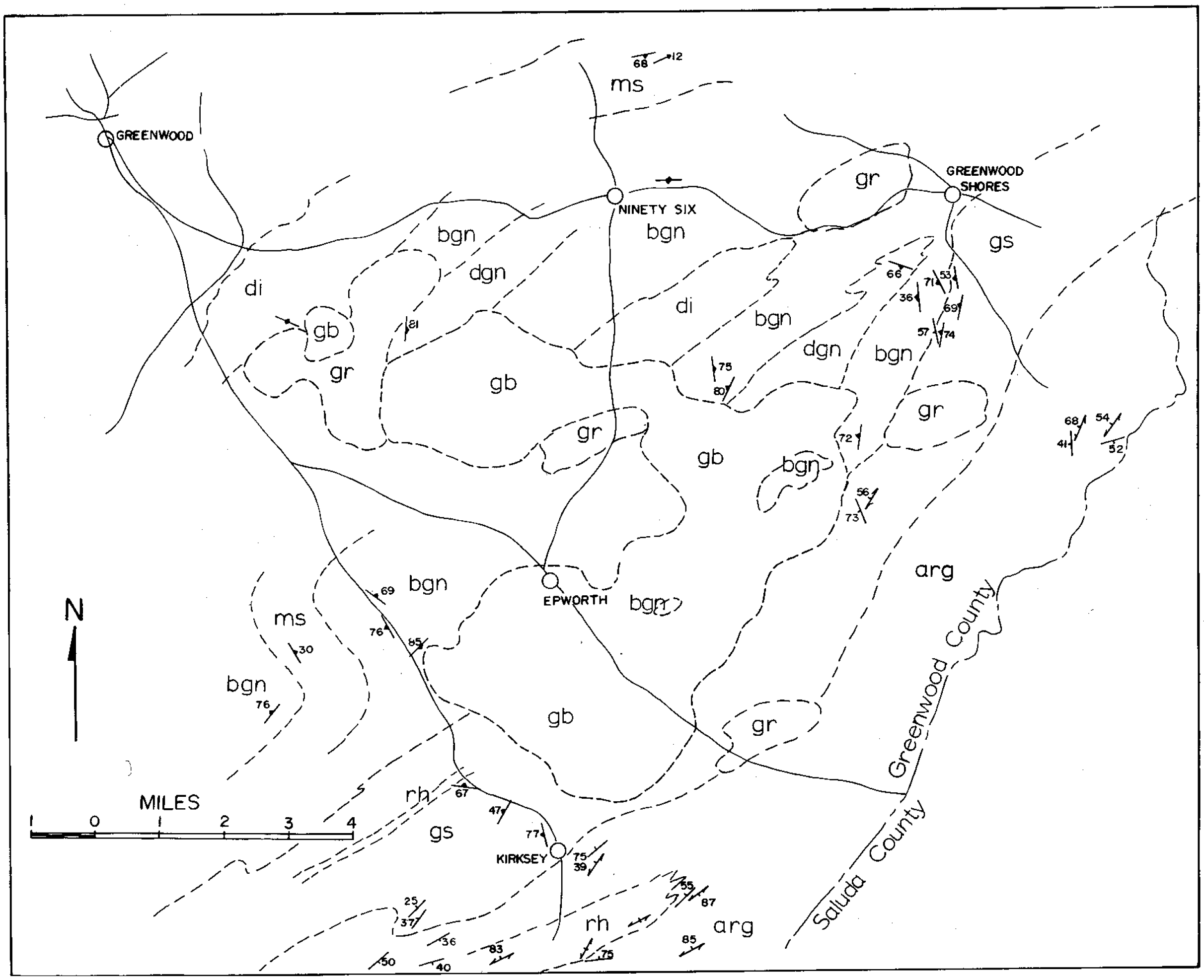
Granite and granodiorite form small stocks 1-5 square miles in area. The granites are coarse-grained, particularly the alaskitic occurrences. The granodiorites are medium-grained and equigranular.

Rhyolite porphyry dikes are found intruding most of the Charlotte belt rocks. The dikes appear to be subvertical with a northeast strike. Porphyritic dolerite dikes with large lath-shaped plagioclase phenocrysts are most common within 2000 feet of the Greenwood pluton. These dikes typically range from 1-4 feet in width.

Due to paucity of outcrop, age relations between intrusive rocks are unclear. Dolerite dikes apparently related to the Greenwood pluton intrude granitic stocks. The porphyritic rhyolite dikes appear to be quite late in the intrusive history of the region, for they are widely distributed within Charlotte belt, slate belt and the rocks of the Greenwood pluton.

STRUCTURAL AND GEOPHYSICAL DATA

Macroscopic folds, roughly 2000-4000 feet in width, are present in the slate belt rocks. Gentle plunges to the southwest have been detected. Poor outcrop has made the delineation of faults in the slate belt impossible. The strikes of wallrocks locally appear to wrap around the gabbro-diorite



EXPLANATION

Symbols	Rocks of the Charlotte belt
Approximate lithologic contact	bgn Biotite gneiss
75 Strike and dip of bedding	ms Muscovite schist, pink-weathering
85 Strike and dip of slaty cleavage	dgn Diorite gneiss
36 Strike and dip of schistosity	
12 Plunge of minor fold axis	

Intrusive plutonic rocks	Rocks of the Carolina slate belt
gr Granite, quartz monzonite, or granodiorite	arg Argillite, brown to green, may have pronounced cleavage as well as relict thin bedding
di Diorite	rh Metarhyolite tuff or flows
gb Gabbro	gs Greenstone, meta-tuff, and black amphibolite

Figure 1. Geologic sketch map of southern Greenwood County, South Carolina.

pluton making the intrusion appear concordant. The forceful injection of magma appears to be the major mechanism of emplacement.

A gravity survey of the Greenwood area is nearly complete. Gravity stations are on a one mile spacing dependent upon access. A 20 milligal Bouger anomaly marks the Greenwood gabbro. Further analysis of data should provide a better indication of the shape of the intrusive body than the poor exposure permits.

PETROGRAPHY

Microscopic examination of rock samples of the Greenwood pluton reveals that plagioclase, olivine, augite, hypersthene, and hornblende are the major primary minerals. Biotite, magnetite, pyrite, apatite, and quartz are also present. Alteration of varying intensity has produced chlorite, serpentine, epidote, and sericite.

Point counting has been completed on selected samples from within the pluton following the procedures outlined by Chayes (1956). The major rock types identified are diorite, gabbro, and olivine gabbro. (Table 1).

TABLE 1. Modal analysis data for Greenwood pluton rocks. Values given are in volume percent.

	Diorite	Gabbro	Olivine Gabbro
Plagioclase	51.0	50.9	62.4
Augite	5.9	20.3	13.3
Hypersthene	1.7	8.3	1.9
Olivine	-	11.0	17.5
Magnetite	3.9	2.7	-
Quartz	1.6	-	-
Biotite	2.9	4.0	0.5
Hornblende	25.7	2.7	1.2
Epidote	5.0	-	-
Chlorite	2.2	Trace	Trace
Apatite	Trace	-	-
Serpentine	-	Trace	-
	99.9	99.9	99.8

The rocks of the Greenwood pluton are medium-grained and display considerable textural variation including hypidiomorphic-granular, ophitic, subophitic as well as porphyritic textures. Reaction rims are obvious in many thin sections; multiple rims are developed as predicted by Bowen's reaction series.

Plagioclase normally occurs as subhedral laths with anorthite content ranges from 25 to 59 percent. Alteration of plagioclase is a common occurrence. Sausuritization yielding epidote and sericite is the most frequent alteration.

Subhedral grains of olivine reaching 4 mm in diameter occur in the olivine gabbros. Alteration of olivine has produced distinct grains and dendritic networks of magnetite and serpentine. Hypersthene reaction rims often surround olivine crystals.

The most abundant mafic mineral in the gabbroic rocks is subhedral-anhedral augite. Alteration of augite generally yields epidote, chlorite, and minor calcite or hornblende.

Hypersthene occurs as subhedral to anhedral crystals or as coronas surrounding polygonal olivine grains. Strongly pleochroic red coronas are found in samples of high modal olivine content. Alteration of hypersthene produces a uralite or chlorite.

Hornblende is the most abundant mafic mineral in the dioritic rocks of the Greenwood pluton. It occurs as primary subhedral grains with strong pleochroism (green-yellow brown-brown) or as reaction rims enclosing grains of augite, hypersthene, or magnetite.

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STRATIGRAPHY AND STRUCTURE OF THE BELAIR AND KIOKEE BELTS NEAR AUGUSTA, GEORGIA

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INTRODUCTION

The area straddling the Savannah River near Augusta, Georgia exposes the structurally "easternmost" rocks of the Piedmont province of South Carolina and Georgia before the overlap of the sediments of the Atlantic Coastal Plain. These low-grade, greenschist facies rocks, originally named the Belair belt (Crickmay, 1952), are commonly correlated with the Carolina slate belt. However, geologic data on this terrane are sparse and the nature of its boundary with the adjacent amphibolite facies Kiokee belt is poorly understood. The purpose of this report, therefore, is to summarize recent geologic mapping in this area, and to present some preliminary comments on how the Belair belt may relate to the tectonic evolution of the eastern Piedmont.

ROCKS OF THE BELAIR BELT

The Belair belt consists of interlayered felsic and intermediate pyroclastic rocks with subordinate epiclastic rocks, all metamorphosed to greenschist facies. Geologic mapping indicates that the belt can be tentatively subdivided into four major lithologic units: I. silver phyllitic metatuffs, II. felsic metatuffs, III. mafic (intermediate) metatuffs and metasediments, IV. felsic metatuffs and flows. Complex structural relations make this subdivision a simplistic generalization.

I. The silver phyllitic metatuffs are the structurally lowest unit in the Belair belt, and this unit thins out against the Augusta fault zone. Feldspar crystals and small flattened lapilli are the common volcanic fragments. On a mesoscopic scale, the lithology is commonly massive but lamination is locally apparent. The rocks are well foliated with a multitude if small-scale deformational structures.

II. The felsic metatuff unit is heterogeneous with intercalations of intermediate tuff and minor epiclastic rocks. The clasts typical of the felsic metatuff unit include plagioclase and quartz crystals, volcanic rock lapilli, and flattened pumice lapilli. The unit is either massive or bedded on a scale of feet. The contact with the underlying silver phyllitic metatuff is gradational.

III. The intermediate metatuffs and associated metasediments are intercalated on a large and small scale. The intimate intercalation of tuffs and sediments in this unit and the compositionally immature nature of the associated sediments (wackes, siltstones, and mudstones) indicate that the epiclastic rocks were derived from the erosion and reworking of the pyroclastic debris. The metatuffs in this unit commonly contain plagioclase crystal clasts, volcanic rock fragments and sparse scoriaceous bombs whose diameter reach a foot. Minor flows and sills are also present.

IV. The structurally highest unit in the area is dominated by felsic flows and tuffs, with subordinate intermediate rocks. A rock with quartz and feldspar phenocrysts and a tough, gray silicic mesostasis in a common lithology. The mesostasis and the nonfragmental character of the rock suggests that it is associated with fragmental rocks such that relations, within the unit as a whole, are quite complex. Many lithologic aspects of this upper metavolcanic unit are similar to the lower metatuff units.

All the rocks which constitute the Belair belt have undergone greenschist facies regional metamorphism. The rocks are phyllites and slates, often with a green hue reflecting their high content of epidote and chlorite. Other common constituents include quartz, albite, white mica, opaque oxides, and calcite. No biotite has been observed in Belair belt rocks implying that the physical conditions characteristic of the chlorite zone have not been exceeded.

A fossil was found in a boulder of volcanic wacke within semiconsolidated stream alluvium rested on bedrock. The size and angularity of the boulder indicate that it had not been transported far, and the lithology is identical to the underlying bedrock. The fossil locality is shown in Fig. 1. The specimen has been identified as a thorax section of a trilobite (A.R. Palmer and R.J. Ross, Jr., written communication, 1978) and a detailed report is in preparation.

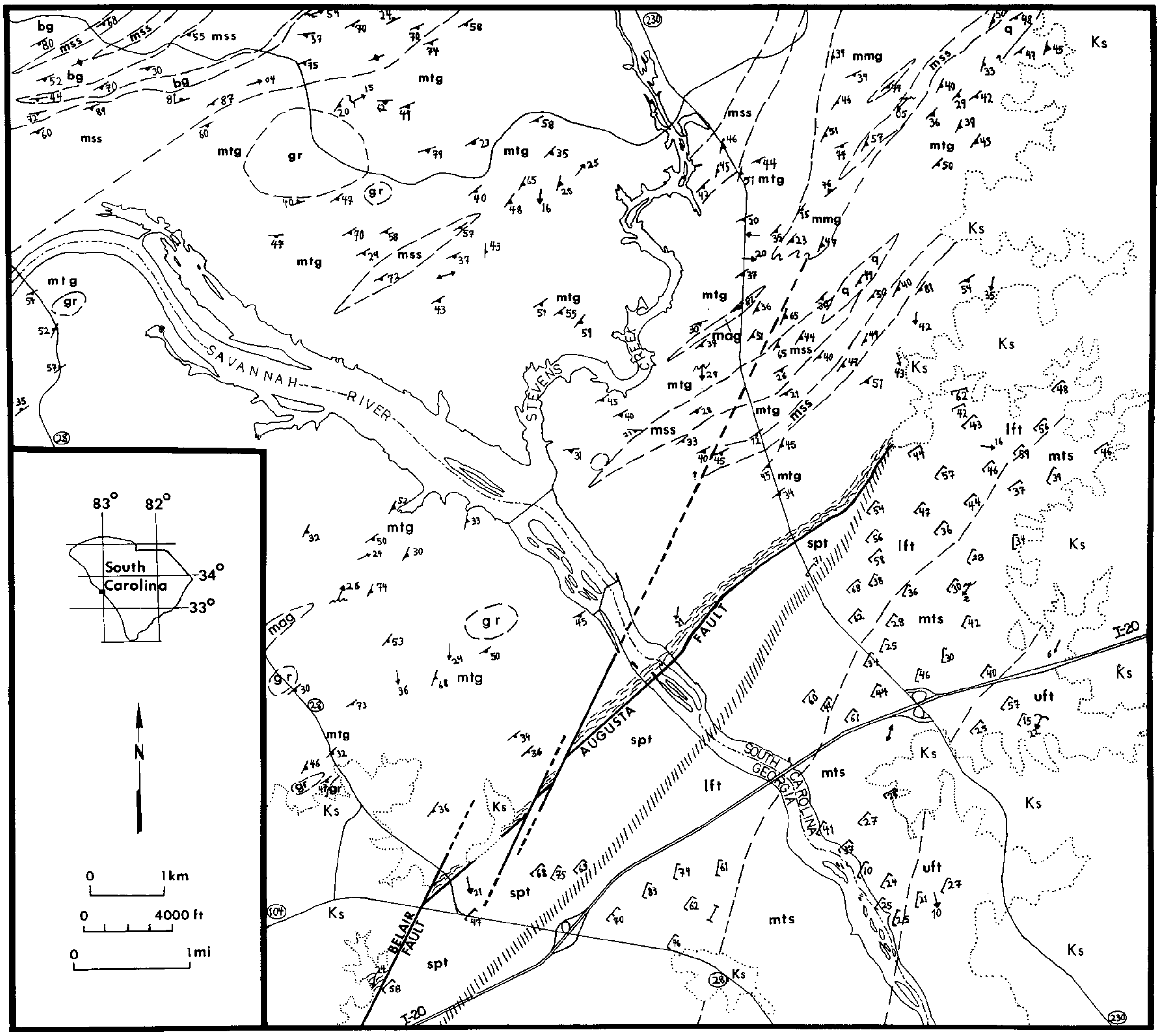
ROCKS OF THE KIOKEE BELT

The Kiokee belt is a high-grade metamorphic terrane which has undergone polyphase deformation. A simple stratigraphic pattern does not exist, but several lithologic units are mappable creating a complex somewhat discontinuous map pattern (Fig. 1).

The most widespread lithologic unit of the Kiokee belt is a migmatitic, two-mica gneiss, with a variable mica content. The gneiss is fine- to medium- grained, and biotite is the dominant varietal mineral. Subordinate layers of amphibolite, schist, and muscovite gneiss are also present in this unit.

Within the two-mica gneiss terrane, several other distinctive lithologies can be subdivided and mapped. These include a homogeneous muscovite gneiss; migmatitic, sillimanite-bearing two-mica schist; metaquartzite; biotite gneiss; and leucocratic granite. Pegmatite and aplitic dikes, both concordant and discordant, permeate the Kiokee terrane.

The metapelites contain the assemblage: quartz-biotite-muscovite-sillimanite-feldspar-garnet indicating upper



EXPLANATION

Symbols

- Lithologic contact
- Gradational contact
- Fault
- Possible fault extension
- Strike and dip of foliation (Kiokee belt)
- Strike and dip of cleavage (Belair belt)
- Strike and dip of cleavage parallel to bedding
- Trend and plunge of lineation
- Minor fold axis
- Road numbers
- Roads
- State border

Lithology

- Ks Coastal Plain sediments

Belair belt

- uft Upper felsic metatuffs and flows
- mts Mafic (intermediate) metatuffs and metasedimentary rocks
- lft Lower felsic metatuffs
- spt Silver phyllitic metatuffs

Kiokee belt (no stratigraphic order implied)

- mtg Migmatitic two-mica gneiss
- mmg Migmatitic muscovite gneiss
- mss Migmatitic sillimanite schist
- mag Migmatitic amphibole gneiss and/or amphibolite
- bg Biotite gneiss
- q Metaquartzite
- gr Synkinematic granite
- Mylonitic rocks

Figure 1. Geologic map of the Savannah River area, near Augusta, Georgia.

amphibolite facies metamorphism. Especially spectacular sillimanite paragenesis is developed in the northernmost schist unit where sillimanite clusters reach 4-5 cm (Fig. 1). The gneisses contain two feldspar, quartz, muscovite, biotite, garnet, and sometimes sphene; these rocks have apparently also undergone upper amphibolite facies regional metamorphism. An interesting paradox is that amphibolites within the Kiokee terrane characteristically contain prograde epidote suggesting local disequilibrium.

STRUCTURAL FEATURES

Augusta fault zone

The Augusta fault zone has a polyphase history involving both ductile and brittle components and, therefore, is analogous to the Modoc fault zone (Secor and Snoke, this volume). In the study area, a mylonite zone forms the southeastern margin of the Kiokee belt. The mylonitic rocks are juxtaposed to the Belair belt by a brittle fault dipping to the southeast. Brecciation is locally conspicuous along the boundary, and fragments of mylonite and Belair belt rocks are incorporated into the breccia. Silicification and calcitization are ancillary processes associated with the brecciation. The dip of the brittle fault is problematic, but J. Stevens, a Martin-Marietta Corporation geologist, related that drill hole data suggest a moderate dip of 35 to 45° SE. The direction of movement is uncertain; the available data are consistent with either a reverse fault (steep thrust fault) or a low-dipping normal fault. The magnitude of displacement is equally uncertain, but in that lower greenschist facies rocks have been juxtaposed against an amphibolite facies terrane implies a major tectonic boundary.

The mylonite which parallels the Augusta fault is best exposed in a Martin-Marietta Corporation crush rock quarry near the Savannah River, Augusta, Georgia. The mylonitic rocks were deformed ductilely at high temperatures and presumably high strain rates. Their lithologies are similar to rocks which constitute the migmatitic core of the Kiokee belt.

Belair fault zone

The Augusta fault zone has been offset by a series of en echelon faults named the Belair fault zone (Prowell, this volume). The faults trend approximately N25 - 30E and dip variably to the southeast. The offset pattern is shown in Fig. 1.

Belair belt mesoscopic fabric elements

Original bedding (S_0) is often well preserved in the rocks of the Belair belt. S_0 and S_1, the regional metamorphic foliation, are commonly parallel. S_1 planes strike N10E to N65E and dip 10° to 70° SE throughout the study area. The S_1 foliation is the result of the preferred orientation of platy minerals (chiefly chlorite and white mica) and flattened casts. I am impressed that the Belair belt rocks generally appear more strained than my observations of the Carolina slate belt.

The S_1 foliation is deformed by a crenulation cleavage which strikes N10E to N30E and dips to the SE. This cleavage is locally axial planar to small-scale asymmetric folds. The fold axes and the intersection lineation plunge shallowly southward.

Another lineation is common in many of the Belair belt rocks; however, no folds have been found associated with this fabric. These lineations trend approximately east-west and typically plunge moderately to the east. They appear to be equivalent to similar structures in the Kiokee belt where fold hinges parallel the stretching direction.

Kiokee belt mesoscopic fabric elements

The rocks of the Kiokee belt have been intensely transposed and primary lithologic layering (S_0) has been all but obliterated. Early folds are commonly intrafolial, and deformation is commonly so intense that even earlier deformation phases may be masked.

The main foliation is called S_1, but Secor and Snoke (this volume) believe that the main phase amphibolite facies metamorphism of the Kiokee belt is regional D_2. The foliation in the Kiokee belt is roughly similar in strike and dip to S_1 in the Belair belt, although their relative age relations are uncertain. The foliation is defined by compositional layering and the preferred orientation of various metamorphic minerals including mica, amphibole, and sillimanite. The mylonitic foliation of the southeast flank of the Kiokee belt grades into the regional foliation of the Kiokee migmatitic core. Recrystallization apparently outlasted deformation in the migmatitic core of the Kiokee belt.

A second deformational event has been recognized in the Kiokee belt which appears analogous to the crenulation of the Belair belt. Folds associated with this deformational phase in the Kiokee belt have the same orientation as those in the Belair belt, but the style is suggestive of a more ductile deformation.

Finally, another fold phase is locally recognized and is manifested by low amplitude, symmetrical folds. These folds trend approximately N85E and plunge to the NE; a lineation is associated with them, but there is no related penetrative foliation.

DISCUSSION AND CONCLUSIONS

The Belair belt is a low-grade greenschist facies terrane consisting chiefly of pyroclastic rocks and associated sediments. The Kiokee belt is a migmatitic terrane composed of granitoid gneiss intercalated with high-grade metasedimentary and metaigneous rocks. These belts are separated by the

Augusta fault zone which records a polyphase deformation history. There is at present no data to support the hypothesis that a metamorphic transition exists between the two belts. Also, the intensity of metamorphism and migmatization of the Kiokee belt precludes any straightforward stratigraphic correlations with Belair belt lithologies. However, the deformation plan of both belts is grossly similar suggesting that they have experienced analogous tectonic histories.

Probably numerous tectonic models are feasible to relate the two belts, but two hypotheses are often mentioned: 1) a regional anticlinorium with the Kiokee belt in the core and the Carolina slate and Belair belts on the flanks (Howell and Pirkle, 1976), 2) an infrastructure-suprastructure interpretation which views the Kiokee belt as mobile migmatitic infrastructure and the flanking Carolina slate and Belair belts as suprastructure (Snoke and others, 1977; Metzgar, 1977). Another model is that the Belair belt is allochthonous in respect to the Kiokee belt, and the brittle Augusta fault is a thrust or low-angle normal fault which has telescoped two parts of an evolving orogen. At the present stage of geologic knowledge concerning the Belair and Kiokee belts, none of the above models can be eliminated, and the reconciliation of these working hypotheses must await more detailed investigations.

This research was supported by the Division of Earth Sciences National Science Foundation, NSF Grant EAR76-22323 under the direction of Donald T. Secor, Jr., and Arthur W. Snoke.

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DISTRIBUTION OF CRYSTALLINE ROCKS AROUND AUGUSTA, GEORGIA, AND THEIR RELATIONSHIP TO THE BELAIR FAULT ZONE

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INTRODUCTION

The Belair fault zone (Fig. 1) is a series of northeast-trending en echelon reverse faults cutting the inner margin of the Coastal Plain near Augusta, Georgia (O'Connor and Prowell, 1976); Prowell and O'Connor, in press). The fault zone is composed of at least eight individual faults that dip southeasterly and is at least 24 km (15 miles) long. The location and geometry of the fault zone has been determined on the basis of vertical offsets of a subhorizontal unconformity of Late Cretaceous age (Fig. 2). The apparent maximum vertical offset of the unconformity between the Coastal Plain sediments and the underlying crystalline rocks is about 30 m (100 ft.).

The Coastal Plain sediments serve as an excellent indicator of vertical displacement along the fault zone, but they yield only qualitative information regarding lateral displacements. Slickensides in the fault gouge and small-scale displacements along secondary reverse faults indicate a left lateral component to the fault movement. A regional investigation of the distribution of moderately to steeply dipping crystalline rocks cut by the Belair fault zone has more rigidly defined the magnitude and direction of lateral dislocation.

CRYSTALLINE ROCK STRATIGRAPHY

Regional mapping and subsurface investigation in the Piedmont of eastern Georgia and western South Carolina have shown that tow basic rock types are present in the vicinity of the Belair fault zone: (1) metavolcanic and volcaniclastic phyllite of the Belair belt of the Little River Series (Crickmay, 1952) at the greenschist facies of regional metamorphism and (2) gneisses at the amphibolite facies in the

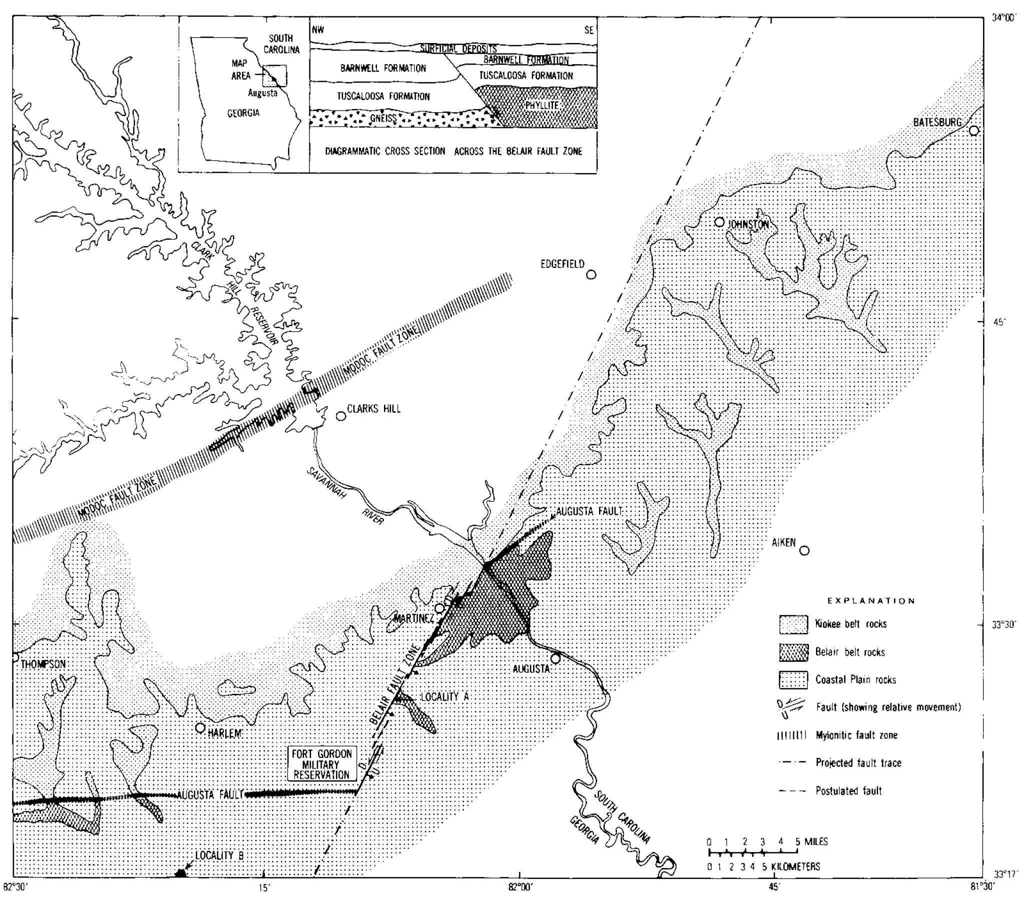

Figure 1. Geologic map of Augusta, Georgia and vicinity showing the location of the Belair fault zone.

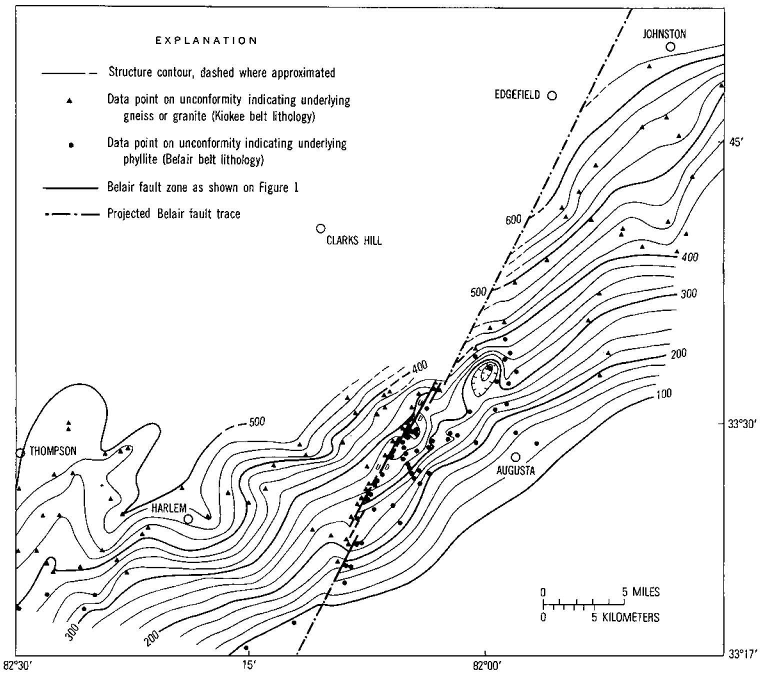

Figure 2. Contour map on the base of the Tuscaloosa Formation showing the type of crystalline basement at contact localities. Contour interval: 25 ft. (7.6 m).

Kiokee belt (Crickmay, 1952). The Belair belt is the southernmost exposed crystalline terrane in eastern Georgia. Prior to metamorphism, these rocks were tuffs, lapilli tuffs, and volcaniclastic rocks. Their compositions range from rhyolitic to andesitic. The oldest phyllites are along the northern edge of the Belair belt and are characterized by abundant lapilli tuffs and water-worn rock fragments. Overlying the lapilli phyllites is a sequence of greenstones containing moderate to abundant epidote. Above the greenstones is a very thick accumulation of tuffs and volcaniclastic rocks characterized by fine-grained textures, graded bedding, and fine lamination. The rocks of the Belair belt are locally contorted and have a conspicuous axial plane cleavage that strikes north-northeast and dips moderately southeast.

The rocks immediately north of the Belair belt are largely granitoid and amphibolite gneisses, amphibolite, and intrusive granite of the Kiokee belt. In eastern Georgia, the typical rock type of the Kiokee belt is a two-feldspar mica-gneiss. The most common Kiokee belt rock types in the vicinity of the Belair fault are hornblende gneiss, biotite gneiss and schist, and granitoid gneiss. North of Augusta, amphibolite, mica schist, and intrusive rocks are more common. Most Kiokee belt gneisses are probably paragneisses, although some of them could be orthogneisses. The foliation in the gneisses generally strikes northeast and dips gently to moderately southeast.

The contact between the Belair belt and the Kiokee belt is a zone about 0.5 km (0.3 miles) wide that dips moderately to steeply (45° -75°) southward. Mylonitized, brecciated, and contorted gneisses and some phyllonites characterize this contact zone. The contact trends east to east-northeast across eastern Georgia, terminating at the Belair fault zone on Fort Gordon Military Reservation (see Fig. 1). The contact emerges on the east side of the Belair fault zone near Martinez, Georgia, and trends northeastward into South Carolina, where it is obscured by overlying Coastal Plain sediments. Control points on the location of this contact are shown on Fig. 2. The delineation of the mylonitized Belair-Kiokee belt contact has been the subject of several geophysical interpretations (Fig. 3). Daniels, (1974) suggested the existence of the mylonite zone in western South Carolina on the basis of steep linear aeromagnetic gradients roughly corresponding to the phyllite-gneiss contact. Hatcher and others (1974) further extrapolated the zone on the basis of regional aeromagnetic data and named it the Augusta fault. The aeromagnetic map shown in Daniels (1974) suggests that the Augusta fault bifurcates just northeast of Augusta and that branches go both north and south of the city. Therefore, it is unclear which segment west of the bifurcation should be called the Augusta fault. Hatcher and others (1977) applied their Augusta fault terminology to the magnetic gradient south of the city (see Fig. 3). I have chosen to extend the Augusta fault nomenclature along the magnetic gradient north of the city of Augusta (see Fig. 1) because the magnetic gradient coincides with a lithologic contact marked by mylonitic rocks. This portion of the Augusta fault is critical to my discussion of lateral displacement along the Belair fault zone.

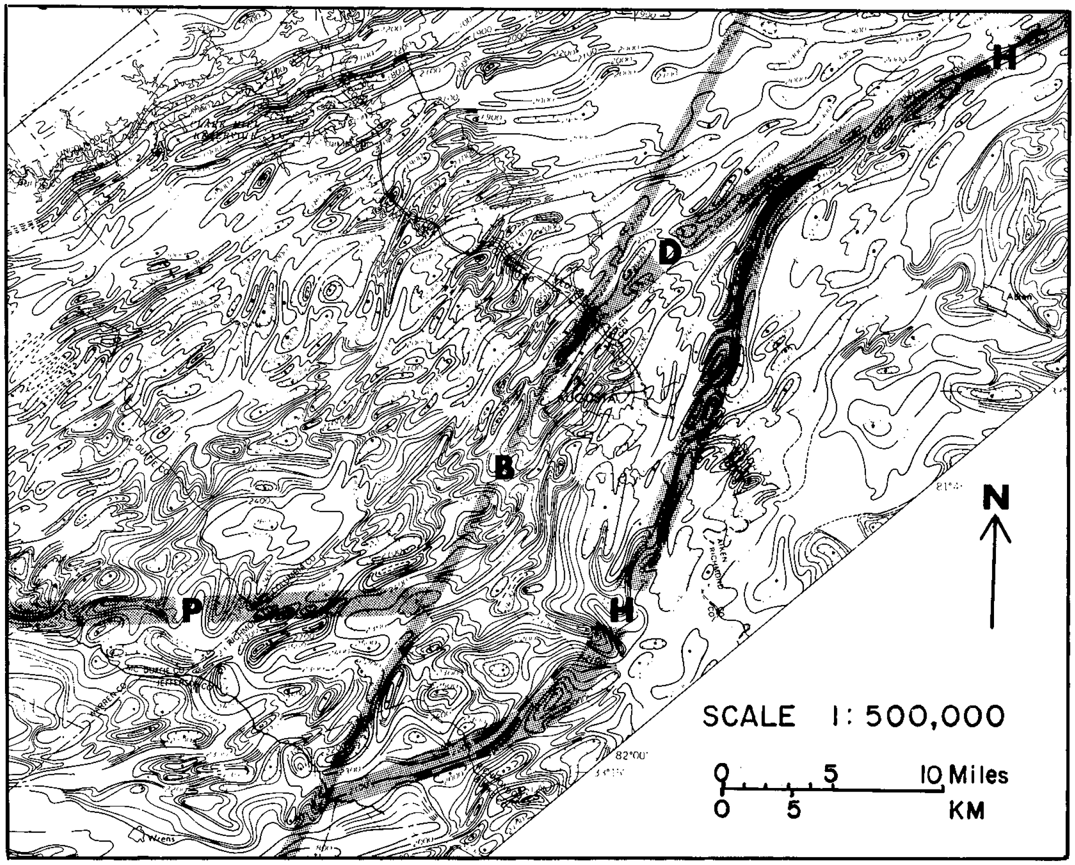

Figure 3. Aeromagnetic map from Daniels (1974) showing proposed zones near Augusta, Georgia. Fault zones are identified as: B, Belair fault zone of Hatcher and O'Connor (in press); H, Augusta fault of Hatcher and others (1977); D, fault of Prowell and O'Connor (in press); P, extension of Augusta fault from Prowell and O'Connor (in press).

STRUCTURAL GEOLOGY

The southeast-dipping en echelon reverse faults that constitute the Belair fault zone extend from Fort Gordon Military Reservation northward to the Savannah River (Fig. 1). At localities where the faulting has juxtaposed crystalline and sedimentary rocks, the fault plane consistently strikes N25° - 30° E and dips 50° SE, subparallel to the cleavage in the Belair belt phyllite. Where only crystalline rocks are involved in the faulting, the fault planes are much steeper (approximately 70° - 80°). Shear zones in the crystalline rocks are as much as 8 meters (26 ft.) wide and are easily recognized by the brittle fracturing of the hard strata. Gouge zones along which major movement has taken place, are commonly filled by as much as 15 cm (6 in.) Of chlorite.

The relatively steep contact (45° - 75°) between the Belair belt phyllites and the Kiokee belt gneisses (the Augusta fault, Fig. 1) is cut by the Belair fault zone, and it serves as an excellent indicator of lateral displacement. Mapping of this regional structural boundary indicates a left lateral separation of 23 km (14 miles) along the Belair fault zone. Drill-hole data and field observations have verified that the Belair fault zone forms a sharp boundary between phyllites and gneisses for most of its known length (see Fig. 2). The two rock types are separated by a crush zone about 5 meters (17 ft.) wide or less. Because the mylonitic contact between the Belair and Kiokee belts probably formed during regional metamorphism approximately 350 million years ago (Kish and others, 1978), the brittle deformation resulting in lateral displacement along the Belair fault zone must have taken place subsequent to cooling of the crystalline rocks. Whether the lateral displacement occurred before or after the deposition of Coastal Plain strata is discussed elsewhere (Prowell and O'Connor, in press).

CONCLUSIONS

Geologic mapping shows that the Belair fault zone is a major structural feature at the margin of the Atlantic Coastal Plain. The fault zone is composed of at least eight en echelon reverse faults and is at least 24 km (15 miles) long. Vertical displacement of the erosional unconformity between the Coastal Plain sediments and crystalline rock has been at least 30 meters (100 ft.) since the late Cretaceous. Lateral displacement of the Augusta fault by the Belair faulting indicates a horizontal displacement of approximately 23 km (145 miles) since the cooling of the crystalline rocks in the Belair and Kiokee belts and the formation of the Augusta fault mylonite. The importance of the Belair fault zone to geologists mapping crystalline rocks in the southeastern United States is that it represents post-Paleozoic faulting that dramatically altered the distribution of crystalline rocks. It also proves that postmylonitization brittle deformation is of such magnitude that it should be of major concern to Piedmont geologists.

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SUMMARY OF GEOCHRONOLOGICAL DATA FOR LATE PALEOZOIC PLUTONS FROM HIGH GRADE METAMORPHIC BELTS OF THE EASTERN PIEDMONT OF NORTH CAROLINA, SOUTH CAROLINA, AND VIRGINIA

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Recent geological and geochronological studies of the southern Appalachians have presented evidence that all major metamorphism and deformation in the Blue Ridge and Piedmont occurred before the beginning of Carboniferous time (Fullagar, 1971; Butler, 1972). Since the major deformational events in the Valley and Ridge are probably late- to post- Carboniferous, there is a major problem in establishing a tectonic relationship between these areas. Early K-Ar studies (Kulp and Eckelmann, 1961) did suggest there may have been a late Paleozoic metamorphic event in the eastern Piedmont. However, the realization that K-Ar mineral ages reflect times of cooling below a relatively low temperature (~200°C suggests these mineral ages could represent slow cooling and uplift.

New geochronological studies utilizing Rb-Sr whole-rock dating provide the first clear evidence for late Paleozoic metamorphism and deformation in the eastern Piedmont. Earlier studies by Fullagar (1971) present evidence that many late Paleozoic plutons of the southern Appalachians are undeformed. However, late Paleozoic plutons of the Kiokee belt of South Carolina and portions of the Raleigh belt of North Carolina-Virginia (Figure 1; Table 1) show evidence of relatively intense deformation which can be related to deformation and associated metamorphism in adjacent country rocks (Kish and others, 1978). This relationship seems to be most pervasive in the Kiokee belt of South Carolina and can be directly related to the regional penetrative structures in the adjacent country rock. Both the Kiokee and Raleigh

Table 1. Rb-Sr Whole-Rock Ages of Late Paleozoic Plutonic Rocks of the Kiokee and Raleigh Belts

Map Reference No.	Igneous Unit	Age, m.y.[1]	$(^{87}Sr/^{86})_0$	Structural Features in Pluton
1.	Clouds Creek Pluton[2]	313 ± 27	0.7097 ± 0.0010	Moderate to well-developed foliation(s). Some structures appear to be associated with movement on the Modoc fault zone.
2a	Lake Murray Gneiss	313 ± 24	0.7119 ± 0.0013	Well-developed foliation which is folded to form tight-to-open folds.
2b.	Lake Murray Pegmatite	299 ± 7	0.7099 ± 0.0018	Possibly contains local S_1 foliations; folded to form open folds.
3.	Lexington Pluton[2]	292 ± 15	0.7047 ± 0.0004	Moderate to poorly developed foliation and lineation; locally unfoliated
4.	Augen Gneiss, Batesburg, S.C.	291 ± 4	0.7045 ± 0.0002	Well-developed foliation which appears to correspond to primary (S_1) foliation in the country rock.
5.	Granites, Pegmatites, Edgefield, S.C.	254 ± 11	0.7107 ± 0.0007	Moderately well-foliated (igneous foliation?). Foliation and pegmatite dikes are folded.
6.	Bugs Island Granite Gneiss	313 ± 8	0.7046 ± 0.0002	Well-developed foliation; foliation and pegmatite dikes are locally folded; both are cut by narrow unfoliated pegmatite dikes.
7.	Castella Pluton[3]	313 ± 13	0.7141 ± 0.0045	Unfoliated, located on the eastern edge of the Raleigh belt.
8.	Sparta Complex[4]	289 ± 2	0.7035 ± 0.0004	Unfoliated. Portions have higher $(^{87}Sr/^{86})_0$ (Fullagar and Butler, 1978).

[1] Ages calculated using $M^{87}Rb = 1.42 \times 10^{-11}$ yr^{-1}
[2] Data from Fullagar and Butler (1978)
[3] Data from Julian, (1972), Fullagar and Butler (1978)
[4] Data from Fullagar and Butler (1978)

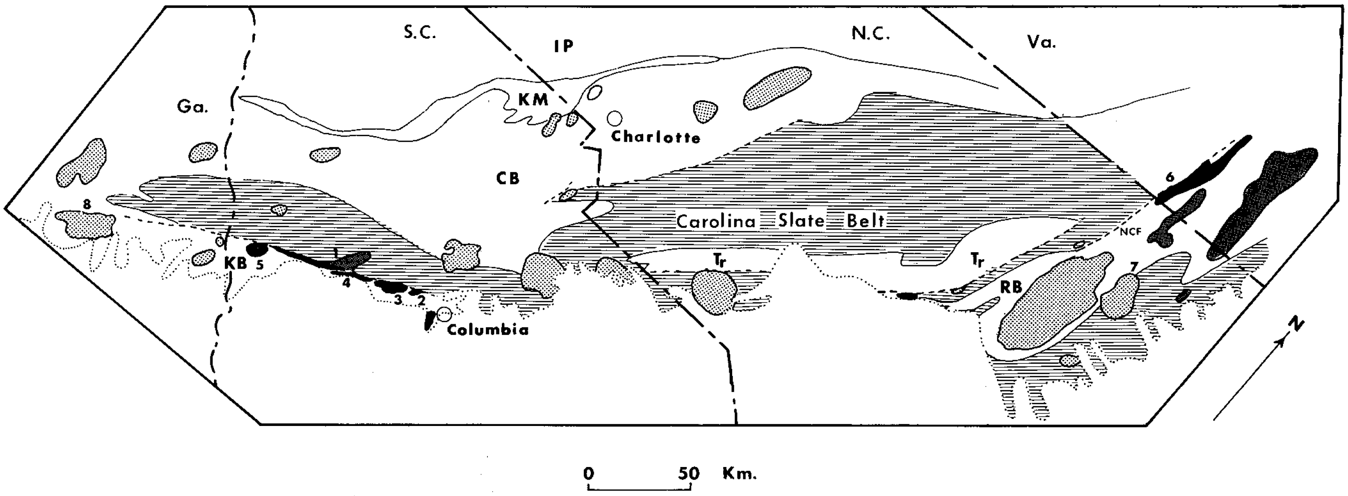

Figure 1. Distribution of Late Paleozoic Plutons in the Eastern Piedmont of the Southern Appalachians.
Ruled pattern: Low grade metamorphic rocks, primarily Carolina slate belt. Large stippled pattern: Undeformed late Paleozoic plutons (including nos. 7 and 8). Small stippled pattern: Locally deformed late Paleozoic plutons (including no. 1). Black: Deformed late Paleozoic plutons (including nos. 2,3,4,5, and 6). Dashed line: Faults. NCF-Nutbush Creek Fault. Dotted line: Coastal Plain-Piedmont contact. KB-Kiokee belt. RB-Raleigh belt. Tr-Triassic basins. CB-Charlotte belt. KM-Kings Mountain belt. IP-Inner Piedmont. Information regarding numbered plutons is given in Table 1.

belts are characterized by being fault-bounded and by being at higher metamorphic grade than adjacent areas.

As the Kiokee belt passed into Georgia, the intensity of tectonic activity appears to decrease. The Sparta complex (Figure 1, no. 8) is undeformed. A biotite from this complex has a K-Ar age (Kulp and Eckelmann, 1961) which is nearly concordant with the Rb-Sr whole-rock isochron age suggesting that this granite was emplaced into relatively cold country rock and is post-metamorphic.

Late Paleozoic plutons of the Raleigh belt are foliated only along the margin of the belt (Figure 1), possibly where they are adjacent to the Nutbush Creek fault. Since the character and extent of this fault zone is uncertain (J. M. Parker, III, 1977 pers. comm.) the exact nature of late Paleozoic deformation in this area must await more detailed mapping and structural analysis.

ACKNOWLEDGMENTS

These studies were supported by NSF Grants DES73-06495-A01 and EAR77-23277 and the South Carolina Geological Survey.

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STRATIGRAPHY, STRUCTURE, AND PLUTONISM IN THE CENTRAL SOUTH CAROLINA PIEDMONT

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INTRODUCTION

A fundamental aspect of the Piedmont province of South Carolina is its division into lithologic belts of contrasting metamorphic grade (Plate 1--immediately after Forward). Although the location and nomenclature of these belts are well known (Crickmay, 1952; King, 1955; Overstreet and Bell, 1965a, 1965b; Hatcher, 1972), the nature of the boundaries or transition zones from one belt to another have remained controversial. The purpose of this report and the accompanying field trip guide is to summarize new data on the boundary between the Carolina slate and Kiokee belts as manifested in a study area that extends from near Batesburg, South Carolina to the Lake Murray region (Plate II). The key aspects which will be compared and contrasted between the belts are:

1. Lithology (i.e. stratigraphic correlation),
2. Intrusive plutonic history,
3. Structural chronology,
4. Intensity and ages of metamorphism.

The conclusions drawn are based essentially on areal geologic mapping but have been supplemented by Rb-Sr geochronologic studies (Kish and others, 1978; Fullagar and Butler, in press; Snoke, Kish, and Secor, in preparation).

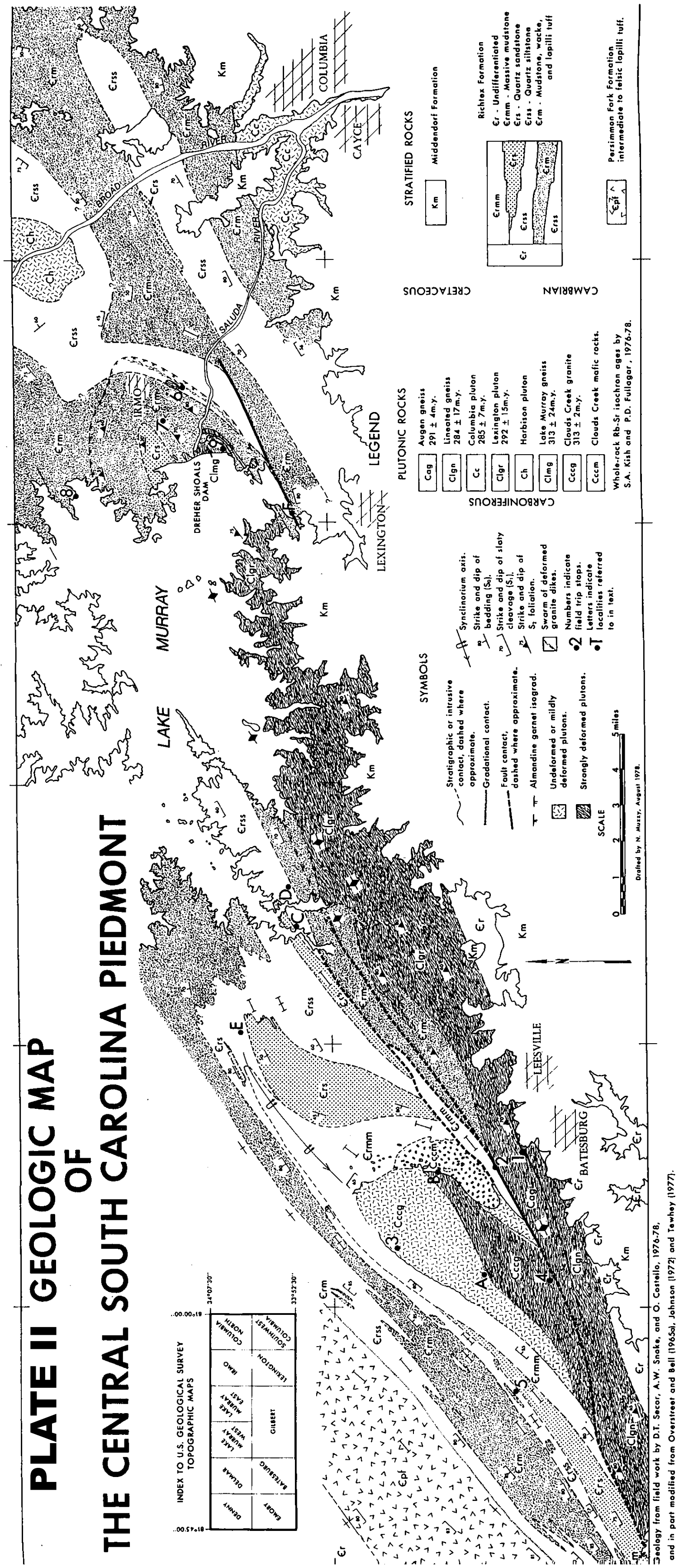
Beginning with the work of Overstreet and Bell (1965a), it has become increasingly clear in many places that the boundary between the southern flank of the Carolina slate belt and the northern margin of the Kiokee belt is a fault or zone of faults. The maps of both Overstreet and Bell (1965a, Plate I) and Daniels (1974, Sheet 1) show the boundary as being faulted from the Shull Island peninsula area on Lake Murray to Clark Hill reservoir on the Savannah River. While studying this boundary in the Clark Hill reservoir area, Howell and Pirkle (1976) designated it the “Modoc Fault zone”, and we adopt this name for our study area. Hatcher and others (1977) have suggested that the Modoc fault zone is part of a complex fault system that can be traced from Alabama to Virginia. According to these authors the “Eastern Piedmont fault system” is perhaps the most extensive in eastern North America, and, therefore, played a fundamental role in the tectonic evolution of the southern Appalachian orogen.

An important conclusion of our studies is that this boundary displays a polyphase, diachronistic history involving a transition from ductile to brittle behavior. Furthermore, Rb-Sr isotopic dating of plutonic orthogneisses from the Kiokee belt (Kish and others, 1978; Fullagar and Butler, in press) indicates that the boundary is in part the product of polymetamorphism. An early greenschist facies event (Taconian or Acadian?), now only well-preserved in the Carolina slate belt, has been overprinted by a Late Paleozoic (i.e. Hercynian) regional metamorphism, manifested in the amphibolite facies Kiokee belt. The decipherment of the polyphase folding characteristic of both belts further substantiates these conclusions. The available data suggest that the Kiokee belt of South Carolina and Georgia is the *only* metamorphic terrane in the southern Appalachian internal zone which has experienced *intense* Late Paleozoic regional metamorphism. We, therefore, suggest that the boundary between the Kiokee and Carolina slate belts may also be considered the approximate western edge of the Hercynian (Variscan) metamorphic front as developed in the southern Appalachian orogen. The boundary between the Carolina slate and Kiokee belts is a unique example of overlapping tectonism involving multiple metamorphism and late brittle faulting. We believe that important geotectonic implications concerning the evolution of the southern Appalachians can be deduced from these relations.

GEOLOGIC OVERVIEW

Similar stratigraphic sequences occur in both the Carolina slate and Kiokee belts; however, the intensity of deformation, metamorphism and plutonism have been much greater in the Kiokee belt. The Kiokee belt underlies the southern part of the study area and is characterized by amphibolite facies metasedimentary and metavolcanic rocks and by stratiform granitic masses of plutonic orthogneiss (Plate II). The Kiokee belt is bordered on the north and east by the greenschist facies metasedimentary and metavolcanic rocks of the Carolina slate belt. The Modoc fault zone, extending east-northeast from the southwestern corner of the study area to Lake Murray, forms part of the boundary between the slate and Kiokee belts. To the east, near Irmo, South Carolina, the boundary between the two belts is gradational and is characterized by a steep metamorphic gradient and intense mylonitization. In this region, the almandine garnet isograd is arbitrarily taken as marking the boundary. Thus eastern terminus of the Kiokee belt is interpreted as the nose of a late-metamorphic antiformal fold in the boundary that originated before the brittle history of the Modoc fault zone.

Coastal Plain rocks of Mesozoic and Cenozoic age unconformably overlie the Piedmont rocks in the southern part of the study area. Deposits of Quaternary alluvium occur along some of the larger stream valleys. In that the main emphasis of this report is directed toward the crystalline rocks, the Coastal Plain sedimentary rocks and the Quaternary alluvium will not be discussed. The distribution of



the Coastal Plain sedimentary rocks is indicated on Plate II.

CAROLINA SLATE BELT

The Carolina Slate Belt , extending from south-central Virginia to eastern Georgia, is a thick sequence of volcanic, volcaniclastic and epiclastic rocks that have been strongly deformed and recrystallized to mineral assemblages characteristic of greenschist facies metamorphism. Nevertheless, it is possible in most places to recognize original sedimentary and volcanic textures and structures. In the descriptions of slate belt strata in this section the prefix "meta" will generally be omitted, and the rocks will be described in terms of their inferred sedimentary or volcanic protolith.

The Carolina slate belt is generally considered to have originated in an island arc environment (Butler and Ragland, 1969). The basement on which this arc developed has not been recognized. Butler and Ragland (1969) and Glover and others (1978) favor a continental margin situation involving some sialic crust, whereas Whitney and others (1978) have suggested that the arc was built directly on oceanic lithosphere/

The deposition of the slate belt sequence is considered to have occurred in the Late Precambrian to Cambrian based on a combination of radiometric ages and fossils. In the Virgilina area, in the slate belt along the Virginia-North Carolina border, Glover and Sinha (1973) and Cloud and others (1976) have reported zircon ages of 620 ±20 m.y. for pyroclastic rocks and associated volcaniclastic sediments containing Precambrian metazoan fossils. They also reported a zircon age of 650 ±30 m.y. for the epizonal Moriah pluton, the eruptions from which are presumed to have supplied pyroclastic sediments for the unit containing the fossils. This Late Precambrian sequence was folded and faulted and then intruded by the 575 ±20 m.y. Roxboro pluton. These relations document a Late Precambrian or very early Lower Cambrian deformational event named the Virgilina deformation by Glover and Sinha (1973). To the south Black and Fullagar (1976) have reported Rb-Sr whole rock isochron ages in the vicinity of Chapel Hill, North Carolina, which suggest that the Virgilina deformation also affected the slate belt rocks in this area. Southwest of Chapel Hill in North Carolina, South Carolina, and Georgia the available geochronological and fossil evidence (Hills and Butler, 1969; Stromquist and Sundelius, 1969; Fullagar, 1971; St. Jean, 1973; Butler and Fullagar,

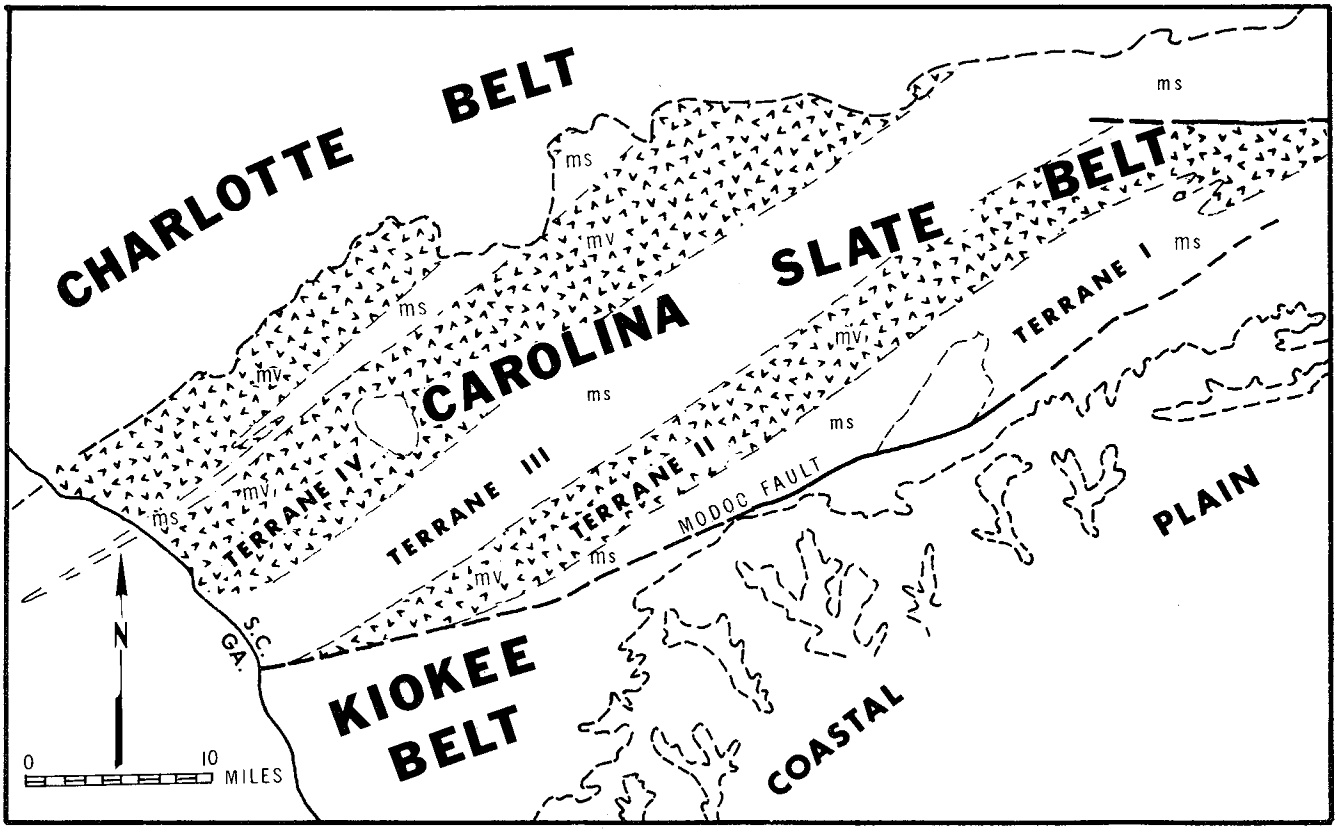


Figure 1. Map showing the distribution of metavolcanics (mv) and metasedimentary (ms) terranes in the Carolina slate belt. Generalized from Overstreet and Bell (1965a), Secor and Wagener (1968), Daniels (1974), and Whitney and others (1978).

1975; Seiders and Wright, 1977; Wright and Seiders, 1977; Black, 1978; Carpenter and others, 1978, in press) indicate that the bulk of the slate belt is Cambrian in age and too young to have been affected by the Virgilina deformation.

Stratigraphic studies in the Carolina slate belt in central North Carolina (Conley and Bain, 1965; Stromquist and Sundelius, 1969), in South Carolina (Secor and Wagener, 1968) and in east-central Georgia (Whitney and others, 1978; Carpenter and others, in press) have revealed grossly similar sequences characterized by an older series of intermediate to felsic volcanic and volcaniclastic rocks overlain by a younger series of epiclastic rocks. Although the equivalence of these sequences in North Carolina, South Carolina and Georgia has not yet been demonstrated by detailed field mapping in the intervening areas, the geochronological and fossil evidence suggests that the sequences are roughly correlative.

In the area northwest of Columbia, South Carolina, Secor and Wagener (1968) subdivided the slate belt strata into three formations. In order from oldest to youngest, these are: 1/ the Wildhorse Branch Formation, a sequence containing approximately 20% carbonaceous shale, 40% mafic tuff and flows and 40% felsic tuff; 2/ the Persimmon Fork Formation, primarily composed of dacitic tuff with subordinate andesitic tuff and shale; and 3/ the Richtex Formation composed predominantly of mudstone. Our reconnaissance work indicates that the Richtex Formation and the Persimmon Fork Formation can be traced continuously from the area northwest of Columbia (where they were first recognized) southwest into the Batesburg-Emory area. The Wildhorse Branch Formation has not been recognized in the Batesburg-Emory area. It probably pinches out in some, as yet unknown, manner along the north shore of Lake Murray.

In central and western South Carolina the slate belt contains two northeast-trending terranes of volcanic and volcaniclastic rocks that are flanked and separated by terranes composed predominantly of epiclastic rocks. For purposes of the discussion which follows these terranes are numbered I though IV as illustrated in Fig. 1. Recent field studies in central and western South Carolina have led to some conflicting interpretations of the geologic relationships between these terranes.

In the Clark Hill Reservoir area along the Savannah River, Howell and Pirkle (1976) interpreted the Carolina slate belt as a synclinorium. The epiclastic rocks of a portion of Terrane III were interpreted to be a homoclinal sequence on the south limb of the synclinorium, with the stratigraphic top to the northwest.

In the Red Hill quadrangle, Pirkle (1977) mapped a sequence involving Terrane III and parts of Terranes II and IV as a homoclinal sequence. He suggested correlating the older volcanic and volcaniclastic rocks of Terrane II with the Persimmon Fork Formation of central South Carolina, and also suggested that the younger volcanic and volcaniclastic rocks of Terrane IV might correlate with the Cid Formation in central North Carolina.

Daniels (1974) mapped a synclinal axis trending through the middle of Terrane III. By his interpretation, Terranes II and IV are correlative and older than Terrane III. The epiclastic rocks in Terrane I are beneath the volcanic and volcaniclastic rocks in Terranes II and IV.

In the Lincolnton, Georgia and McCormick, South Carolina area, Carpenter (1976) and Carpenter and others (in press) have proposed that the volcanic and volcaniclastic rocks in Terrane IV are older than the epiclastic rocks in Terrane III. As previously mentioned, the stratigraphic sequence proposed by Carpenter and others (in press) resembles the sequences in central South Carolina (Conley and Bain, 1965; Stromquist and Sundelius, 1969). The radiometric ages reported by Carpenter and others (1978, in press) for the Lincolnton metadacite (Rb-Sr whole rock- 562 +-20; U-Pb zircon- 568) suggest that Terrane IV is more nearly correlative with the Uwharrie Formation in North Carolina than with the younger volcanic units in the Cid Formation, as proposed by Pirkle (1977).

In our reconnaissance work in South Carolina we have adopted a simple stratigraphic model in which an older volcanic sequence is overlain by a younger epiclastic sequence(Terrane 1 = Terrane III = Richtex Formation). The evidence for the equivalence of Terranes II and IV is that identical quartz crystal lapilli tuffs are found in Terrane IV in the Lincolnton-McCormick area, in Terrane II in the Batesburg-Emory area, and in the Persimmon Fork Formation near Columbia, South Carolina. Terranes I and III are equated with each other and with the Richtex Formation because of lithologic similarity. We interpret the Richtex Formation of Terrane I to be conformable with the Persimmon Fork Formation of Terrane II because of the gradational nature of the contact between them. The data that suggest that the Richtex Formation is younger than the Persimmon Fork Formation are top criteria derived from sedimentary structures and the structural position of the Richtex Formation in the core of a major upright F1 syncline in the area between Batesburg and Lake Murray (Plate II).

Persimmon Fork Formation

The Persimmon Fork Formation forms part of a northeast-trending band crossing the central and northeastern part of the Emory quadrangle and extends to the western end of Lake Murray (Plate II). This unit is predominantly coarse-grained intermediate to felsic lapilli and crystal-lapilli tuffs with some fine-grained vitric tuff. These rocks are interlayered with lesser amounts of epiclastic rocks and are intruded by small masses of mafic to felsic hypabyssal rocks. The coarse-grained tuffs are very poorly sorted, and intermediate and felsic lithologies are intimately interbedded so that meaningful subdivision has not been accomplished. The typical metamorphic mineral assemblage in the felsic rocks is quartz-albite-epidote-white mica-chlorite-opaque oxides-apatite. Potash feldspar is not present and there is no textural evidence for its former existence; therefore the felsic rocks are probably keratophyres or quartz keratophyres. The intermediate rocks containing less quartz and more epidote and chlorite are probably andesitic in composition. The epiclastic rocks, predominantly volcanic siltstones and wackes, contain the same metamorphic mineral assemblage as the metavolcanic rocks, however they are better sorted, and relic sedimentary structures suggest aqueous transportation and deposition. The mafic to felsic hypabyssal rocks have also undergone greenschist facies metamorphism. These bodies appear to be similar to the shallow level intrusions that are commonly found in thick volcanic accumulations.

The boundary between the Persimmon Fork Formation and the overlying Richtex Formation is gradational with volcanic rocks interlayered with epiclastic rocks through an interval of a hundred meters or more. Although the bottom of the Persimmon Fork Formation has not been identified in the Batesburg-Emory area, its thickness probably exceeds 2 km.

Richtex Formation

The Richtex Formation is a heterogeneous sequence of epiclastic rocks locally interbedded with felsic to intermediate fragmental volcanic rocks. It underlies extensive areas in the Batesburg and Emory quadrangles, is well-exposed along the southwestern shores of Lake Murray (e.g. Shull Island peninsula) and is widespread in the Columbia area (Plate II). Although the top of the Richtex Formation has not been identified by mapping in the slate belt of South Carolina, at least 5 km of strata are present in the Batesburg-Emory area.

The lower and middle parts of the Richtex Formation contain lenses and layers, up to 1500 m thick, of a distinctive quartz-rich siltstone. In most places this siltstone contains bifurcated wavy flaser bedding (Reineck and Wunderlich, 1968), in which lenticular, quart-rich layers (sometimes cross-stratified), 0.3 - 30 mm thick and 5 -30 cm long, are separated by very thin pelitic seams (Fig. 2 and STOP 5). In a few places planar bedding and lenticular bedding with connected lenses have been observed in this unit. These sedimentary structures are similar to those found in modern environments where sedimentary transport and deposition are dominated by tidal currents (Reineck, 1972; Reineck and Singh, 1975). The quartz-rich siltstone grades laterally and vertically into evenly laminated mudstone, graywacke, inter-

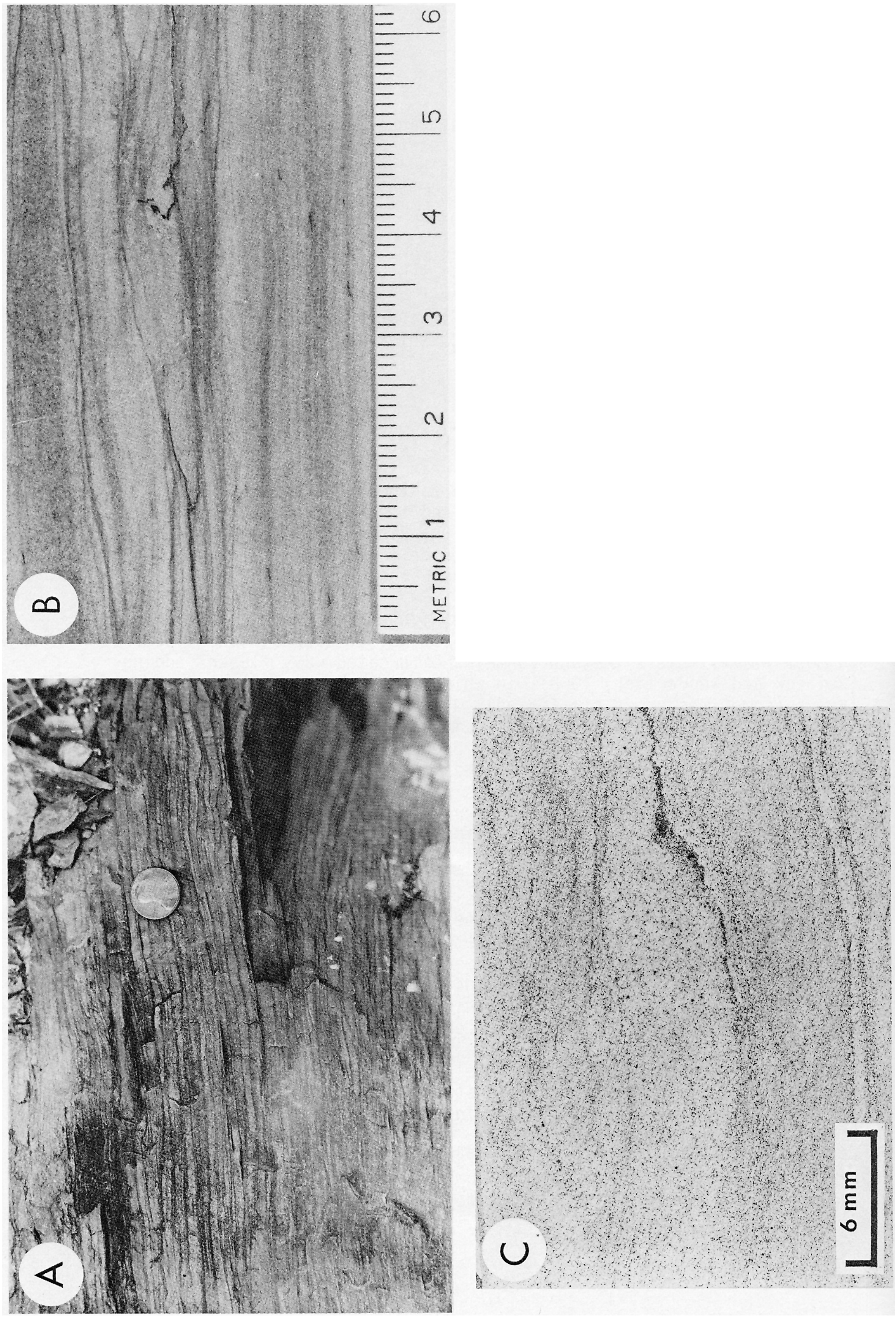


Figure 2. Relict sedimentary structures in the quartz-rich metasiltstone (Richtex Formation--STOP 5). A, An outcrop surface of the metasiltstone showing even laminations passing into small ripples on middle right; B, sawed slab of metasiltstone--note discontinuous laminations; C, Photomicrograph of quartz metasiltstone (ordinary light) showing laminations partially defined by concentrations of heavy minerals.

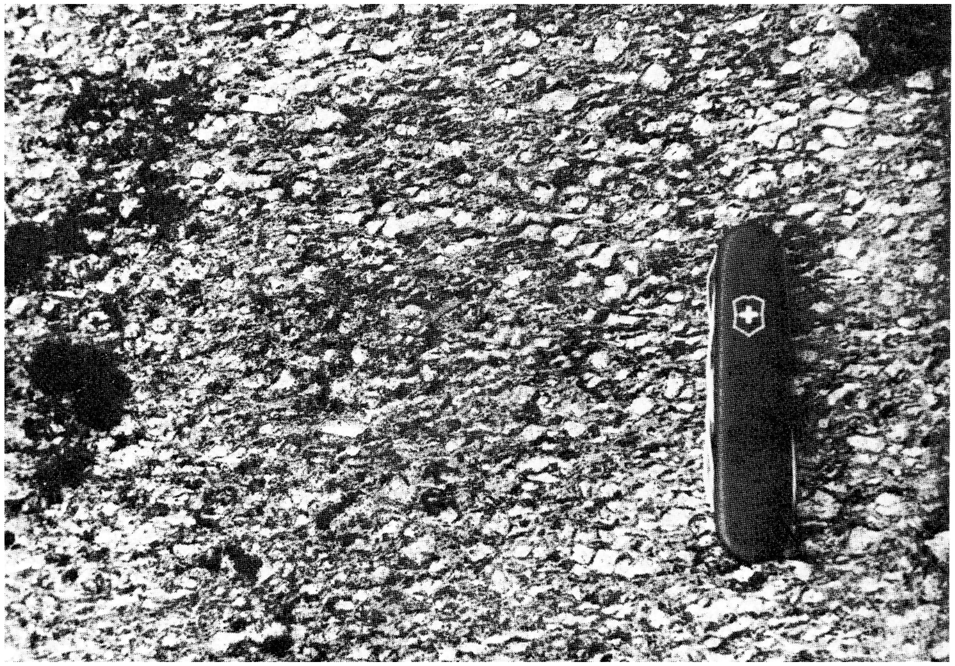


Figure 3. Augen gneiss of the mixed gneiss unit of the Kiokee belt. The foliation in this rock is S_2. In that the Rb-Sr whole rock isochron age of this augen gneiss is 291 ± 4 m.y. (Kish, personal comm., 1978), the foliation must be as young or younger than the Late Carboniferous.

mediate to felsic lapilli tuff, and medium- to coarse-grained felspathic quartz sandstone. The quartz sandstone contains lenticular sets of crossbedded strata, 10-200 cm thick, which in some places are draped by thin seams of pelitic material (again suggestive of tidal deposition). The upper part of the Richtex Formation, located west, north and northeast of the Clouds Creek igneous complex, contains a sequence of massive siltstone and mudstone. In most outcrops of this upper sequence it is difficult or impossible to recognize original bedding.

Facies relationships between the various lithologies of the Richtex Formation are incompletely understood. The quartz-rich siltstone and sandstone lithologies, which we interpret to be tidal shelf deposits, are of widespread distribution. Johnson (1972) reported these lithologies in the Columbia area, and our reconnaissance suggests that this sequence can be traced from Columbia at least as far west as Edgefield, South Carolina, and possibly to Clark Hill reservoir on the Savannah River. The quarts-rich lithologies are interbedded with and grade into most of the other lithologies characteristic of the Carolina slate belt, such as wacke, mudstone, and lapilli tuff. This suggests that these other lithologies were either deposited directly on a tidal shelf or in environments adjacent to a tidal shelf.

The Richtex Formation in the Batesburg-Emory area has been traced along strike into rocks mapped as Richtex Formation by Secor and Wagener (1968). The abundance of tidal shelf sediments in the Batesburg-Emory area raises questions concerning the turbidite origin originally made for the Richtex Formation by Secor and Wagener (1968). Quartz-rich rocks are also apparently abundant in the eastern slate belt of North Carolina (Stanley and others, 1977).

KIOKEE BELT

The Kiokee belt was originally named by Crickmay (1952) for exposures of schists and gneisses in Kiokee Creek, Columbia County, Georgia. Recently Daniels (1974) revived the name and applied it to the rocks of medium- to high-grade metamorphic and associated plutonic rocks that occurs between the Carolina slate belt on the northwest and the Belair belt on the southeast. This belt, which includes Crickmay's type locality, extends from the Irmo area, South Carolina to near Warrenton, Georgia where structural trends of the belt are lost in the Sparta granite complex (see Daniels, 1974, Sheet 1- Interpretative Geologic Map).

Subdivision of the Kiokee belt has recently been attempted in several areas of South Carolina. Near Irmo, South Carolina, Tewhey (1977) has delineated numerous lithologic unties in rocks of the Kiokee belt and has argues that these rocks are metamorphosed equivalents of the Carolina slate belt. Although we are not in total agreement with either Tewhey's (1977) stratigraphy or correlations, his work is the most detailed lithostratigraphic study between the rocks of the Carolina slate and Kiokee belts, and our geologic data in the area support many of his conclusions.

Details of lithology and petrography of Kiokee belt rocks in the Irmo area are given in the field trip itinerary (see STOPS 6,7,8, and 9).

In the Edgefield area, Metzgar (1977) has divided the Kiokee belt into the following units: Edgefield granite, orthogneiss, feldspathic metasandstone/schist, impure quartzite/amphibolite, and migmatitic muscovite-biotite schist/gneiss. Distribution of the lithologic units preclude a direct correlation from the Kiokee terrane into the Carolina slate belt, but the feldspathic metasandstone/schist unit is remarkably similar to the feldspathic metasandstone-quartz metasiltstone unit that we have found widespread in the Carolina slate belt of the Batesburg and Emory quadrangles. Further conclusions concerning Metzgar's (1977) Kiokee belt stratigraphy are incertain and must await detailed mapping along strike.

Near the Savannah River, Maher (this volume) has had some success in subdividing the high-grade, migmatitic core of the Kiokee belt into several distinctive paragneiss and orthogneiss units.

In the Batesburg-Emory quadrangles, the Kiokee belt rocks are dominantly granitic orthogneisses but also include metapelite, paragneiss, and feldspathic metaquartzite. The Kiokee belt orthogneisses, which are well exposed in the Batesburg quadrangle, have been divided into two mappable units: 1) mixed gneiss typically characterized by granitic augen gneiss (Fig. 3) and 2) a fine- to medium-grained granitic gneiss typically strongly lineated but weakly foliated. Contact relations between these units are well-exposed at STOP 1 (Plate II) where a sharp but interdigitated contact has been mapped. At this locality, lensoidal masses of the fine-grained gneiss as well as xenoliths of paragneiss occur within the augen gneiss. Furthermore, at this locality foliation in both the augen and homogeneous, fine-grained gneiss cuts across the lithologic contact between the units. These data, therefore, imply that the penetrative deformation ubiquitous throughout the orthogneiss massif was superimposed on an originally crystallized or nearly crystallized igneous rock. The orthogneisses are pre-kinematic in the sense that they have been deformed subsequent to their emplacement into the crust.

Rb-Sr isotopic data are available for several orthogneisses of the Kiokee belt (Kish and others, 1978; Fullagar and Butler, in press; Snoke, Kish and Secor, in preparation). The details of these studies will be presented elsewhere; however, in regard to the Batesburg area, the augen gneiss (STOP 1) yielded a Rb-Sr whole rock isochron age of 291± 4 m.y. with $(Sr^{87}/Sr^{86})_0$ = 0.7045 ± 0.0002 (S.A. Kish, written communication, 1978). This fine-to medium-grained lineated granitic gneiss yielded an age of 284 +- 17 with $(Sr^{87}/Sr^{86})_0$ =0.7045± 0.0005 S.A. Kish, written communication, 1978). We (Kish, Snoke and Secor) believe that these whole rock isochron ages represent the time of igneous crystallization, and the deformation and recrystallization characteristic of these granitoids must post-date these ages. Furthermore, the relatively low $(Sr^{87}/Sr^{86})_0$ ratios suggest primitive source material for the magmas. Other granitoids in the Kiokee belt (i.e. Lake Murray gneiss- STOP 9) yield considerably higher $(Sr^{87}/Sr^{86})_0$ ratios (S.A. Kish, written communication, 1978) suggesting differences in source terrane or degree of crustal contribution during magmatism. The delineation of such variations in initial Sr^{87}/Sr^{86} ratios coupled with detailed geochemical data on the granitic rocks may provide important clues concerning the nature of the Kiokee belt basement.

As the Modoc fault zone is approached from the south, rocks of the Kiokee belt, especially the mixed gneiss unit, become mylonitic, and the prominent foliation is a flattening fabric with a strong subhorizontal elongation axis. The mylonitic augen gneiss is strongly foliated with lensoidal porphyroclasts of K-feldspar and plagioclase in a recrystallized matrix of quartz, feldspar, white mica, biotite, epidote, and sparse apatite. The streaky lineation is defined by elongate mineral aggregates. We interpret these mylonitic rocks are ductilely deformed tectonites where deformation dominated and/or outlasted recrystallization. The strain these rocks exhibit is, therefore, a manifestation of the early, high-temperature ductile history of the Modoc zone. Although these mylonitic rocks are localized along the northwest flank of the Kiokee belt and, therefore, commonly are adjacent to the brittle Modoc fault, a cause and effect relationship is not substantiated. There are many localities where less deformed Kiokee belt rocks are adjacent to the fault zone or involved in fault slivers; the development of the mylonitic rocks predates the brittle faulting. Furthermore, when mylonitic Kiokee belt rocks are adjacent to the brittle Modoc fault, they are invariably retrograded and commonly brecciated.

Although plutonic orthogneiss is an important component of the Kiokee belt in the Batesburg-Emory area, metasedimentary and metavolcanic rocks are widespread to the northeast (Irmo area-Tewhey, 1977) and to the southwest (Edgefield quadrangle- Metzgar, 1977). In the Batesburg quadrangle, Kiokee belt metamorphic rocks form a wedge-shaped terrane in the east-central part of the quadrangle (Plate II). These rocks include feldspathic metasandstone interlayered with metapelite. Biotite is a ubiquitous metamorphic mineral in this metasedimentary sequence, while the sporadic occurrence of almandine garnet indicates the attainment of amphibolite facies metamorphism. A few pegmatitic lenses occur in this sequence, but the rocks are not migmatitic.

South of the town of Batesburg, a belt of metasedimentary rocks has been delineated on the map (Plate II). Lithologic aspects of these rocks are similar to the quartz-rich metasiltstone and metasandstone of the Carolina slate belt north of the Modoc fault zone. Texturally these rocks appear more recrystallized than typical slate belt rocks and sparse garnet is locally present indicating at least lower amphibolite conditions. This belt of rocks is clearly "within" the Kiokee

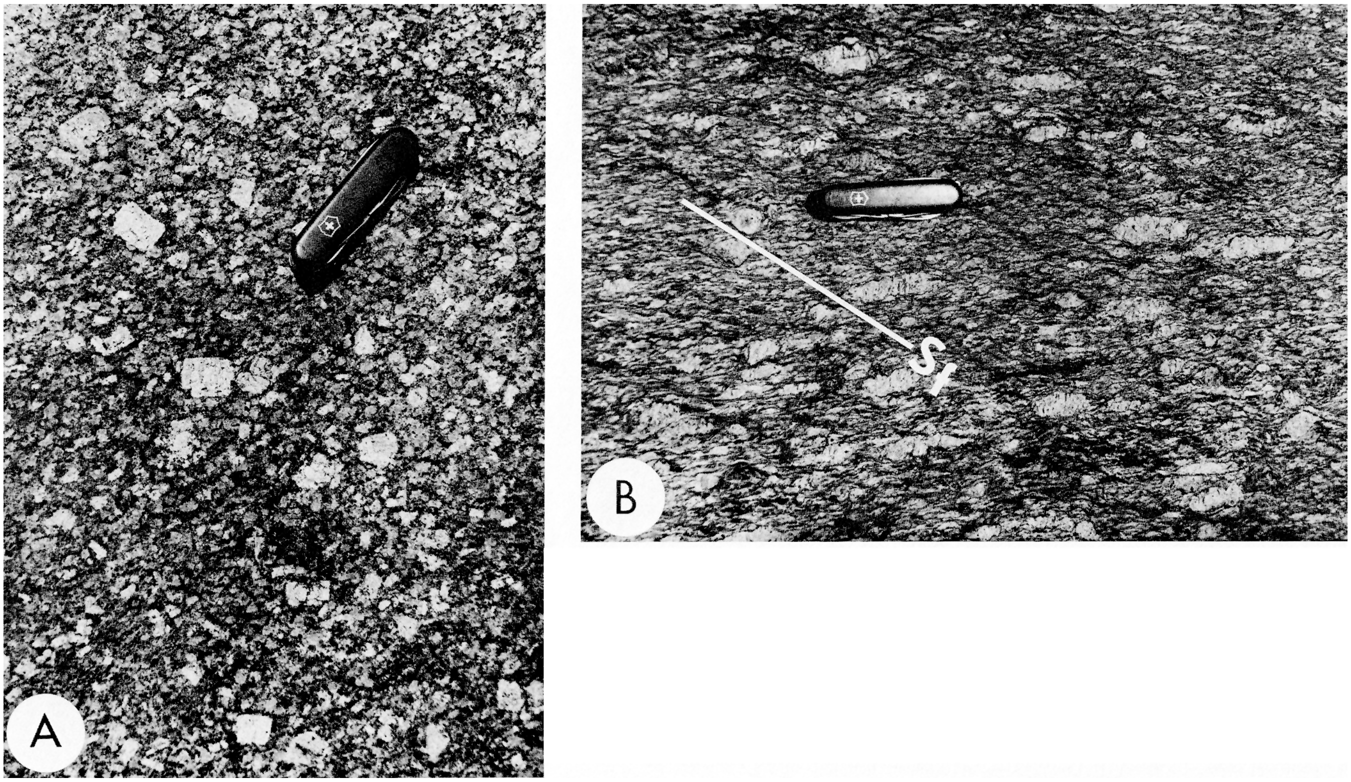


Figure 4 - A. Massive, nonfoliated Clods Creek megacrystic granite. B. Strongly foliated Clouds Creek granite (gneissic phase), Moores Creek--STOP 4. Note that a weak second foliation (S_f) transects the prominent protoclastic foliation. The S_f foliation trends approximately E-W and apparently is best developed in the Clouds Creek gneiss near the trace of the Modoc fault.

belt, for unquestionable Kiokee belt lithologies (i.e. granitoid gneiss) are found in erosional windows beneath Coastal Plain sediments to the south.

Both Overstreet and Bell (1965b) and Daniels (1974) correlated these rocks with the Carolina slate belt. We also conclude that these rocks are equivalent to lithologies in the slate belt (i.e. the Richtex Formation). In fact, we argue that considerable parts of the metasedimentary and metavolcanic rocks which constitute the Kiokee belt are the metamorphic equivalents of the low-grade Carolina slate belt. In areas where a brittle fault does not exist between the two belts, the garnet isograd is the most reliable arbitrary boundary between the terranes. Therefore, our data along with the work of others (Tewhey, 1977; Metzgar, 1977) indicate that the Carolina slate belt and Kiokee belts share a similar stratigraphic history. However, in that neither the stratigraphic base nor the top of the Carolina slate belt has been identified in South Carolina, some lithologies in the Kiokee belt and likewise parts of the slate belt may not be represented in the Kiokee terrane.

CLOUDS CREEK IGNEOUS COMPLEX

The Clouds Cree igneous complex has intruded and contact metamorphosed rocks of the Carolina slate belt and is truncated on its southern margin by the Modoc fault zone (Plate II). Recent Rb-Sr data on the Clouds Creek pluton yield an are of 313 ± 2 m.y. and a rather high initial $(Sr^{87}/Sr^{86})_o$ ratio of .7099 ± 0.0001 (Fullagar and Butler, in press; P.D. Fullagar, personal comm., 1978).

Field mapping indicates that the Clouds Creek igneous complex can be divided into two distinct sequences: 1) a megacrystic granite pluton ranging from massive to gneissic and 2) a heterogeneous mafic complex developed on the east flank of the felsic pluton. A crude contemporaneity between these two magmatic phases seems probable in that age relations appear in part to be conflicting. To a first approximation, the presence of granitic cupolas in the mafic complex suggests an older age for the mafic rocks. Furthermore, some of the mafic rocks have undergone an intense static alteration which appears analogous to the widespread retrogression characteristic of the contact aureole that partially envelopes the felsic pluton. However, along the eastern margin of the pluton where granitic rocks are strongly deformed, adjacent melanocratic quartz diorite is massive and essentially undeformed. Farther north, also along the eastern margin of the felsic pluton, composition variation in the granitic rocks suggests possible hybridization between coexisting felsic and mafic magmas. In summary, the Clouds Creek complex appears to be a composite intrusion which developed

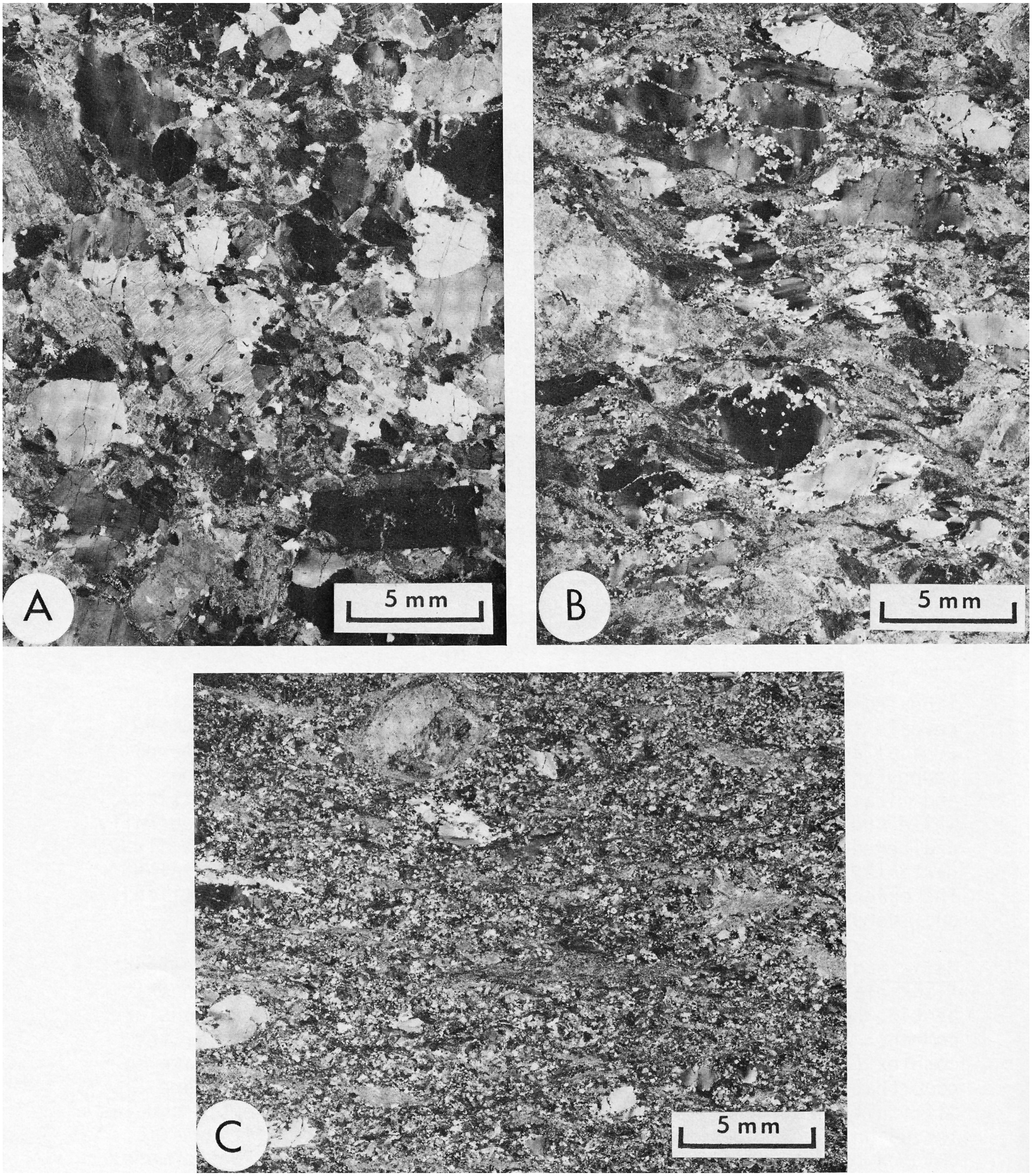


Figure 5. Photomicrograph of Clouds Creek granite; crossed polarizers. A, nonfoliated, megacrystic granite. The rock consists chiefly of perthitic K-feldspar, plagioclase, quartz, and biotite. Note that quartz displays undulose extinction, although the rock does not exhibit a mesoscopic fabric. B, Gneissic phase of the granite. Sericitization of the feldspar is ubiquitous as well as extensive alteration and deformation of biotite. Quartz occurs as intensely strained lenticular grains, partially polygonized. C, Blastomylonitic gneiss from the eastern margin of the Clouds Creek pluton. Porphyroclasts of feldspar and quartz in a matrix consisting chiefly of recrystallized quartz, feldspar, biotite, and muscovite.

through the interaction and multiple injection of intermediate and silicic magmas.

Field relations and petrography

Unfoliated megacrystic biotite granite.

Massive, unfoliated megacrystic biotite granite is the most widespread plutonic phase characteristic of the Clouds Creek igneous complex (Fig. 4A). Abundant outcrops of this unit occur along many creeks and large bouldery exposures and "pavement" outcrops are relatively common in uplands between drainages. Although detailed systematic modal data are not available at present, field relations suggest that the unit is homogeneous except along its eastern margin where hybridization is suspected. A particularly good locality to collect fresh megacrystic granite is an abandoned quarry, in the west-central part of the pluton, shown on the Batesburg 7½ minute quadrangle map (Locality A, Plate II).

Contacts with contact metamorphosed Carolina slate belt rocks are sharp with the granite exhibiting insignificant grain size variation up to the contact. In a few places we have found porphyries near the contact, but these rocks appear to be either intrusive masses or cognate xenoliths of early dikes and sills rather than a chilled marginal phase.

The typical unfoliated megacrystic granite consists chiefly of plagioclase, perthitic K-feldspar, quartz, and biotite (Fig. 5A). Common accessory minerals are apatite, opaque oxides, sphene, and zircon. Although K-feldspar is the typical megacryst, plagioclase megacrysts also occur. The rock invariably exhibits considerable alteration of the primary mineral phases. Sericitization of plagioclase is widespread; biotite is complexly altered to chlorite, epidote, sphene, and opaque oxides. Furthermore, although this rock is mesoscopically unfoliated, effects of strain are common. Undulatory recrystallization of quartz is ubiquitous, and fracturing and incipient recrystallization along grain boundaries are also common phenomenon in these rocks.

Gneissic granite to blastomylonitic gneiss.

Strongly deformed and partially recrystallized gneissic granite is ubiquitous along the southern margin of the pluton where it contacts the Modoc zone (plate II). This belt of deformed Clouds Creek granitic rocks trends away from the Modoc zone near Holston Crossroads and eventually forms a gradually narrowing marginal facies along the eastern contact of the pluton. The intensity of the granitic rocks is particularly pronounced immediately adjacent to the eastern contact northward of Shady Grove cemetery. In this segment of the foliated belt, augen gneisses pass rapidly into a blastomylonitic gneiss essentially devoid of megacrysts except scattered feldspar porphyroclasts. On the other hand, the transition from unfoliated to foliated granite (i.e., gneissic granite) is a gradational phenomenon involving the alteration of foliated and nonfoliated rocks until one or another is dominant and eventually exclusive. This transition zone is highly variable in width but commonly is manifested over a distance of several hundred meters or more. Good exposures of the transition from massive to foliated granite and eventually augen gneiss are particularly common along Moore Creek south of U.S. 178; excellent exposures of the Clouds Creek augen gneiss are particularly common along Moores Creek south of the Dye Creek intersection.

The gneissosity which characterizes the deformed Clouds Creek granite is defined by oriented biotite, streamline K-feldspar porphyroclasts, lensoidal quartz, and elongated xenoliths (Fig. 4B). Under the microscope the typical gneissic granite displays a variety of mineralogic alterations as well as strain effects (Fig. 5B). Both plagioclase and K-feldspar grains have undergone intense sericitization. Biotite is commonly crinkled and partially altered to epidote, muscovite, sphene, and opaque oxides. The lenticular quartz is undulose and partially recrystallized into unstrained aggregates.

The intensely deformed Clouds Creek blastomylonitic gneiss is lineated as well as very strongly foliated. Microscopic examination reveals that recrystallization is considerably more advanced than the typical augen gneisses of the deformed zone of the pluton. Scattered porphyroclasts are set in a granoblastic matrix of quartz, feldspar, and mica (Fig. 5C). Feldspar porphyroclasts are intensely sericitized while the recrystallized feldspars are clear and generally unaltered. Elongated quartz porphyroclasts are still present but always partially polygonized to aggregates of unstained granoblastic grains. The original mica of the granitoid has been extensively recrystallized, and muscovite is exceptionally abundant in these rocks.

Mafic and ultramafic rocks.

The mafic complex which occurs on the east flank of the Clouds Creek felsic pluton consists chiefly of melanocratic biotite-hornblende quartz diorite but textural and modal variations are common. At one locality a serpentinitized ultramafite is part of the complex (Locality B, Plate II). Exposures of the mafic complex are so poor that contact and age relations are difficult to discern. At many localities we have found granitic cupolas intruding the mafic complex clearly indicating that part of the mafic complex predates the felsic magmatism of the main pluton. Furthermore, many of the mafic rocks have undergone an intense static alteration which we attribute to expulsion of deuteric fluids during the emplacement and solidification of the adjacent felsic pluton. On the other hand, undeformed, relatively dioritic rocks outcrop along the intensely deformed eastern margin of the pluton. These mafic rocks appear to post-date the emplacement of the felsic pluton. We reconcile these relations by a multiple intrusion history for the mafic complex which was roughly contemporaneous with the felsic magmatism of the main pluton, but was episodic, such that contrasting age relations are locally manifested.

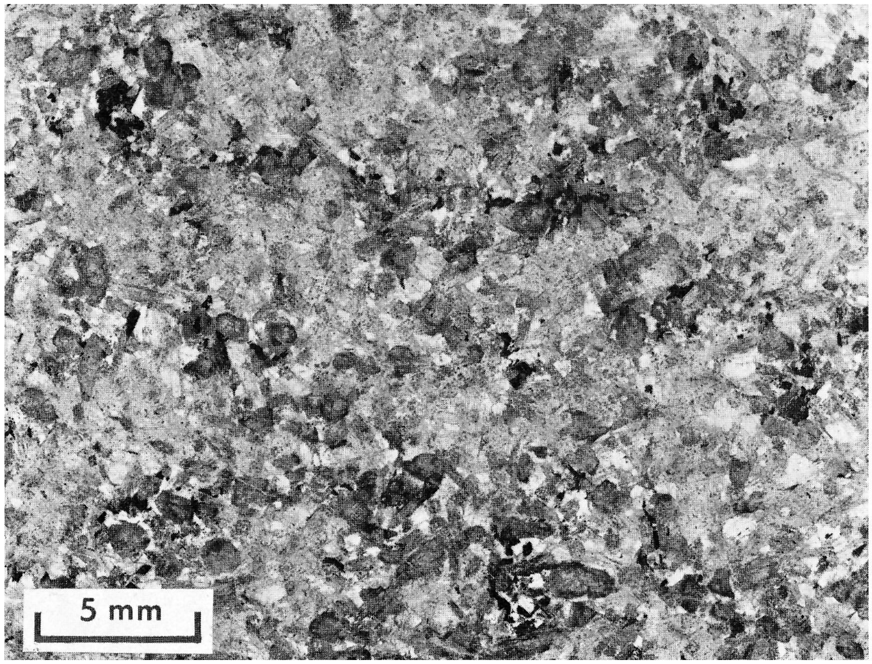


Figure 6. Photomicrograph of melanocratic hornblende (quart-bearing) diorite of the mafic complex of the Clouds Creek igneous complex. This rock has experienced extensive static alteration. The primary hornblende is altered to actinolitic amphibole and chlorite. Likewise, plagioclase is partially altered to clinozoisite-epidote, chlorite, and actinolite. Other mineral species present are quartz (interstitial), sparse biotite, opaque oxides, apatite, zircon, and very scarce tourmaline. Ordinary light.

The melanocratic quartz diorite is commonly massive and unfoliated, although a foliation has been observed at a few localities. Under the microscope, the dioritic rocks exhibit a complex mineral paragenesis which is a combination of the original primary igneous assemblage and an overprint of hydrothermal alteration (Fig. 6). The primary olive-brown hornblende is extensively altered to actinolite amphibole and chlorite. Bleached cores in the altered hornblende grains suggest that pyroxene was also a primary magmatic phase. Biotite, a common subordinate varietal mineral phase, is altered to chlorite and opaque oxides. The primary mafic mineral paragenesis is, therefore, in accord with Bowen's reaction series: pyroxene-hornblende-biotite. Plagioclase, commonly displaying conspicuous normal zoning, is charged with actinolite needles, clinozoisite-epidote aggregates, and chlorite inclusions. Quartz which is interstitial is a ubiquitous constituent in the dioritic rocks. Accessory minerals include apatite, sphene, opaque oxides, zircon, and tourmaline.

Serpentinized ultramafic rocks are a minor component of the mafic complex, and a particularly fresh exposure is located on Plate II (Locality B). At this locality the ultramafite is massive with a well-preserved igneous texture but is extremely altered to a complex secondary mineral assemblage consisting of chlorite, serpentine-group minerals, tremolite-actinolite, talc, carbonate, and opaque oxides (Fig. 7). No primary pyrogenetic minerals were recognized in the rock, but the relict euhedral to subhedral shape of the pseudomorphs and their relative abundance are suggestive of an original cumulate texture. Further conclusions can not be drawn, but the association of small quantities of cumulate ultramafic rock is common in some calc-alkaline plutonic complexes (see, for example, Nockolds, 1941; Pitcher, 1978).

Dikes and other minor intrusions.

The history and lithologic variation of the Clouds Creek complex is complicated by several suites of minor igneous intrusions. The present data suggest at least three distinct groupings:

1. Biotite quartz diorite porphyry,
2. Nonporphyritic to microporphyritic biotite quartz diorite,
3. Aplite-pegmatite.

Cross-cutting age relations suggest that the magmas responsible for groups 2 and 3 were generated late in the crystallization history of the complex. The porphyries, however, commonly occur as irregular masses or small xenoliths in the megacrystic granite or gneissic granite, and appear t be early dikes or sills engulfed and partially assimilated by a rising pluton (STOP 3). Similar relations have been well-documented in shallow level plutons of the Cascade Range, Washington (Fiske and other, 1963).

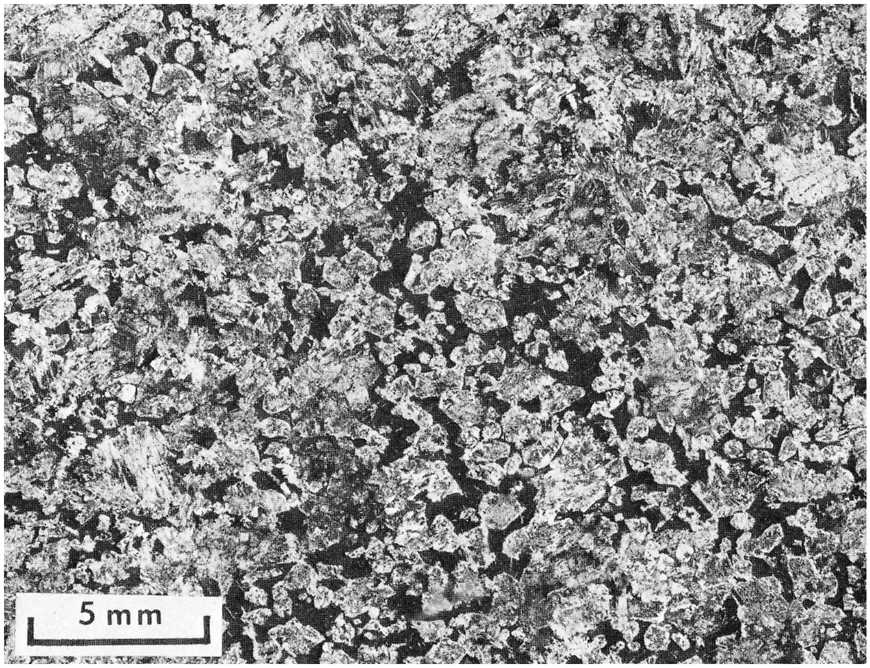


Figure 7. Photomicrograph of altered ultramafite of the mafic complex of the Clouds Creek igneous complex. All original pyrogenetic minerals have been altered to a complex assemblage of secondary minerals. Tremolite-actinolite/opaque oxides pseudomorphs (after pyroxene?) Are very common. Other minerals present are chlorite, serpentine-group minerals, talc, and carbonate, Ordinary light.

Contact metamorphism

A well-developed aureole of thermally metamorphosed metasedimentary rocks surrounds the Clouds Creek igneous complex. The aureole is very well exposed along the northwest flank of the pluton where a series of resistant knobs of hornfels define the southeast margin of the Clouds Creek drainage system. Hornfelsic rocks can be traced around the northern end and along the eastern margin of the complex. It is important to emphasize that no evidence, either field or petrographic, suggests that the Kiokee belt rocks (chiefly orthogneiss) immediately south of the “Modoc line” have experienced contact metamorphism. This observation is ancillary evidence that the southern boundary of the Clouds Creek pluton is a fault.

The thermally metamorphosed rocks of the aureole are variable depending on protolith characteristics, but many are massive, granular rocks with little or no fabric. Original sedimentary features are locally well-preserved; for example, overturned flaser bedding has been identified in hornfelsic rocks along the northwest margin of the pluton. Muscovite poikiloblasts are very common, and the rocks have a spotted appearance related to mineralogic variations and inhomogeneities in grain size. Considerable portions of the aureole have experienced retrogression manifested by extensive sericitization and local pyritization. Hornfelsic rocks from the inner aureole that have retained their prograde mineral assemblage unaltered commonly consist of various proportions of quartz, biotite, muscovite, plagioclase and opaque oxides. Tourmaline is a very common accessory mineral in many of the hornfelses. No aluminosilicates or cordierite have yet been identified in the rocks of the Clouds Creek aureole. Calc-silicate minerals were observed in metamorphosed concretions along Lick Creek southwest of St. John’s Church (Batesburg quadrangle). With progressive distance from the intrusive contacts of the Clouds Creek igneous complex, the massive character of the hornfels is less evident, and the rocks of the outer aureole grade into penetratively deformed, regionally metamorphosed rocks of the Carolina slate belt. In summary, both field and petrographic data indicate that a contact aureole attaining hornblende hornfels facies (?) has been superimposed on previously deformed and metamorphosed rocks. These observations coupled with the Rb-Sr isotopic data from the Clouds Creek complex (Fullagar and Butler, in press) indicate that the age of the regional greenschist facies metamorphism that characterizes the Carolina slate belt must pre-date 313 ±2 m.y. However, the more definite question concerning Acadian vs. Taconian age for the regional metamorphism cannot be solved in this segment of the Piedmont with the present available data.

Origin of foliation in the granitic rocks

The foliated granitic rocks which constitute a large segment of the southern part of the Clouds Creek pluton are unusual for plutonic rocks intrusive into the Carolina slate belt during the interval 330 to 270 m.y.b.p. (Fullagar and Butler, in press). Carboniferous-Permian plutonic rocks of this age bracket are typically described as post-kinematic (i.e. post-metamorphic), and noticeable fabrics are commonly considered to be related to the streaming or flowage of a viscous silicate melt. The 2-kilometer width and local intensity of the deformed belt (including the blastomylonitic textures of some rocks) seem to preclude a simple igneous flow interpretation.

Additional constraints on the origin of the fabric within the foliated zone of the pluton are:

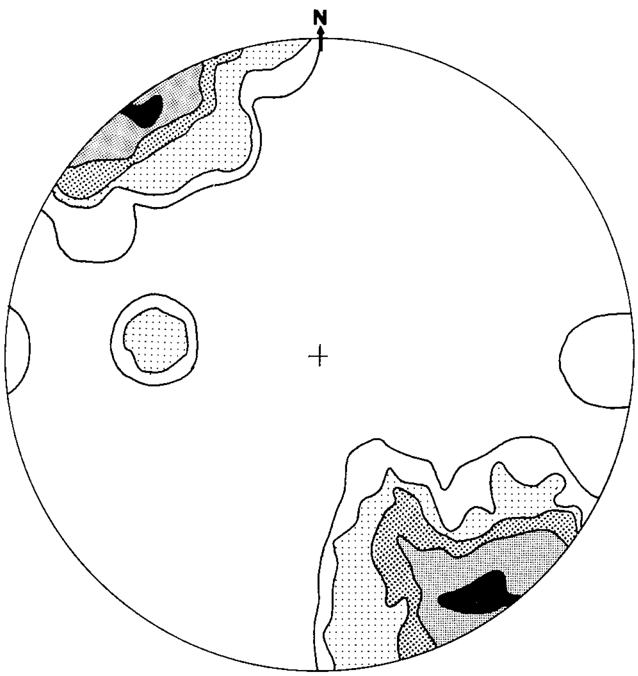


Figure 8. Lower hemisphere, equal-area projection of poles to 52 foliation planes measures in the gneissic phase of the Clouds Creek granite in the Batesburg and Emory quadrangles. Contours: 26-13-7-3-1%.

1. The position of the foliated zone is not exclusively adjacent to the Modoc fault zone (see Plate II and Fig. 8);
2. Contacts between nonfoliated and foliated granitic rocks are gradational, commonly over an interval of several hundred meters;
3, Undeformed aplite dikes (late differentiates of the granitic magma) intrude both foliated and nonfoliated rocks (Fig. 9 and STOP #);
4. Superimposed on the prominent foliation is a complex sequence of later events including a secondary foliation (S_f), small-scale ductile shears, and minor brittle faults (STOP 4).

Figure 9. Aplite dike intruding the gneissic phase of the Clouds Creek granite. The pen is parallel to the foliation in the granite which trends approximately N60E and dips steeply. The aplite dike trends N85W and is subvertical (?). Although the aplite clearly truncates the protoclastic foliation of the granite, wedge-shaped aplite apophyses have locally intruded subparallel to the foliation of the deformed granite.

The confluence of these data indicate three distinct stages in the history of the deformed granitic rocks: 1. initial magmatic emplacement, 2. deformation and recrystallization during solidification, and 3. late ductile to brittle deformation related to movement along the Modoc fault zone. Stage 2 is, therefore, considered to be an event related to largely solid igneous flow within a nearly crystalline or perhaps subsolidus granitic pluton. The foliated zone in the Clouds Creek pluton is perhaps a manifestation of the evolving Hercynian metamorphic front which caused widespread deformation and recrystallization in the adjacent Kiokee terrane.

Table 1. Mescopic Fabric Elements

	Carolina slate belt	Kiokee belt
D_1 (Taconian or Acadian?)	F_1 - map scale, upright near isoclinal folds; southeast vergence	
	S_1 - ubiquitous penetrative foliation	Inferred to be the same as the Carolina slate belt but transposed by intense later deformation
	L_1 - L_{0x1}	
D_2 (Hercynian)	F_2 - flexural slip to flexural flow, approximately coaxial with F_1 folds	F_2-passive to flexural flow; synmetamorphic to late metamorphic (F_2*-type folds)
	S_2 - a penetrative foliation is typically absent, although local development of crenulation cleavage	S_2- penetrative foliation, locally a mylonitic flattening foliation
	L_2 - L_{1x2} (often a subhorizontal crinkle lineation); well developed rodding and mullion structure near the Modoc fault	L_2-L_{0x2}, L_{1x2} ; mineral streaking (i.e. an elongation lineation) in orthogneisses
D_3 (Late Hercynian)	F_3 - passive; subvertical fold axes, typically dextral vergence; NNE-trending axial surfaces	
	S_3 - crenulation cleavage to well developed axial plane foliation, locally transposes S_1	Same as the Carolina slate belt but overall style suggests a more ductile deformation, perhaps related to somewhat higher temperature and pressure conditions
	L_3 - L_{0x3}, L_{1x3}	
D_4 (Late Paleozoic to Mesozoic)	Local cleavage development (S_f) Modoc fault zone-brittle faulting	

DEFORMATIONAL HISTORY

The rocks of both the Carolina slate belt and the Kiokee belt have been affected by at least four different episodes of deformation (D_1-D_4 --Table 1). D_1 is Early or Middle Paleozoic in age and was synchronous with regional greenschist metamorphism in the slate belt. The metasedimentary and metavolcanic rocks that are now part of the Kiokee belt probably also experienced the D_1 event, along with regional greenschist metamorphism, but evidence for this has been nearly obliterated by an intense Late Paleozoic (Hercynian) D_2 deformation and accompanying amphibolite facies metamorphism. D_1 and D_2 were primarily periods of folding and metamorphism. F_1 folds, along with facies variations, mainly control the distribution of map units in the Carolina slate belt. In the Kiokee belt, F_2 folds, along with irregularities in the intrusive contacts of orthogneiss massifs, control the map pattern (Plate II).

D_3 was a relatively weak late Hercynian episode of folding and cleavage development that affected both the slate and Kiokee belts. At present, F_3 folds have been identified only on the microscopic and mesoscopic scales. D_4 includes a number of miscellaneous structures such as the late brittle faults, late kink bands, and a crenulation cleavage (S_f) that is especially conspicuous near the Modoc fault zone.

D_1 System

The earliest recognizable deformation to affect the rocks of the Carolina slate belt (D_1) was synchronous with regional greenschist facies metamorphism and resulted in the development of a penetrative slaty cleavage (S_1) and a series of

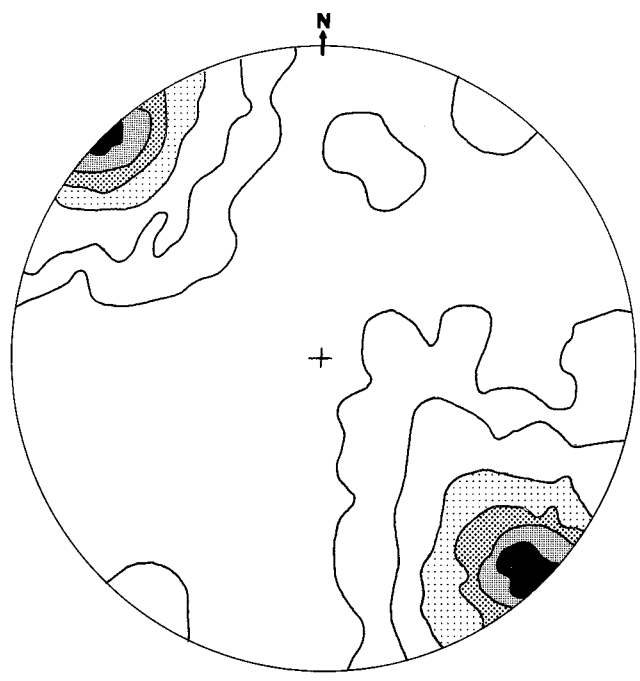


Figure 10. Lower hemisphere, equal-area projection of poles to 490 S_1 foliation planes measured in the slate belt rocks of the Batesburg and Emory quadrangles. Contours: 35-25-15-5-1-0%.

tight to isoclinal F_1 folds (Fig. 10). The largest F_1 fold recognized in the study area is a tight southwest-plunging synclinorium having a wave length and amplitude of several kilometers. The Clouds Creek igneous complex has been emplaced into the axial zone of this synclinorium, which extends from the north end of the Clouds Creek pluton, trending N55E, to Rocky Creek on the south shore of Lake Murray. The Persimmon Fork Formation and the tidal shelf sequence in the lower and middle part of the Richtex Formation form the steep northwest limb of the synclinorium. The massive mudstone unit in the upper part of the Richtex Formation is in the core of the synclinorium, and the underlying tidal shelf sequence reappears in the southeast limb.

D_1 deformational effects have not been unequivocally identified in the metasedimentary rocks of the Kiokee belt. However, as the boundary between the slate and Kiokee belts is approached, in areas where brittle faults are not localized along the boundary, it appears that S_1 is gradually sheared out and transposed into S_2 by intense strain associated with D_2 deformation. We, therefore, infer that D_1 structures and the associated greenschist facies metamorphism were originally present but have been so strongly overprinted by D_2 that they can no longer be recognized.

Our reconnaissance indicates that the effects of D_1 deformation and metamorphism in the Batesburg-Emory area are very similar to the effects of D_1 elsewhere in the Carolina slate belt in North and South Carolina, although the intensity of D_1 folding may decrease to the northeast in North Carolina.

The time of occurrence of D_1 is only loosely constrained on the range 520-300 m.y. by the available geochronological data. The youngest Rb-Sr whole rocks ages for metavolcanic rocks in the Carolina slate belt in North and South Carolina is approximately 525 m.y. (Hills and Butler, 1969; Fullagar, 1971; Butler and Fullagar, 1975), and a suite of prekinematic granite plutons were intruded into the slate and Charlotte belts around 520 m.y. (Fullagar, 1971). The time of the D_1 deformation must, therefore, be more recent than 520 m.y. In numerous places the Carolina slate belt and the Charlotte belt are intruded by a distinctive suite of ~300m.y.-old, post-tectonic granite plutons (Fullagar and Butler, 1977; in press). In our study area the Clouds Creek granite (Rb-Sr whole-rock and mineral isochron age 313 ±2 m.y.— Kish and others, 1978; P.D. Fullagar, unpublished data) belongs to this suite of post-tectonic granite plutons. The static contact metamorphism hornfels aureole surrounding the Clouds Creek igneous complex clearly overprints D_1 greenschist facies metamorphism and S_1 slaty cleavage. A Taconian age for D_1 is suggested by the 400 m.y.-old Salisbury group of plutons, interpreted by Butler and Fullagar (1978) to be late-tectonic. Most of the K-Ar and Rb-Sr mineral dates for rocks in the Charlotte and slate belts are in the range of 300-250 m.y. (Long and others, 1959; Kulp and Eckelmann, 1961) and are commonly interpreted as cooling dates representative of post-tectonic uplift and erosion (Hadley, 1964; Dallmeyer, 1978). However, a few anomalously old dates in the range of 400-430 m.y. have been reported by Bell and others (1972). If these dates are significant and not the product of excess radiogenic argon or some other problem inherent in the samples, the D_1 event could not be younger than Taconian (Butler and Howell, 1977). A Taconian age for regional metamorphism has also been suggested by Black and Fullagar (1976) from Rb-Sr studies of metavolcanic rocks near Chapel Hill, North Carolina. Conversely, Briggs and others (1978) and Seiders and Wright (1977) have argued for regional metamorphism based on lower concordia intercepts from U-Pb zircon studies of the Roxboro metagranite and Uwharrie Formation, respectively. In summary, although there is considerable uncertainty concerning the time of the D_1 event, the available information suggests that its age is pre-Alleghanian (i.e. pre-Hercynian).

D_2 System

The effects of the D_2 deformation are variably developed between the Carolina slate belt and Kiokee belts. The D_2 deformation in the Kiokee belt was accompanied by high-grade, amphibolite facies metamorphism and was a protracted event that involved a complex synmetamorphic to late metamorphic fold chronology. The effects of the D_2 event in the Carolina slate belt were considerably less intense and more localized. We have considered F_2 folds in the Carolina slate belt to constitute a single population, although a synchronous age is unlikely. Folds associated with F_2 in the Kiokee belt have been divided into two groups: F_2 (synmetamorphic-synchronous with the development of the S_2 foliation) and F_2* (late synkinematic-post--S_2 but late metamorphic).

Flexural folding of S_0 and S_1 is the characteristic style of F_2 folds developed in the Carolina slate belt. Along the southwest shore of Lake Murray (Localities C and D, Plate II) the axes of F_2 folds are parallel to L_{0x1} indicating that F_1 and F_2 folds are coaxial. In this region F_2 folds have no associated cleavage, and their axial surfaces are nearly flat or dip moderately to the northwest. In the Rocky Creek area (Locality E, Plate II), F_2 folds are intensely developed in the axial zone of the major F_1 synclinorium. At this locality, there are two distinct sets of mesoscopic F_2 folds, both having the same fold style, but one with subhorizontal axes, and the other with axes that plunge steeply to the northeast. In slate belt rocks along the Modoc fault zone in the Johnston quadrangle, D_2 is manifested as a crenulation cleavage dipping moderately to the northwest.

At the east end of Lake Murray, the boundary between the slate and Kiokee belts is folded by a major late metamorphic fold (F_2* generation) plunging steeply to the northeast (the Irmo structure— see Tewhey, 1977, Plate 1; Plate II, this study). In this region the boundary between the slate and Kiokee belts is a narrow transition zone about 1 km wide containing biotite and almandine garnet isograds. As this boundary is approached from the slate belt the intensity of F_2 folding markedly increases (STOP 8), and S_1 is progres-

Figure 11. A folded aplite dike in Lake Murray gneiss, Lake Murray spillway. Note that the foliation (regional S_2) in the gneiss is parallel to the axial surface of the fold. The dike, therefore, is pre-metamorphic and the isoclinal fold is an F_2 structure (synchronous with the development of the Hercynian-age foliation in the Carboniferous granitic rocks of the Kiokee belt).

sively sheared out and transposed into S_2. Within the transition zone the rocks have been intensely strained and characteristically contain a prominent elongation lineation which parallels the axes of mesoscopic F_2 and F_2* folds. Strain rates in these rocks were probably high, and ductile deformation apparently outlasted or dominated thermal recrystallization resulting in a mylonitic texture. Within the southeast limb of the Irmo structure are many small granitic intrusions (stocks, sills and dikes--STOP 6). These granitoids are pre-kinematic to synkinematic for they commonly contain the S_2 regional foliation. These intrusions are petrographically similar to the plutonic orthogneisses common in the interior of the Kiokee belt. Pegmatites are also widespread within the southeast limb of the Irmo structure (Tewhey, 1977), Plate 1 and STOPS 7 and 9). The pegmatites are also commonly deformed by F_2* folds (STOP 7) but often truncate the S_2 foliation (STOP 9). At least some aplites in the Lake Murray gneiss are apparently pre-S_2. At STOP 9 (the Lake Murray spillway) the S_2 foliation in the gneiss is parallel to the axial surface of isoclines defined by folded aplite dikes in gneiss (Fig. 11).

In the Kiokee belt southwest of Lake Murray, near Batesburg, S_2 foliation and L_2 lineation are strongly developed in the mixed gneiss (chiefly augen gneiss--see Fig. 3) and lineated granitic gneiss units, respectively (Fig. 12 and STOP 1). In this region L_2 also is an elongation lineation, plunging gently to the northeast. Furthermore, the presence of a brittle fault between the Carolina slate and Kiokee belts is suggested by the divergence of strike between S_2 and the mapped boundary (Plate II).

The differences in style and intensity of D_2 structures between the slate and Kiokee belts is probably directly related to differences in the physical properties of the rocks in the two belts are the time of deformation. D_2 structures are weakly developed in the Carolina slate belt because the rocks were relatively cool and behaved in a competent manner. The Kiokee belt underwent intense folding and was penetratively deformed during D_2 because the rocks were greatly weakened by the higher temperatures of amphibolite facies regional metamorphism. The rocks in the metamorphic transition zone between the slate and Kiokee belts underwent extreme deformation because of their location in a zone of accommodation between two contrasting strain and displacement fields. Because of somewhat lower temperatures and high strain rates in the transition zone, deformation dominated or outlasted thermal recrystallization, locally producing a mylonitic fabric.

The data on the character and distribution of D_2 structures indicates that in the Late Paleozoic a metamorphic "front" existed in this part of South Carolina separating a region undergoing intense deformation and amphibolite facies metamorphism on the southeast from a region on the northwest that experienced only mild Late Paleozoic deformation. The transition zone or boundary between these two

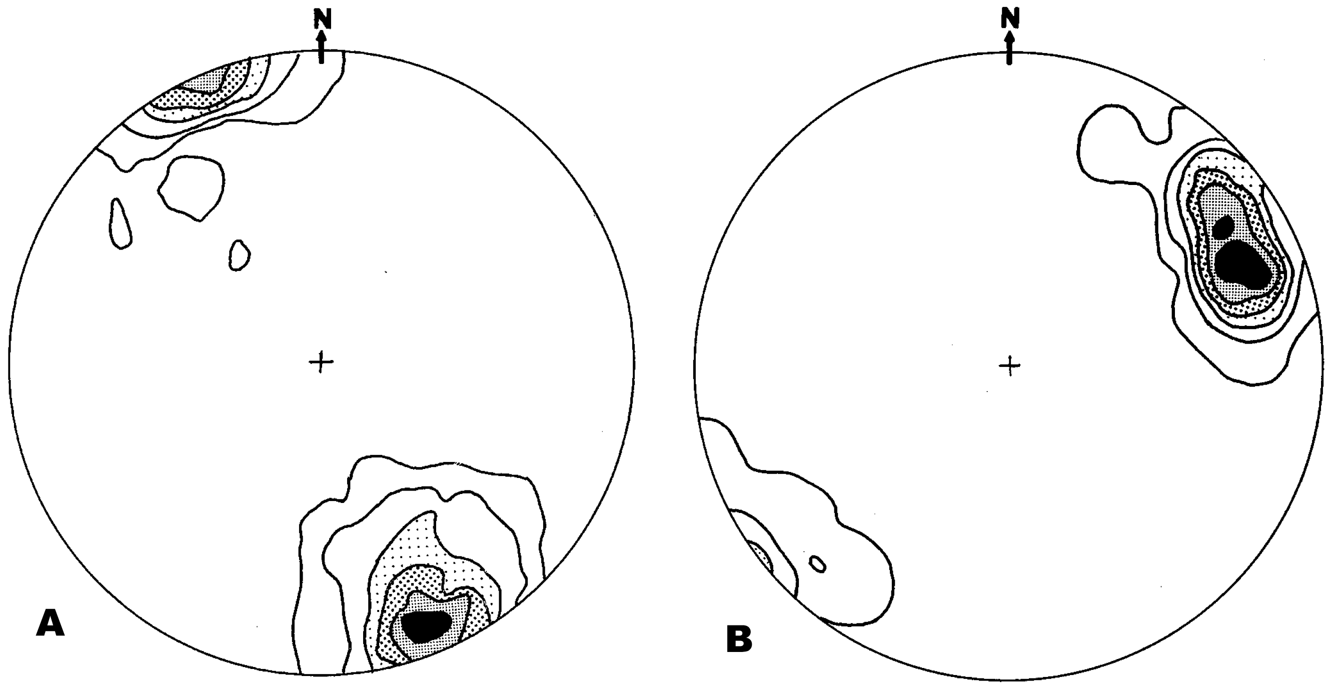


Figure 12 - A. Lower hemisphere, equal-area projection of poles to 122 S_2 foliation planes measured in the Kiokee belt rocks of the Batesburg and Emory quadrangles. Contours: 25-20-15-10-5-1%. B. Lower hemisphere, equal-area projection of 46 L_2 lineations measured in the Kiokee belt rocks of the Batesburg and Emory quadrangles. Contours: 35-28-21-14-7-2%.

regions was characterized by a steep metamorphic gradient and intense mylonitization. This transition zone along with adjacent parts of the Kiokee and slate belt exhibits many earmarks of an *Abscherungszone* separating infrastructure, as defined by Wegmann (1935) and applied by Haller (1956, 1971) in the East Greenland Caledonides and by Griffin (1970, 1971, 1978) and Tobisch and Glover (1971) in the southern Appalachian Piedmont.

We are aware that recent geochronological investigations in the East Greenland Caledonides have cast doubt on many of the interpretations made by Haller (Higgins, 1976; Henriksen and Higgins, 1976). However, we feel that the "stockwerk" tectonic model, modified to account for multiple periods of deformation and integrated into a plate- tectonics framework, is the most promising orogenic concept for explaining the D_2 structures along the boundary between the slate and Kiokee belts. The Modoc fault zone is a polyphase deformed belt of rock which is a metamorphic transition from greenschist to amphibolite facies metamorphism, a zone of high-temperature ductile deformation (i.e., mylonitization), and a locus of late brittle faults. It, therefore, represents a unique boundary which displays a diachronistic history in part related to tectonic overprinting.

The time of occurrence of D_2 is clearly Late Paleozoic. The augen gneiss unit in the Kiokee belt near Batesburg, South Carolina, carries a well-developed S_2 foliation (Fig. 3 and 12A) and has a whole rock Rb-Sr isochron age of 291 ± 4 m.y. (Kish and others, 1978; Snoke, Kish and Secor, in preparation). Granite and pegmatites also in the Kiokee belt from near Edgefield, South Carolina, do not carry the intense S_2 foliation recorded in surrounding rocks, and yield a whole rock Rb-Sr isochron age of 254± 11 m.y. (Metzgar, 1977; Snoke, Kish and Secor, in preparation). Therefore, the D_2 deformation occurred in Late Carboniferous or Early Permian time between the interval 290 to 250 m.y.b.p.

D_3 System

D_3 structures have been identified only on the microscopic and mesoscopic scales and occur in both the slate and Kiokee belts. In the Carolina slate belt, S_3 is preferentially developed in the ripple-laminated quartz metasiltstone unit of the Richtex Formation, especially in the subvertical northern limb of a major F_1 synclinorium (Plate II and STOP 5). In this region S_0 parallels S_1, and S_3 is manifested as either a slaty or crenulation cleavage that weakly transposes S_0 and S_1. In most places F_3 folds are dextral when viewed down plunge, and fold axes parallel the intersection lineations, L_{0x3} and L_{1x3} (Fig. 13). F_3 folds characteristically are steeply plunging (Fig. 14B), and the S_3 cleavage (Fig. 14A) can usually be identified by its unique N10E-N40E strike direction. In the Kiokee belt F_3 folds have the character of narrow, vertically dipping dextral shear bands also commonly trending N10E-N40E. In a few places in the slate and Kiokee belts, steeply plunging sinistral folds having axial surfaces striking northwest have been observed. These folds may be conjugate to the widespread northeast-trending folds

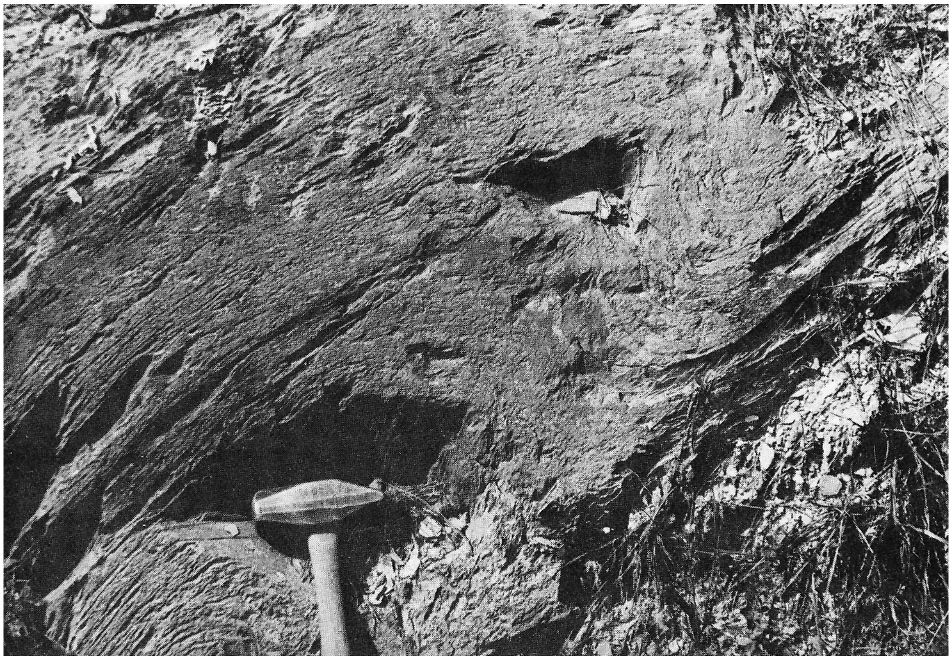


Figure 13. A steeply plunging F_3 fold in the quartz metasiltstone facies of the Richtex Formation (Carolina slate belt--STOP 5). Note that a penetrative cleavage (S_3) parallels the axial surface of the fold. At this locality, S_0 is parallel to S_1 and intersection lineations (L_{0x3}, L_{1x3}) are also steeply plunging. Vergence is dextral (i.e. southeastward).

characteristic of the D_3 system.

The intensity of development of D_3 structures is uniformly weak in both the slate and Kiokee belts. We, therefore, infer that the D_3 structures formed after the dissipation of the steep thermal gradient that developed between the slate and Kiokee belts during D_2 time.

Granite and pegmatites near Edgefield, South Carolina, containing F_3 and S_3 (Metzgar, 1977) have a Rb-Sr whole rock isochron date of 254± 11 m.y. (S.A. Kish, written communication, 1978). The age of D_3 is, therefore, Permian or younger.

D_4 System

The most recent deformational episode recognized in our study area is manifested by a group of brittle faults that occur along the boundary between the slate and Kiokee belts. We also include data on a late crenulation cleavage (S_f) that is commonly localized near the brittle Modoc fault. Post-metamorphic kink bands have been recognized in many places in the study area, but a systematic study of these has not been made.

A system of late brittle faults is inferred along the northwestern edge of the Kiokee belt in the Batesburg area (Plate II). Although these faults are not exposed in outcrop, their presence is indicated by the truncation of the Clouds Creek igneous complex, and by the juxtaposition of amphibolite facies orthogneiss and paragneiss of the Kiokee belt against the greenschist facies mudstone and wacke of the Richtex Formation. To the northeast, in the Lake Murray West quadrangle, the evidence for brittle faulting is less clear, and it appears that there is an abrupt increase in the grade of metamorphism and in the intensity of D_2 deformation adjacent to the orthogneiss of the Kiokee belt. Although the brittle faults inferred in the Batesburg area probably continue to the northeast into the Lake Murray West area, they may gradually veer into the Carolina slate belt or the magnitude of displacement diminishes. Therefore, along the south shore of Lake Murray, the boundary between the slate and Kiokee belts is a steep metamorphic gradient adjacent to an intrusive contact between plutonic orthogneiss (Lexington metagranite) and the Richtex Formation.

A brittle fault, marked by the presence of silicified fault breccia, occurs along the south shore of Lake Murray, but this fault is in the southeast limb of the Irmo structure, the macroscopic fold in the slate-Kiokee belt boundary (Locality F, Plate II; Heron and Johnson, 1958; Tewhey, 1977).

A steeply dipping, approximately east-west-trending, crenulation cleavage (S_f) is developed in the rocks of the Carolina slate belt adjacent to the brittle Modoc fault (i.e., the slate-Kiokee belt boundary-- see STOP 2). The acute angle of the intersection between S_f and S_1 causes the fine-grained schists of the slate belt to weather into button-shaped fragments; the rock is colloquially known as “button schist”. North of Batesburg (STOP 2) where we first observed this structure we have inferred a genetic relationship between S_f and the brittle fault (Snoke and others, 1977) and the field distribution of button schist can be used in tracing the brittle fault. However, button schists are also known to occur

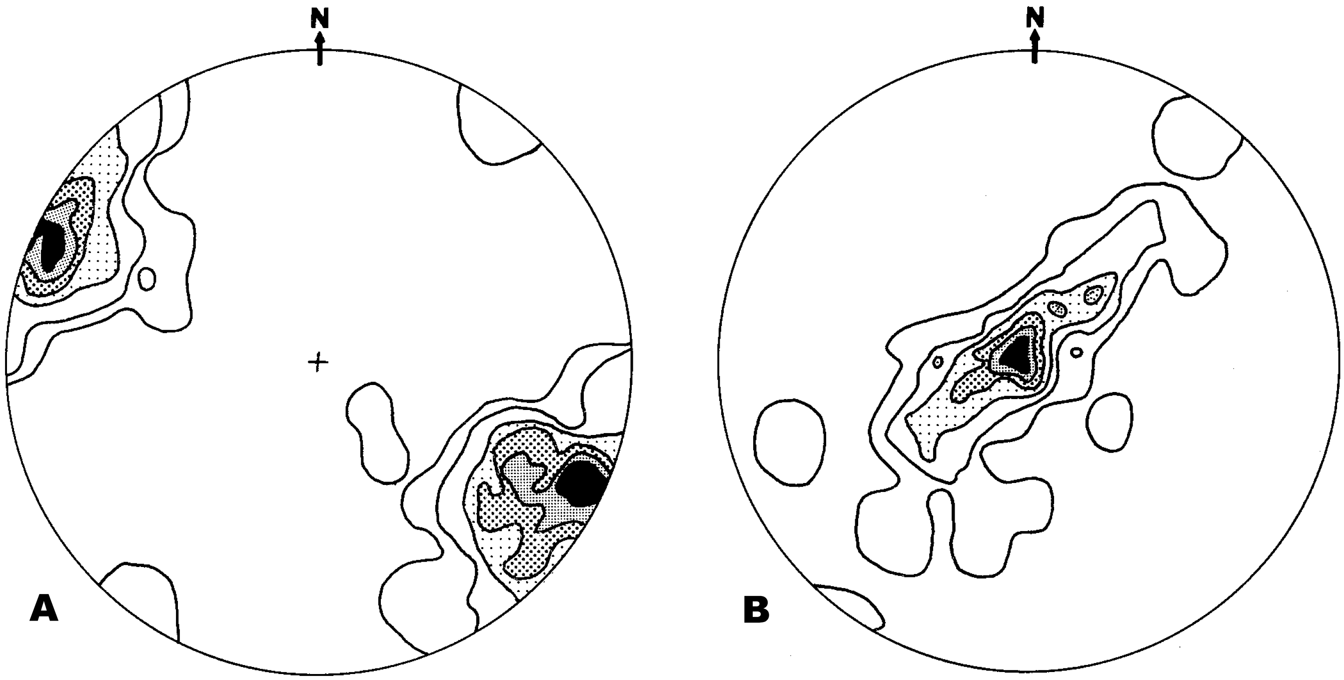


Figure 14. - A. Lower hemisphere, equal-area projection of poles to 75 S_3 foliation planes measured in the slate and Kiokee belts of the Batesburg, Emory, Lake Murray West and Delmar quadrangles. Contours: 20-16-12-8-4-1%. B. Lower hemisphere, equal-area projection of 90 L_3 lineations (including L_{0x3}, L_{1x3}, and F_3 fold axes) measured in the slate and Kiokee belts of the Batesburg, Emory, Lake Murray West and Delmar quadrangles. Contours: 11-9-7-5-3-1%.

within the Kiokee belt where the presence of brittle faults are not evident.

An analogous east-west trending S-surface is locally found in the foliated belt of the Clouds Creek granite near the Modoc fault (Fig. 4B and STOP 4). This secondary cleavage is superimposed on the conspicuous protoclastic foliation but is locally truncated by later events, including brittle microfaults. We correlate this S-surface with the crenulation cleavage (S_f) common in fine-grained schist of the slate belt near the brittle Modoc fault (i.e., STOP 2). The origin of these east-west penetrative surfaces is problematic. Although they are especially conspicuous near the trace of the Modoc fault, the limited age relations suggest that a simple cause and effect relationship is unlikely, and that S_f is somewhat older than the brittle faulting. Perhaps S_f is a structural element generated during the diachronistic transition from ductile to brittle behavior inferred as the history of the Modoc fault zone.

The time of brittle faulting is known only within broad limits. The faults are presumably post-metamorphic; therefore, they can be no older than Late Paleozoic. Silicified fault breccias, similar to those observed along the south shore of Lake Murray, are found along the Jonesboro fault in North Carolina, which is known to have undergone displacement during the Triassic. Near Augusta, Georgia, O'Connor and Prowell (1976) and Prowell (this volume) have described the N30E-trending Belair fault zone which is clearly post-Cretaceous in age. The relationship between faults of the Belair system and the brittle faults in the Batesburg-Emory area is not known at present.

SUMMARY AND CONCLUSIONS

Comparative studies of the Carolina slate belt and Kiokee belt indicate that the same stratigraphic sequences are found in both belts and suggest a stratigraphic model in which an older dominantly volcanic and volcaniclastic sequence (Uwharrie Formation, Persimmon Fork Formation, Lincolnton metadacite and associated volcaniclastic rocks) is overlain by a volcaniclastic and epiclastic sequence (Albemarle Group, Richtex Formation). These rocks are thought to have been deposited in a volcanic arc 570-520 m.y. ago during the Cambrian period. Much of the Richtex Formation is composed of quartz-rich siltstone and sandstone containing sedimentary structures suggestive of a tidal shelf depositional environment. The interbedded lapilli tuff, wacke, and mudstone probably accumulated in adjacent terrestrial and marine depositional environments.

Two major deformational episodes (D_1, D_2) and two minor deformational episodes (D_3, D_4) have affected the slate and Kiokee belts in the Batesburg-Emory area (Fig. 15).

The timing of the first episode (Taconian or Acadian) is poorly constrained by available data, but definitely predates the intrusion of a distinctive suite of ~300 m.y.- old granite

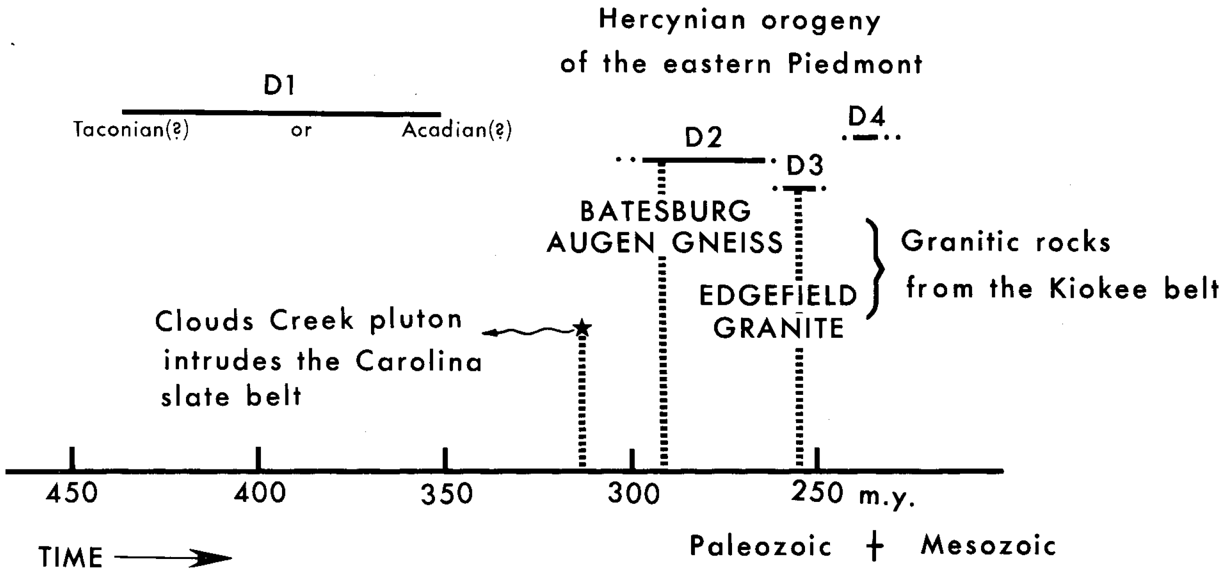


Figure 15. Time line showing the chronologic relationships between the deformation phases of the Carolina slate and Kiokee belts.

plutons found in the Piedmont from Virginia to Georgia. In the Batesburg-Emory area D_1 was a period of tight to isoclinal folding and greenschist facies regional metamorphism that uniformly affected the rocks in both the slate and Kiokee belts.

D_2 occurred in the period 290-250 m.y. and affected the rocks in the Kiokee belt much more intensively than those in the slate belt. We interpret the boundary between the slate and Kiokee belts to be a D_2 *Abscherungszone*, characterized by a steep metamorphic gradient and intense strain manifested as a high-temperature mylonitic fabric. This transition zone, therefore, separates Late Paleozoic, amphibolite facies Kiokee belt infrastructure from less deformed, greenschist facies Carolina slate belts rocks (i.e., the suprastructure during the Late Paleozoic orogenesis). The boundary is, in effect, the approximate limit of the "Hercynian metamorphic front" as developed in the South Carolina Piedmont.

The third deformational episode is characterized by the development of a north-northeast-trending slaty or crenulation cleavage (S_3) associated with mesoscopic, steeply plunging dextral folds (F_3). These structures are developed in both the slate and Kiokee belts and probably formed after the dissipation of the steep D_2 thermal gradient between the metamorphic belts.

The last deformational episode is characterized by the development of brittle faults and an associated crenulation cleavage (S_f) within the transition zone between the slate and Kiokee belts. In the Batesburg area the slip on these faults has juxtaposed amphibolite facies Kiokee belt infrastructure against the slate belt suprastructure, eliminating evidence of the metamorphic transition between the two belts. However, this transition zone is well preserved near Irmo, South Carolina, where a macroscopic late metamorphic fold (F_2*) folds the boundary between the Kiokee and Carolina slate belts.

In the past the terms "Modoc fault" or Modoc fault zone" have been used to refer to both the highly deformed rocks in the D_2 transition zone between the slate and Kiokee belts and to the D_4 brittle faults that are localized along the boundary. Although the characterization of this boundary as a fault may be technically correct, it fails to adequately convey the full spectrum of information on the nature of the boundary.

ACKNOWLEDGMENTS

This research is supported by the Division of Earth Sciences, National Science Foundation, NSF Grant EAR76-22323. Many geologists have visited us in the field and freely shared ideas and opinions. We particularly benefitted from discussions with the following: H. Bell, III; J.R. Butler, D.J. Colquhoun, O.P. Costello, R.V. Fodor, L. Glover, III, V.S. Griffin, Jr., R.D. Hatcher, Jr., M.O. Hayes, J. Horne, D.E. Howell, S.A. Kish, H. D. Maher, C. R. Metzgar, P. Nystrom, J. W. Skehan, S. Schamel, R.A. Schweichert, E.F. Stoddard, P. Talwani, and J.A. Whitney. Preprints of forthcoming articles by P.D. Fullagar and J.R. Butler on the 330 to 270 m.y.-old granitic plutons of the Piedmont and by R.H. Carpenter, A.L. Odom and M.E. Hartley, III on the age of the Lincolnton metadacite were useful in the evaluation of our data. Numerous discussions with S.A. Kish on the geochronology of the southern Appalachian Piedmont were fundamental in the establishment of the plutonic and structural chronology of the area. Several individuals helped with specific aspects of this report: Joyce Goodwin and Diane Moses (manuscript typing), Burk Scheper (photograph), Nanette Muzzy (drafting), Deanna Bultz (computer analysis of structural data), Judy Snoke (road log preparation).

This project initially developed from data collected during the 1976 Spring semester Field Geology course (Geol. 500) taught at the University of South Carolina. Subsequently, the Field Geology classes of Spring 1977 and 1978 participated in the project. The students in these classes were a tremendous help in the execution of this research. They suggested fresh interpretations and challenged us constantly to re-evaluate our hypotheses. They helped define map units, located contacts, discovered new lithologies and structural elements. We truly appreciate their efforts and enthusiasm.

Spring 1976	**Spring 1977**	**Spring 1978**
Jim Adler	Jacyn Adamski	Cintia Emery
Dave Amick	Deanna Bultz	Iris Gatchell
Stormy Attaway	Linda Frame	Glemmie Haimes
Rick Boozer	Jeannie Freeman	Mark Holmes
Chuck Burgin	Helen Mary Johnson	Rick Jolley
Drew Chaplin	Joe Lewis	Ron Jones
Mimi Fleischmann	Alex Moss	Kathi Lee
Boyd Holt	Tom Nichols	Robert Logan
Alan Levander	David Simpson	Willie Lynch
Steve Shirley	Anna Wieckowski	Nancy Searle
Phil Vehorn	Marc Whisenant	Mary Tisdale
Jerry Weisenfluh (T.A.)	Mike Simpson (T.A.)	Rip Van Pelt
		Mark Williams
		Ollie Costello (T.A.)
		Harmon Maher (T.A.)

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FIELD TRI P ITINERARY — ROAD LOG FOR SATURDAY, OCTOBER 7, 1978

NOTE: All field trip stops are on the following U.S.G.S. quadrangles: Batesburg, Emory, and Irmo, South Carolina.

Distance between points	Cumulative distance (miles)
0.0	0.0 The road log begins in Batesburg, South Carolina, at the intersection of South Carolina 23 and 391. Batesburg is situated on a ridge capped with Coastal Plain sediments; rocks of the Piedmont are extensively exposed north of the town but also occur south of town in erosional windows along the major creeks. Go north on Highway 391.
0.2	0.2 Bear left at Line St. at the "Y" intersection (Henry's Five Points Grocery and Gulf Station).
0.7	0.9 Lexington County/Saluda County Line.
0.1	1.0 The approximate boundary between the Coastal Plain deposits and the crystalline rocks of the Piedmont province.
0.2	1.2 **STOP 1:** At this locality we are approximately 1.4 km (0.87 mi.) south of the Modoc fault zone in a terrane of granitic orthogneisses which generally characterize the northern flank of the Kiokee belt in the Batesburg and Emory quadrangles. In the pasture west of the road, we have mapped an interdigitated contact between lineated granitic gneiss and augen granitic gneiss. As you will observe, this boundary is quite distinctive, and we have traced it across both the Batesburg and Emory quadrangles. An exceptional exposure of the contact occurs immediately south of the feed shed, and this is a good place to begin your study of these exposures.

The contact between the lineated gneiss and the augen gneiss is sharp, but lensoidal masses of lineated gneiss (xenoliths?) Are found within the augen gneiss. Also note that the lineated gneiss is usually leucocratic

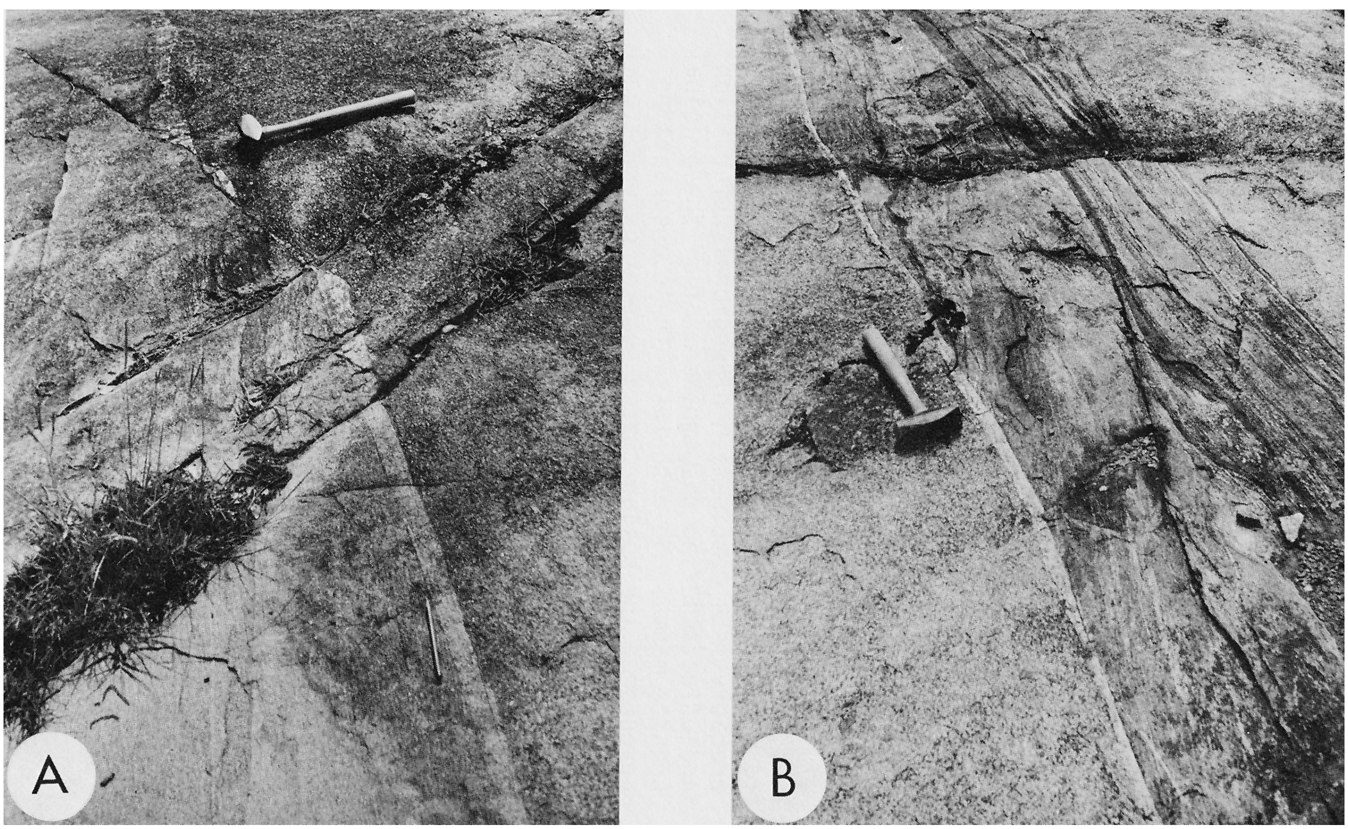


Figure 16. STOP 1— Orthogneisses of the Kiokee belt. A, Sharp contact between fine- to medium-grained granitic gneiss (on left) and granitic augen gneiss (on right). The pencil (lower right) is parallel to the trace of foliation in the gneisses which transects the contact at a low-angle. Also, there is a small fault (upper left) trending approximately N43E that displaces the contact. Finally, note that the fine- to medium-grained granitic gneiss is unusually leucocratic at the contact. B, Large xenolith of "granitized" paragneiss in the granitic augen gneiss. Note that the fabric in the paragneiss xenolith is truncated at its margin, but the foliation in the augen gneiss and the border of the xenolith are subparallel.

immediately at the contact. Furthermore, if you trace the penetrative fabric of the lineated gneiss, you will note that it cuts the contact at an oblique angle and continues into the augen gneiss (Fig. 16A). We believe that the contact is an original intrusive boundary between texturally distinct granitoids. Subsequently, this contact acted as a passive boundary during the Late Paleozoic deformation and amphibolite facies metamorphism which characterized the Kiokee belt. The possible xenoliths of lineated gneiss in the augen gneiss suggest that the latter is younger. Perhaps the lineated gneiss was a marginal phase of a composite pluton, while the protolith of the augen gneiss was a porphyritic core phase. Detailed geochemical comparisons are needed to test this hypothesis.

Another very prominent feature of this exposure is a large "granitized" xenolith of paragneiss within the augen gneiss (Fig. 16B). Several smaller paragneiss xenoliths are also present. The paragneiss is presumably a slab of the country rock into which the original granitic magmas were emplaced. Apparently these rocks were strongly deformed prior to the Late Paleozoic event that deformed the granite, for foliation and compositional layering of the xenolith are truncated at its margin. However, the foliation of the augen gneiss (regional S_2) and the margin of the xenolith are subparallel. The age of deformation preserved in the xenolith is uncertain, for it probably is a combination of regional deformation and effects during the emplacement of the original granite magma. Nevertheless, these observations reinforce the notion that a complex deformational history is recorded in many rock units of the area.

Continue north on county road S-41-150 (Line St.).

0.5 1.7 Exposures of mylonitic augen gneiss on the right near farm building.

0.25 1.95 Cross West Creek and the approximate trace of the Modoc fault.

0.05 2.0 **STOP 2:** We are immediately north of the mapped trace of the brittle Modoc fault, the boundary between the Carolina slate belt on the northwest and the Kiokee belt on the southeast. This low, saprolitic exposure is at first glance quite undistinctive, but a careful perusal of it reveals one of the clearest examples of the progressive development of "button schist" in the eastern Piedmont of South Carolina.

If you begin at the northern end of the exposure (on either side of the road), you will see that the lithology is a phyllite (metamudstone) with one penetrative cleavage (S_1). As you walk south (toward West Creek and the trace of the Modoc fault)m a second cleavage oriented approximately east-west becomes progressively conspicuous. This crenulation cleavage (S_f) eventually is so intense and penetrative that the fine-grained schist upon weathering cleaves into button-like fragments.

The development of "button schist" in this metapelitic unit of the Carolina slate belt is localized near the boundary with the Kiokee terrane. Therefore, to a first approximation, this texture can be used to help delineate the brittle Modoc fault. However, our early speculation that the crenulation cleavage (S_f) is fault-related (Snoke and others, 1977) seems too simplistic. This east-west cleavage (S_f) is unquestionably most prominent near the boundary between the belts; however, we have found identical cleavages both in orientation and style within the interior of both belts. Therefore, we now believe the S_f is a structural element that developed after the main phase of metamorphism (post-D_2 and perhaps D_3) but pre-brittle faulting. It may be an element that reflects the diachronistic transition from ductile to brittle behavior inferred for the Modoc zone.

Continue north on county road S-41-150.

1.0 3.0 Road to Shady Grove cemetery.

0.4 3.4 Intersection with county road S-41-189. Continue on S-41-150.

0.4 3.5 Intersection with county road S-41-26. Turn right.

1.55 5.05 Wesley Chapel on the right.

0.05 5.1 Turn left onto dirt road that crosses the pasture and follow this track always bearing to the right.

1.0 6.1 **STOP 3:** At this locality, megacrystic biotite granite, typical of much of the Clouds Creek pluton, is well-exposed as a large "flat rock" pavement. The granite is massive and unfoliated and consists chiefly of quartz, K-feldspar, plagioclase, and biotite. Accessory minerals include sphene, apatite, zircon, and opaque oxides. Common alteration minerals are white mica, chlorite, epidote, and opaque oxides.

Two aplite dikes are expose in the bedrock pavement, on at the upper end of the exposure (east end) and another at the lower end (west end). The aplite dikes are lens-shaped in that they taper to zero along strike. The maximum thickness of either dike is approximately 11 cm. The upper dike trends N20E and dips moderately to the southeast; the lower dike trends N50W and is subvertical.

Two types of xenoliths have been recognized in the exposure: 1) metasedimentary country rock, hornfelsic but often with compositional layering and 2)

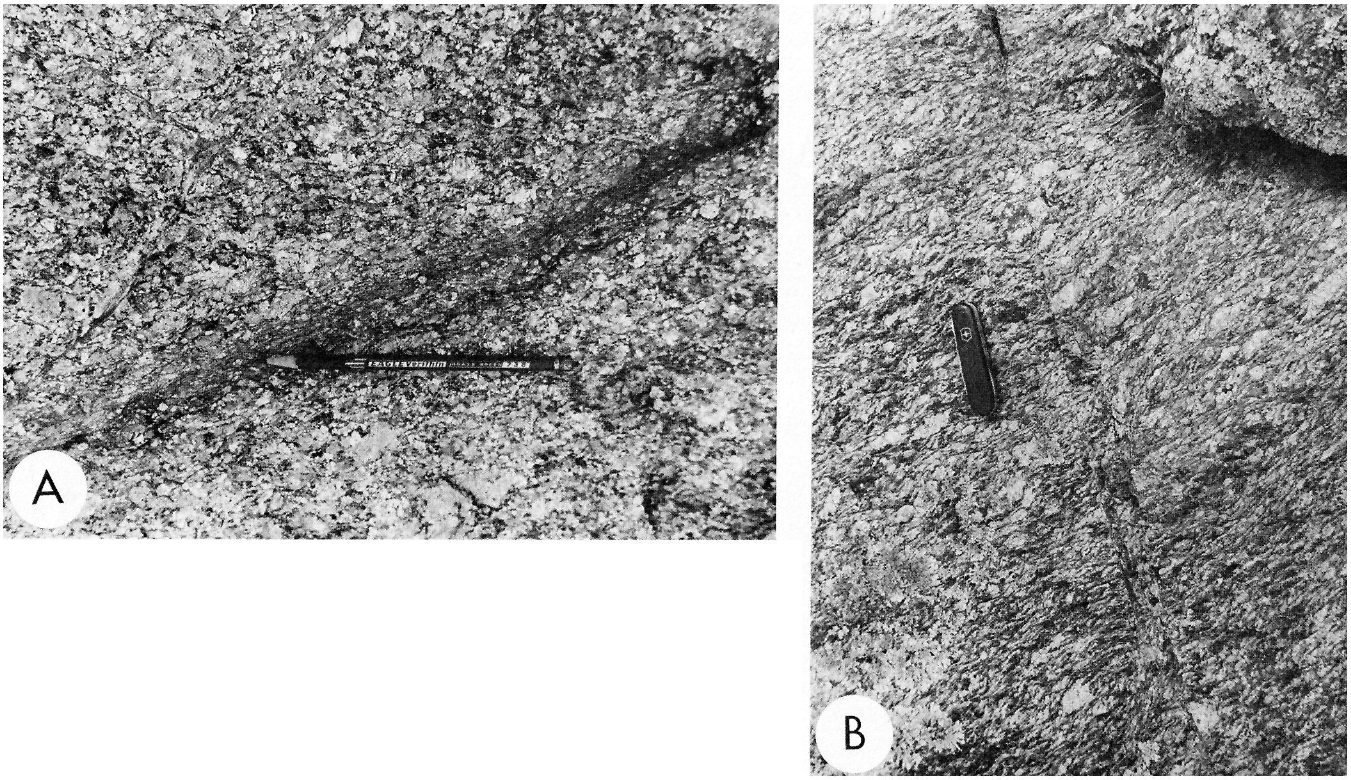


Figure 17 - A. The pencil is oriented subparallel to the protoclastic foliation in the gneissic phase of the Clouds Creek granite. The point of the pencil is on a ductile shear defined by a thin seam of mylonite. STOP 4--Moores Creek. B. Minor brittle fault (N15E 75SE) transecting the protoclastic foliation of the gneissic phase of the Clouds Creek granite. STOP 4— Moores Creek.

biotite quartz diorite porphyry (cognate xenolith). The exposure is about 0.2 km from the northwest contact of the pluton and the country rock xenoliths perhaps attest to the role of stoping in the emplacement history of the pluton. We interpret the cognate xenoliths to be fragmented early dikes or sills that were incorporated into the magma during the final rise and emplacement of the pluton.

Finally, the origin of the "flat rock" and development of incipient soil on its surface are also fascinating aspects of this exposure. Note that weathering pits in all stages of development can be observed: incipient bedrock depressions to mature pits along with a well-developed soil and flora. Many of the pits are along subvertical joint traces, but there are many exceptions, for example, near the middle of the "flat rock" there is a pit developed with a xenolith in its center. This exposure is nearly litter-free so please be careful to take all your trash with you.

1.0 7.1 Retrace our route out of the pasture. Turn right and go south on county road S-41-26.

1.55 8.65 Intersection with county road S-41-150. Turn left.

0.15 8.8 Intersection with county road S-41-189. Turn right.

1.25 10.05 Holston Crossroads. Turn left onto U.S. 178.

0.05 10.1 Turn immediately right onto county road S-41-57 (i.e., the road to West Creek Church).

0.45 10.55 Bear right, stay on the paved road.

0.30 10.85 West Creek Church. Stay on county road S-41-57.

0.45 11.30 Cross Dye Creek.

0.55 11.85 **STOP 4:** In the pastures, both north and south of the road, on the east side of Moores Creek are numerous small exposures of foliated Clouds Creek granite. These exposures are approximately 0.3 km north of the mapped trace of the Modoc fault. The foliation in the deformed granite is defined by strongly oriented biotite, flattened lensoidal quartz, and streamlined augen (porphyroclasts) of K-feldspar. Locally the long dimension of xenoliths commonly parallels the foliation. These exposures of deformed Clouds Creek granite are part of a belt of foliated granite which can be traced from Hart Spring Church near the southwestern tail of the pluton to West Creek along the eastern margin (Plate II). At its maximum width, the belt of foliated Clouds Creek granite is over

2 km across strike. We interpret the foliation to have developed by igneous flow of a nearly solidified granitic magma (i.e., a protoclastic deformation).

In many exposures of the deformed Clouds Creek granite at this locality, a second foliation trending approximately east-west transects the prominent protoclastic fabric (Fig. 4B). This second S-surface is analogous to the crenulation cleavage so well-developed at STOP 2 in the fine-grained pelitic schist of the Carolina slate belt. Both of these structures share a common orientation and are localized near the Modoc fault.

In the pasture south of the road, even younger deformation features are displayed in the Clouds Creek granite. At several exposures ductile shears, trending approximately N50E, transect both of the previously described S-surfaces. These ductile shears are defined by a narrow seam of mylonite (Fig. 17A). A still younger deformation structure in the granite are small brittle faults which commonly trend N15E (Fig. 17B).

In summary, at this locality, we have recognized four distinct deformation features in the Clouds Creek granite (oldest to youngest):

1. protoclastic foliation,

2. secondary E-W foliation,

3. ductile shears,

4. brittle microfaults.

Continue west on county road S-41-57.

0.2 12.05 Turn right on unlabeled dirt road.

0.7 12.75 Turn right at T-intersection (S-41-499).

0.15 12.90 Turn left at the stop sign (S-41-188).

1.45 14.35 Turn left onto U.S. 178 and proceed to the northwest.

0.4 14.75 Cross Clouds Creek.

1.0 15.75 Turn left onto county road S-41-25 (opposite Anderson grocery).

1.2 16.95 Bridge over Jacobs Branch Creek.

1.4 18.35 **STOP 5:** This roadcut exposure is an exceptionally fresh outcrop of the ripple-laminated, quartz metasiltstone of the Richtex Formation. The mineral assemblage is quartz-white-mica-epidote-chlorite-albite-opaque oxides-apatite, and therefore, indicates lowest greenschist facies. Texturally the rocks at this exposure are phyllitic with S_1 parallel to S_0. A younger cleavage, S_3, is axial planar to several small, steeply plunging folds in the outcrop (Fig. 13). These folds are characteristic of the F_3 fold system whose earmarks are passive style with penetrative cleavage, north-northeast trend, steeply plunging fold axes, and dextral vergence.

At the east end of the exposure original bedding characteristics including ripple-laminations are well-preserved. Under the microscope, these laminations are often partially defined by concentrations of opaque oxides (original heavy mineral laminae?) As well as phyllosilicate-rich folia. The sedimentary structures, lithologic composition, and facies relations with other rock units suggest that this lithology was deposited in very shallow water, probably a tidal flat environment.

The buses will turn around here, and we will retrace our route back to U.S. 178 and follow it to Batesburg, South Carolina. At Batesburg, we will go east-northeast along Highway 23 until it intersects U.S. 1, which we will follow for a short distance until the intersection with S.C. 6. We will go north on S.C. 6 until the intersection with S.C. 60 where we will turn to the right and proceed to the east toward Irmo, South Carolina. The total distance from STOP 5 to Irmo is approximately 35.5 miles.

35.5 53.85 This leg of the field trip begins in Irmo, South Carolina at the intersection of Newberry Ave. (S.C. 60) and Woodrow St.

Go south on Woodrow St.

1.1 54.95 Turn right at Wescot Road.

0.35 55.30 Turn right at Nursery Hill Road.

0.35 55.65 Cross bridge across Koon Branch Creek.

0.05 55.70 Turn left into Murraywood at Willow Creek Drive.

0.10 55.80 Turn left at Crossbrook Road.

0.15 55.95 Turn left at Holly Spring Road.

0.10 56.05 Turn right at Cedarbrook Drive.

0.25 56.30 Turn left at Cedarbrook Court.

0.10 56.40 Boulders on left are part of a small granite stock intrusive into amphibolite facies rocks of the Kiokee belt. These granitic rocks are weakly foliated. At STOP 6 we will examine dikes which are probably cogenetic with this stock.

0.15 56.55 **STOP 6:** (Park at the dead end of Cedarbrook Court and walk east along the railroad tracks until large cut is reached.)

This railroad cut consists chiefly of subvertical, flaggy quartz-rich metasedimentary rocks. However, at the west end rather massive biotite amphibolite is present, and at scattered localities throughout the exposure gneissic granite intrusions are common. The protolith of the quart-rich metasedimentary rocks apparently was an interlayered sequence of impure quartz siltstone and sandstone with local pelitic intercolations. Ripple laminations are common relict sedimentary features in the metasiltstone. We believe that these metasediments are probably equivalent at least as far as lithofacies to the chlorite grade quartz metasiltstone exposed at STOP 5. However, the rocks in the railroad cut contain almandine garnet and have at least undergone lower grade amphibolite facies regional metamorphism. If the garnet isograd is accepted as the boundary between the Kiokee belt and the Carolina slate belt, these rocks are within the Kiokee terrane.

Multiple lineations are evident on the slabby foliation surfaces of the metasedimentary rocks. We have recognized at least three distinct lineations (two plunging to the northeast and a third to the southwest). The steeply plunging northeast-trending lineation is probably a L_2 feature, but the other structures do not easily correlate with our regional structural chronology.

The gneissic granite forms dike-like intrusions throughout the quartz-rich metasedimentary rocks, and granitic net-veins are common in the biotite amphibolite at the west end of the cut. The gneissic granite is commonly strongly foliated, and this fabric appears analogous to the prominent foliation in the adjacent metasediments. These metagranites along with several other localities define a north-northeast-trending zone of small intrusions localized on the southeast flank of the Irmo structure (Heron and Johnson, 1958). Although at present, no geochronologic data are available for these rocks, they are similar to other orthogneisses in the Kiokee belt which have yielded Carboniferous igneous ages.

Despite the deformation of these granitic rocks, some original igneous characteristics are still preserved. At several places in the exposure xenoliths are within the gneissic granite. At a few localities, one can find apparent original igneous contacts which truncate S_0 at an oblique angle.

We will retrace our route back to Nursery Hill Road and return to Irmo. We will go east on S.C. 60 until we intersect I-26 which we will tale toward Columbia. We will stay on I-26 until we reach the Holiday Inn-Northwest in West Columbia.

END OF FIRST DAY.

FIELD TRIP ITINERARY--ROAD LOG FOR SUNDAY, OCTOBER 8, 1978

Distance between points	Cumulative distance (miles)	
0.00	0.00	The road log for the second day begins in Irmo, South Carolina, at the intersection of Newberry Avenue (S.C. 60) and Woodrow Street. Go west on Newberry Avenue towards Lake Murray.
0.45	0.45	Mt. Olive Church on the left. Turn left onto Nursery Road (S-32-356).
0.75	1.20	Coldstream Country Club. Turn right into Lancer Drive and go through the gates.
0.05	1.25	Turn left at White Falls Drive.
0.65	1.90	T-intersection with Ripley Station Road. Turn left.
0.05	1.95	**STOP 7:** We are located on the southeast flank of the Irmo structure and well within the garnet isograd. Consequently, the rocks exposed in Rawls Creek at this locality are part of the Kiokee belt according to our definition.

The metamorphic rocks along the creek are quite heterogeneous and vary from amphibolite to hornblende-biotite schist to biotite paragneiss. Subordinate leucocratic mica gneiss is also present. The assortment of lithologies probably reflects an original heterogeneous sequence of volcaniclastic rocks, perhaps chiefly epiclastic deposits. The protolith of the leucocratic mica gneiss may have been felsic pyroclastic rocks although an epiclastic origin also cannot be excluded. Pegmatite dikes intrude this sequence and are commonly folded with the surrounding metamorphic rocks (Fig. 18C).

The metamorphic rocks along the creek are multiply-deformed in that many of the conspicuous folds clearly deform an earlier foliation (Fig. 18A and 18B). Based on orientation and style, we believe that these folds are a late stage manifestation of our D_2 deformation system. This deformation phase was a protracted event; its most intense effects were amphibolite facies regional metamorphism and the deformation of the Hercynian granites of the Kiokee belt. Our interpretation of the folds of this locality as late F_2 structures is analogous to the synchronous refolding concept developed by Wynne-Edwards (1963). The prominent foliation (S_2) was developed during the peak of regional metamorphism; as temperature waned but deformation persisted, this early foliation was refolded by late metamorphic structures. We designate these late kinematic folds of the D_2 system as F_2* folds so as to distinguish them from folds

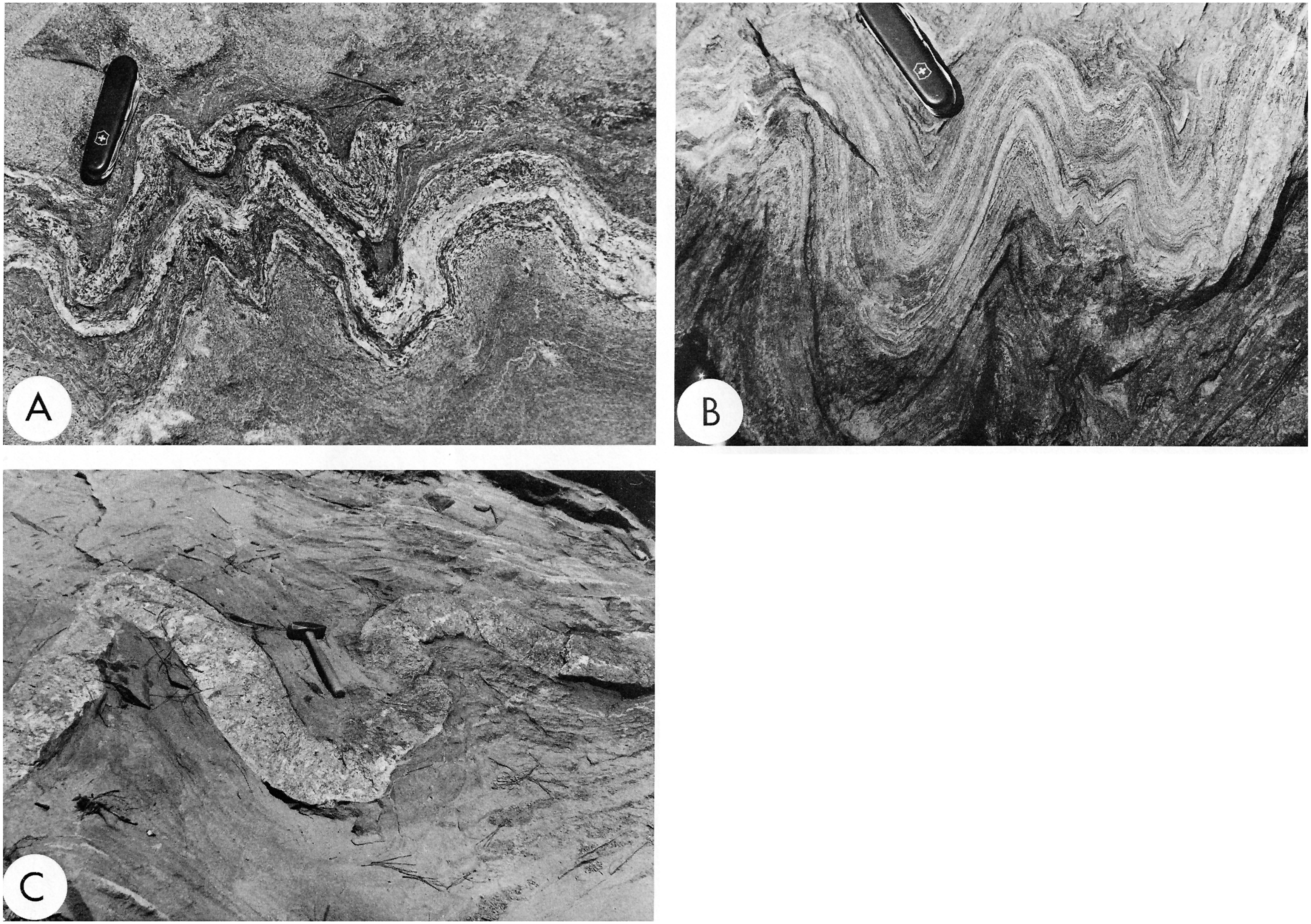
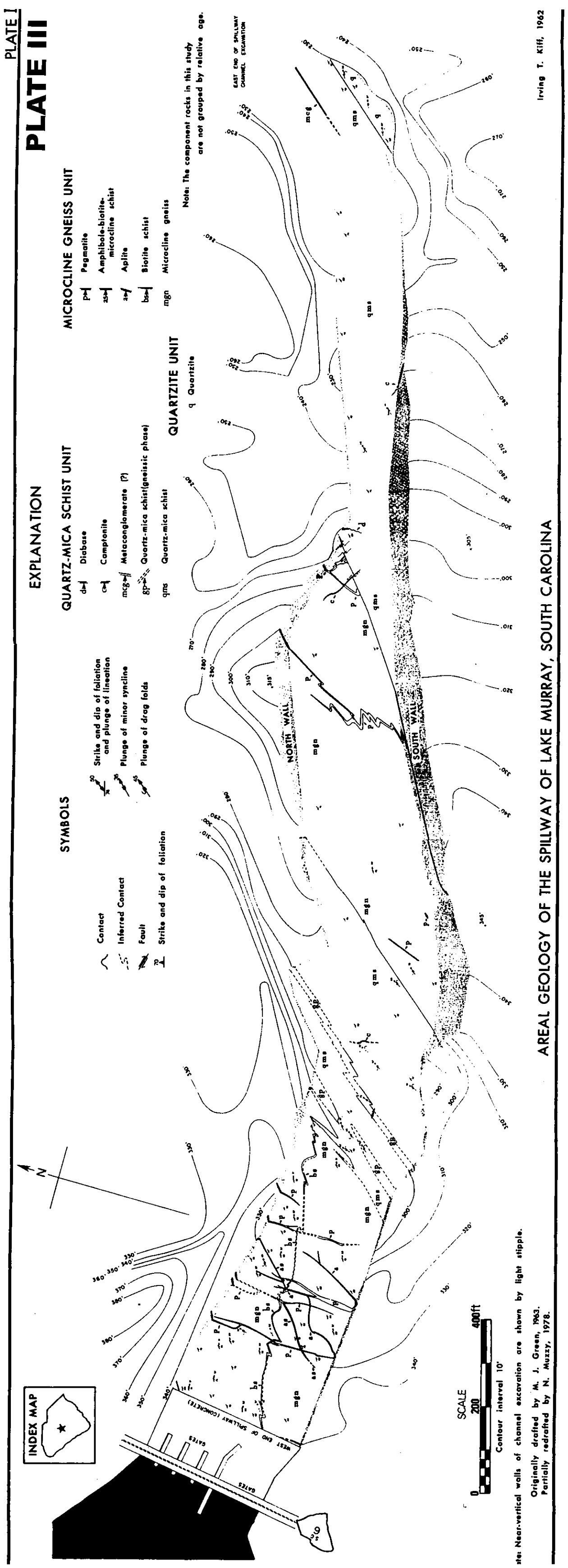


Figure 18. F_2* folds along Rawls Creek, Irmo 7½ minute quadrangle--STOP 7. A and B, Flexural -flow folds in hornblende paragneiss (intermediate amphibolite facies) which deform an earlier penetrative foliation as well as compositional layering. C, Pegmatite dike in biotite (± garnet) paragneiss folded by F_2* folds.



formed during the synkinematic stage of the deformation.

A particularly interesting exercise is to compare the style of F_2* folds as they vary with lithology. Immediately south of the bridge over Rawls Creek, foliation in mafic schist has been partially transposed by a crenulation cleavage (S_2*). The axial surfaces of the adjacent F_2* folds in more competent rock layers are subparallel to this cleavage, but these folds lack an analogous penetrative S-surface. Likewise, note the character of F_2* folds which deform the pegmatite dikes and how layer thickness influences fold wavelength. These relations are spectacularly exposed several hundred yards south of the bridge at the far end of the exposure. Finally, north of the bridge are several curious ellipsoidal features that perhaps are "eye folds".

An alternate interpretation would be boudinage. We're certain that these structures will stimulate debate!

The buses will turn around, and we will retrace our route back to Nursery Road.

0.05 2.00 Turn right at White Falls Drive.

0.65 2.65 Turn right at Lancer Drive and exit Coldstream Country Club.

2.70 Intersection with Nursery Road. Turn left.

0.75 3.45 Intersection with Newberry Avenue (S.C. 60). Turn left and go west toward Lake Murray.

2.10 5.55 Junction with S.C. 6. Turn right. Go north toward Ballentine.

2.75 8.30 Lexington County- Richland County line.

0.6 8.90 Turn left at the Salem United Methodist Church sign.

0.80 9.70 Turn left at Montclair Drive.

0.30 10.00 **STOP 8:** The development of folds and cleavages related to the several deformation episodes are spectacularly displayed in two large outcrops of the Richtex Formation along the shore of Lake Murray.

At this locality the Richtex Formation consists predominantly of evenly bedded mudstone, which grades locally into ripple-laminated siltstone. There are also several boudinaged quartzo-feldspathic layers, up to a meter thick, that may be felsic tuff beds or felsic hypabyssal sills.

In most places bedding (S_0) and S_1 slaty cleavage are parallel (average attitude N60E60NW). At the western end of the outcrop S_0 and S_1 are folded into several tight F_2 folds plunging about 20° to the N50E. In the slate belt in this region, F_2 folds are characterized by the absence of an axial surface cleavage and by axial surfaces which strike parallel to the regional structural trend. At least one F_3 fold plunging 25° to the N38°E can be found at the west end of the outcrop. F_3 folds are characteristically dextral in plan view, have an incipient S_3 axial surface cleavage trending more northerly than the regional structural trend. The S_f cleavage (N85°W vert) is also moderately well-developed in these outcrops. In some places S_f seems to be a spaced cleavage, and in other places it is a crenulation cleavage. If the water level of the lake is low enough we will be able to see a small brittle fault, parallel to S_f, which has a right lateral strike separation of about two meters.

In this series of outcrops F_2 folds and the S_f cleavage are unusually well-developed, and we attribute this to the proximity of an inferred *Abscherungszone* along the boundary between the slate and Kiokee belts, located about 500-1000 meters to the south beneath the waters of Lake Murray.

0.30 10.30 Intersection of Montclair Drive and “Salem Church” road. Turn right.

0.80 11.10 Intersection with S.C. 6. Turn right and go south toward Lake Murray.

0.60 11.70 Richland County - Lexington County line.

3.40 15.10 Intersection of S.C. 6 and 60. Turn right onto S.C. 60 and go toward Lake Murray.

1.8 16.90 Turn left into small parking lot.

STOP 9: The Lake Murray spillway is a geologic “showpiece” unrivaled in the eastern Piedmont of South Carolina for the study of multiple deformations. The spillway was excavated during the construction of the Dreher Shoals dam (~1929) as an emergency outlet for Lake Murray. The spillway channel trends roughly east-west to east-northeast for approximately 3300 feet and then turns northward continuing for another 3000 feet before it intersects the Saluda River (Kiff, 1963). The spillway and the area surrounding it have been the subject of many geologic investigations (Heron and Johnson, 1958; Kiff, 1963; Tewhey, 1968; Carr, this volume). However, the spillway is one of those marvelous exposures where one can always find a new aspect no matter how many times he has previously visited it.

The most detailed geologic map of the spillway was prepared by Irving T. Kiff, who has generously allowed us to reproduce it in this guidebook (Plate III). The main units exposed in the spillway are the Lake Murray gneiss (the so-called western and eastern gneiss units) and a heterogeneous schist sequence which in part is macroscopically infolded with the gneiss.

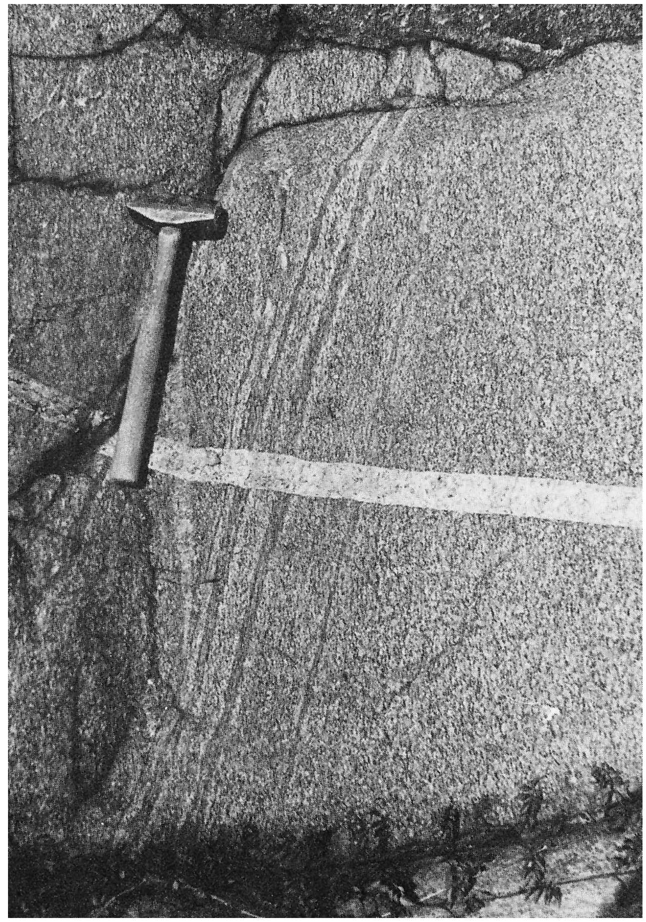


Figure 19. Thin pegmatite dike cutting the prominent foliation (S_2) in the Lake Murray gneiss. Note the curious layered structures within the gneiss. STOP 9--Lake Murray spillway.

The origin of the gneiss has been controversial over the years, but many recent workers including ourselves as well as Kish (personal communication, 1978) and Carr (this volume) believe it is a plutonic orthogneiss (i.e. a metagranite). Its relative homogeneity (at least compared to the obvious metasedimentary schist sequence) and composition argue for a plutonic igneous origin. Subtler characteristics such as major and minor geochemical data, zircon morphology, isotopic data and ghost xenoliths also support the metagranite origin (S.A. Kish, unpublished data). The common association of aplite dikes (some unquestionably pre-metamorphic) and pegmatites are ancillary evidence in accord with a plutonic granitic origin. Among the relict features in the gneiss, distinctive, often branching, layered structures are com-

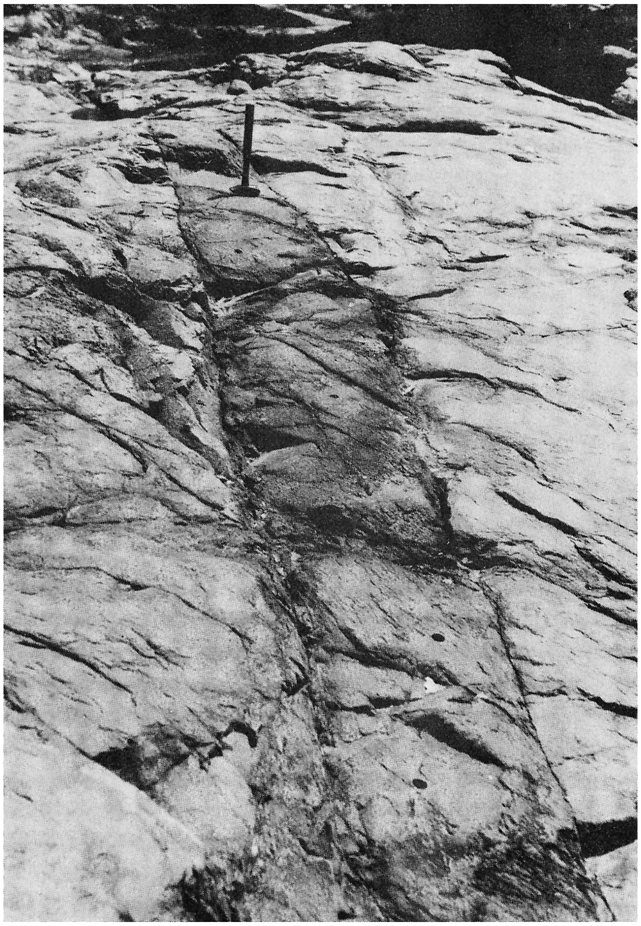


Figure 20. Mafic dike (Kiff's as= amphibole-biotite-microcline schist) within the Lake Murray gneiss. The trend of the dike and the foliation in the gneiss are subparallel. STOP 9—Lake Murray spillway.

mon (Fig. 19). The origin of these structures is puzzling; they may be igneous schieren but another interpretation is that they are pre-metamorphic hydrothermally altered fractures. Perhaps you can devise additional explanations?

The so-called schist unit is amazingly heterogeneous and includes metapelite, quartzo-feldspathic gneiss, metaquartzite, and amphibolite as well as several transitional lithologies. The schist invariably contains almandine garnet porphyroblasts (some with beautifully preserved rotation structures), but aluminous layers also contain coexisting staurolite and kyanite. These metamorphic index minerals suggest intermediate amphibolite facies conditions.

Several mafic dikes intrude the Lake Murray gneiss as well as the schist unit. The oldest dike, mapped by Kiff as "biotite schist" within the western gneiss exposure, is complexly deformed. A younger mafic dike (Fig. 20--*as* = amphibole-biotite-microcline schist) perhaps intruded the gneiss during the late synkinematic stage of the deformation, for its trend is subparallel to the prominent foliation in the gneiss. Younger mafic dikes include lamprophyre and diabase. The diabase is almost certainly Mesozoic (Triassic-Jurassic), but the lamprophyre is undated and could be older (i.e., Permian?).

The structural chronology of the spillway has been summarized by Carr (this volume), therefore, little additional information is necessary. However, perhaps it is appropriate to emphasize that our D_2 deformation phase (the synmetamorphic phase of the Hercynian orogeny of the eastern Piedmont) would include Carr's D_1 and many of her D_2 structural elements. We, therefore, believe that the penetrative foliation in the gneiss is regional S_2, and many of the obvious folds in the gneiss and schist units are F_2* or F_3 folds depending on orientation and style (see Fig. 21 for examples of deformation style in the heterogeneous schist unit). We also note that Carr's D_4 features are similar to S_f structures at STOPS 2 and 4.

The trip is officially over after the examination of the superb exposures in the spillway. Buses will shuttle field trip participants back to the Holiday Inn-Northwest. The approximate distance to the Holiday Inn is 15.2 miles.

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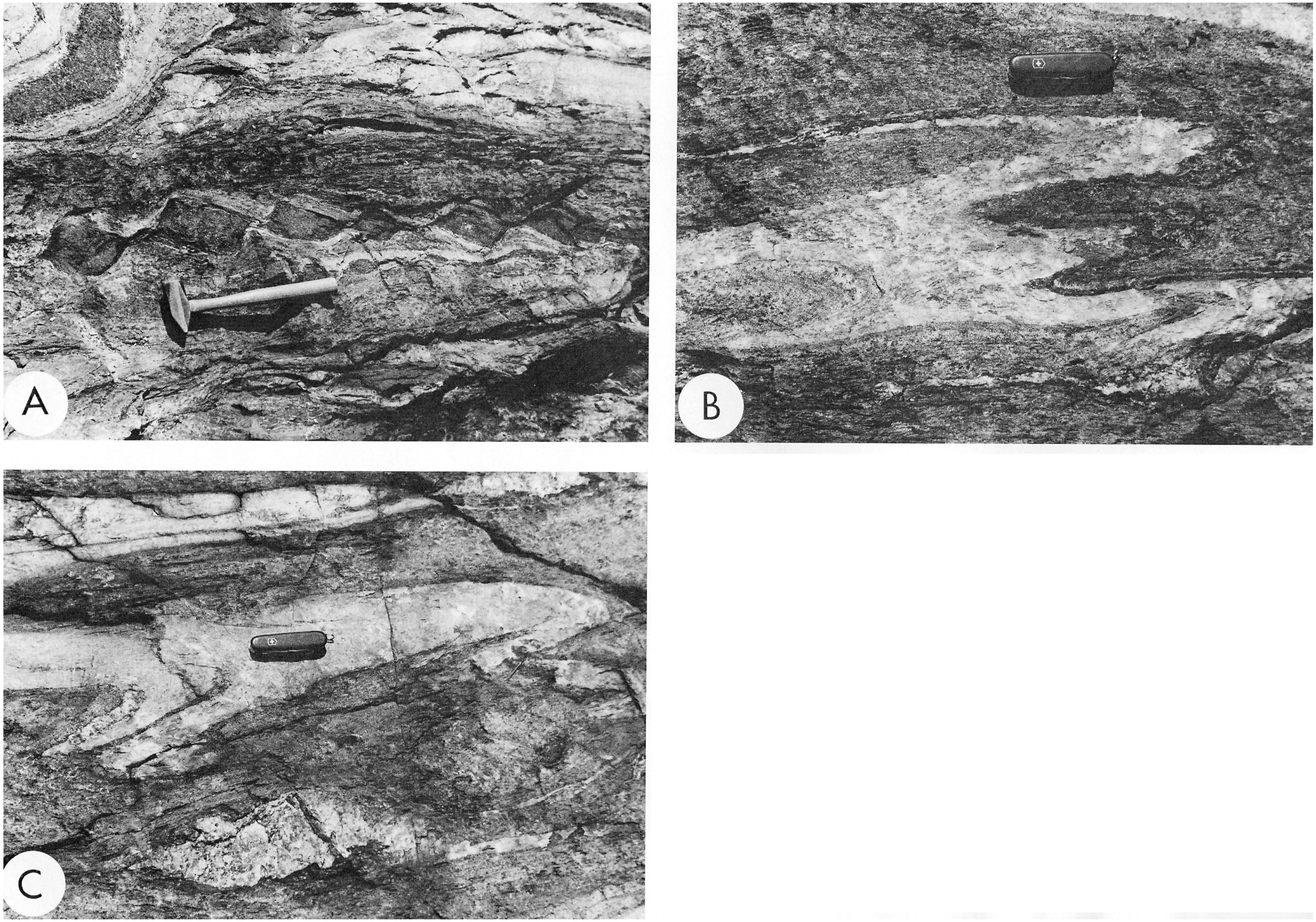

Figure 21. Deformation styles in the "schist" unit, Lake Murray spillway. A, Boudinage of an amphibolite layer within the pelitic and quartzo-feldspathic schist. B and C, Complex folding of quartzo-feldspathic schist in garnetiferous pelitic schist. Note the local development of hook-like structures suggesting a complex interference pattern (refolded folds?).

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