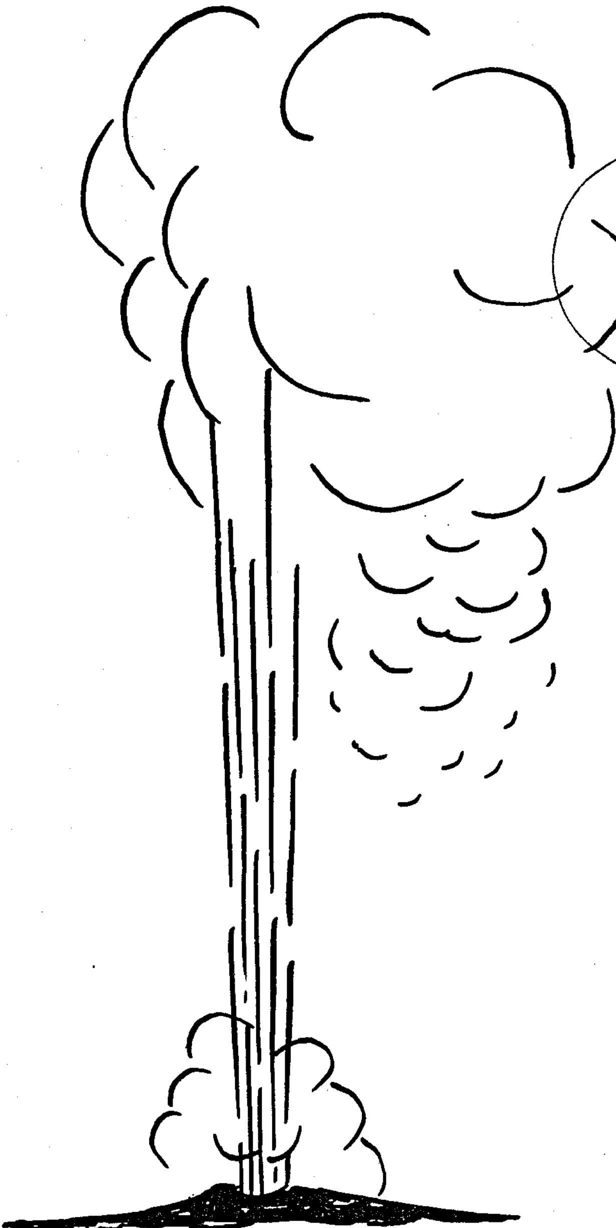
MASTER

ORO-5104-1



SOUTH CAROLINA GEOTHERMAL PROGRAM FINAL REPORT

Tectogenesis of the Rocks Surrounding the Winnsboro Intrusive Complex

Reconnaissance and Petrography of the Pageland Pluton

By
W. Clifford Bourland
Stewart S. Farrar

Work Performed Under Contract No. EY-76-S-05-5104

Division of Geology
South Carolina State Development Board
Columbia, South Carolina

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

NOTICE

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $5.25
Microfiche $3.00

ORO-5104-1
Distribution Category UC-66a

TECTOGENESIS OF THE ROCKS SURROUNDING THE WINNSBORO INTRUSIVE COMPLEX

by

W. Clifford Bourland and Stewart S. Farrar

* * * *

RECONNAISSANCE AND PETROGRAPHY OF THE PAGELAND PLUTON

by

W. C. Bourland

* * * *

Final composite report of work performed under U. S. Department of Energy Contract EY-76-S-05-5104 by Division of Geology, South Carolina State Development Board, Harbison Forest Road, Columbia, South Carolina 29210

1978

CONTENTS

TECTOGENESIS OF THE ROCKS SURROUNDING THE WINNSBORO COMPLEX

Page

ABSTRACT v

INTRODUCTION 1

STRATIGRAPHY 2
Carolina Slate Belt Lithologies 2
Charlotte Belt Lithologies 13

DEFORMATIONAL FEATURES 19
Structural Elements of D_1. 23
Structural Elements of D_2. 23
Structural Elements of D_3. 26
Structural Elements of D_4. 27
Structural Elements of D_5 and D_6 27
Structural Elements of D_7. 29
Cataclastic Deformation 29

REGIONAL METAMORPHISM (M_1) 33

CONCLUSION 35

REFERENCES CITED 37

* * * *

RECONNAISSANCE AND PETROGRAPHY OF THE PAGELAND PLUTON

INTRODUCTION 41

CAROLINA SLATE BELT LITHOLOGIES SURROUNDING THE PAGELAND PLUTON . 43

STRUCTURE. 44
Folds. 44
Faults 45

PAGELAND GRANITE 46

PETROGRAPHY OF THE PG-1 DRILL CORE FROM THE PAGELAND GRANITE . . 51

SUMMARY 53

REFERENCES CITED 54

FIGURES

TECTOGENESIS OF THE ROCKS SURROUNDING THE WINNSBORO COMPLEX

Page

1. Reconnaissance geologic map of the Carolina slate belt and Charlotte belt between the Winnsboro and Liberty Hill plutons . 3

2. Geologic map of the Carolina slate belt southeast of the Winnsboro intrusive complex 6

2a. Detail of structure and stratigraphy along the Cedar Creek fault within inset of Figure 2. 8

3. Geologic map of the Charlotte belt adjacent to the northern border of the Winnsboro intrusive complex 15

4. Poles and S_1 foliations for Carolina slate belt and Charlotte belt lithologies 24

5. Poles and S_2 foliations, Carolina slate belt and Charlotte belt combined 25

6. Poles to S_1 foliations redistributed on the limbs of the Flint Hill anticlinorium 28

* * * *

TABLE

1. Relationship of deformational, structural and metamorphic elements in the Carolina slate belt and Charlotte belt rocks around the Winnsboro intrusive complex. 20

FIGURES

RECONNAISSANCE AND PETROGRAPHY OF THE PAGELAND PLUTON

Page

1. Geologic map of the Pageland granite and the surrounding Carolina slate belt compiled from Butler and Howell (1977). . 42

2a. Quartz-plagioclase-feldspar diagram for the Pageland coarse-grained monzogranite and metavolcanic pendant 47

2b. Quartz-feldspar color-index diagram for the Pageland granite and metavolcanic pendant 48

3. Quartz-plagioclase-potassium feldspar diagram for Rion, Liberty Hill fine-grained monzogranite, and the metavolcanic pendant in the Pageland pluton. 50

4. Combined lithologic and gamma ray log for Pageland drill hole PG-1 52

ABSTRACT

Major post-tectonic plutons of the easternmost Piedmont in the southern Appalachians have been of primary interest because of their high radiogenic heat production. Such heat production comes from a linear map trend including the Winnsboro, Liberty Hill, Pageland, and Lilesville plutons which parallel the proposed eastern Piedmont Fault system of Hatcher and others (1977). This study, in examining regional versus contact metamorphism and crosscutting relationships between the Winnsboro and Pageland complexes and the major folds and mylonitic zones of this area, provides a relative time framework for the tectonic and plutonic events.

The geometry of the Winnsboro complex has been previously discussed by Farrar and Becker (VPI&SU 5103-1) and Farrar (VPI&SU 5103-4). This study confirms that deformation resulting from the instrusion of the Winnsboro granite is confined to an area defined by the outermost exposed granite of the complex. The steeply, inward dipping conical shape of the complex indicates its relatively small size. The geometry and dimensions of the Winnsboro complex are important in understanding the linear heat production - heat generation relation. Small plutons will have serious edge effects especially if they are much deeper than they are wide. Independent geologic evidence of pluton depth and shape aids in interpreting any systematic geometric control of the linear heat production - heat generation relation.

Whether a pluton is emplaced during or subsequent to the metamorphic maximum is important to understanding any possible mobile behavior of U and Th. Bourland's report on the Winnsboro pluton and Farrar's previous report (VPI&SU 5103-4) demonstrate the presence of a contact aureole. Regional metamorphism in the vicinity of the Winnsboro pluton reached the level of

amphibolite facies with kyanite-sillimanite. By the time of the emplacement of the Winnsboro pluton, conditions had changed so that a contact aureole in the cordierite amphibolite facies with andalusite-sillimanite was produced. Speer (VPI&SU 5103-5) made use of the pressure of emplacement of the Winnsoboro pluton--information obtained from the study of the contact aureole--to demonstrate that the depth of emplacement of the granite plutons of the Southeast have no relation to heat generation as previously suggested. While insufficient data were found for the Pageland in this study for quantitative estimate of the depth of emplacement, the mineral assemblages reported are sufficient to demonstrate a similarity to the Liberty Hill and Lilesville adjacent to it.

TECTOGENESIS OF THE ROCKS SURROUNDING THE WINNSBORO INTRUSIVE COMPLEX

by

W. Clifford Bourland

and

Stewart S. Farrar

INTRODUCTION

On the geologic map of the South Carolina Piedmont and Blue Ridge (Overstreet and Bell, 1965) the Winnsboro complex is depicted as a round granitic mass in the core of a large fold in the Charlotte belt-Carolina slate belt contact. Generally, the Winnsboro complex can be described as having a steep inward dipping conical shape, while the Charlotte belt and Carolina slate belt rocks dip steeply away from the border of the Winnsboro complex. The purpose of this paper is to analyze the structure and geometry of rocks in this fold near the Winnsboro intrusive complex in order to determine what effect the granite had on the structure and metamorphism of the area.

Recent detailed mapping of the Winnsboro plutonic complex has been conducted by Wagener (1966, 1968, 1970, and 1973) and Secor and Wagener (1968). Detailed petrographic analyses of the granite complex have been done by Wagener (1973) and Farrar and Becker (1976). Detailed mapping of the granites that compose the intrusive complex is presented in Farrar and Becker (1977). These recent studies indicate that the Winnsboro complex intruded metamorphosed and multiply deformed units, and subsequently overprinted the units with a cordierite-hornfels contact assemblage.

Lithologic, structural, and metamorphic data presented in this report are the result of mapping two 8.5 km by 5 km areas. The southern map area includes the southern border of the Winnsboro pluton and parts of the Winnsboro Mills, Irmo N.E., and Ridgeway 7.5 minute quadrangles (figure 1). The northern map area extends from the northern border of the Winnsboro complex including parts of the Rion and Lebanon 7.5 minute quadrangles (figure 1). In addition, much of the southwestern and northeastern border of the Winnsboro complex has been mapped in reconnaissance fashion.

STRATIGRAPHY

Carolina Slate Belt Lithologies

The Carolina slate belt within the southern map area (figure 2) has been divided into two map units, A and B. Unit A is a series of interlayered metatuffs and phyllites, which can be distinguished from Unit B by the presence of graphite, either concentrated in layers or disseminated in phyllitic layers of Unit A. Unit B is a series of interlayered metatuffs, phyllites, metasiltstones and metasandstones. Units A and B do not represent formations; rather, they represent the presence or absence of graphite in the map unit. The boundary between the two units could be stratigraphic or structural. The sequence of lithologies in this map area is not necessarily the same as that occurring in adjoining map areas; and therefore, the applicability of Units A and B may be limited. Lateral changes in a layered sequence in volcanic stratigraphy are to be expected.

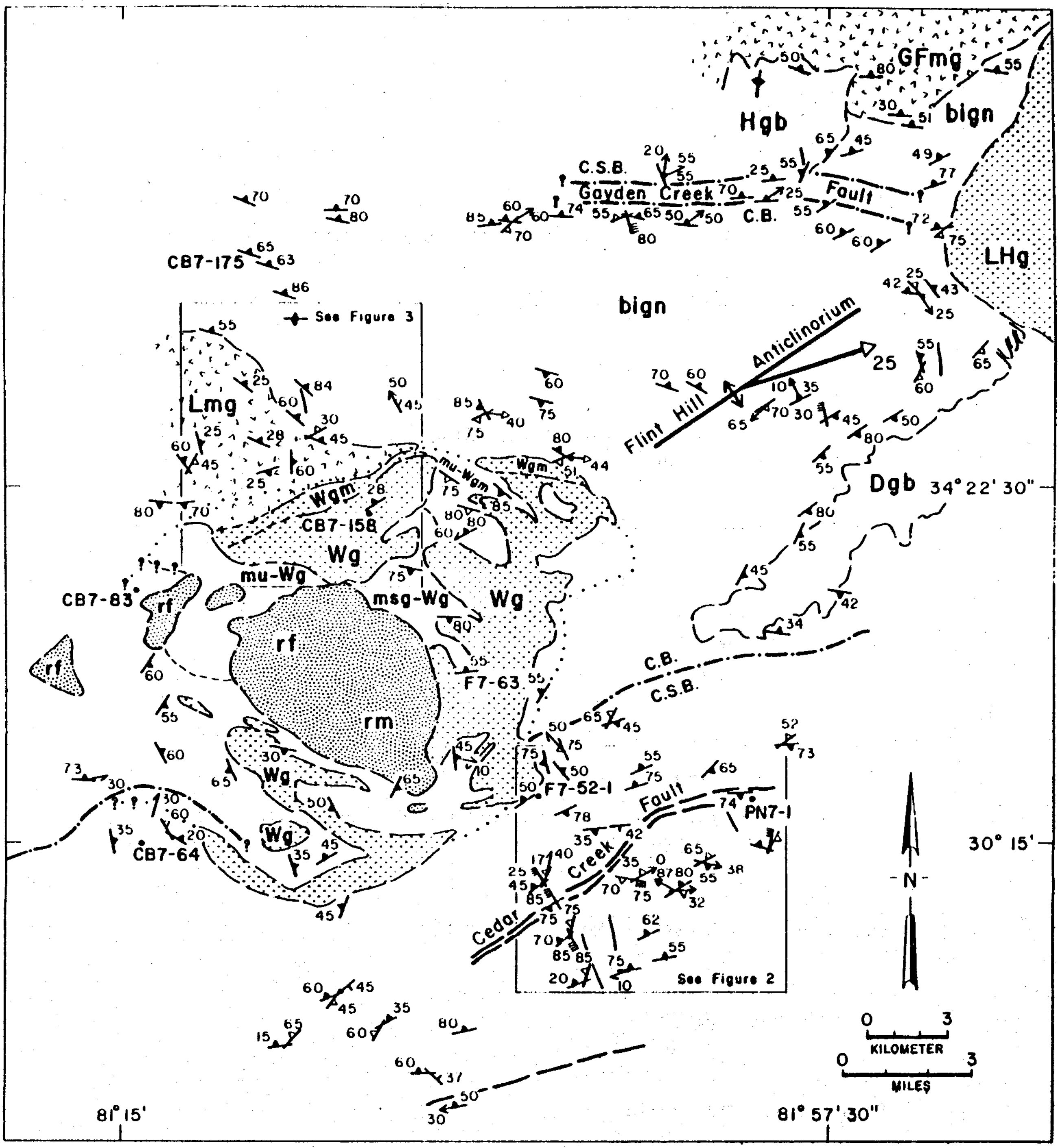


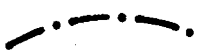
Figure 1. Reconnaissance geologic map of the Carolina slate belt and Charlotte belt between the Winnsboro and Liberty Hill plutons.

EXPLANATION

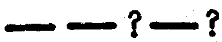
Map Units

	Triassic diabase dike
	Rion Pluton
rf / rm	rf - Fine- to medium-grained biotite monzogranite rm - Medium-grained biotite monzogranite
	Winnsboro Granite
Wg	Wg - Coarse-grained, biotite-hornblende monzogranite, quartz-syenite, and quartz monzonite.
Wgm	Wgm - Medium- to coarse-grained, biotite-hornblende monzogranite
mu-Wgm mu-Wg ms-Wg msg-Wg	Intimate mixtures of small bodies of Winnsboro monzogranite with rock types described by Farrar (1977)
	Liberty Hill Pluton
LHg	LHg - Coarse-grained, biotite-hornblende monzogranite, and quartz monzonite
Dgb	Dutchman's Creek gabbro (McSween, 1972)
Hgb	Hog's Fork metagabbro
GFmg	Great Falls metagranite
Lmg	Lebanon metagranite
bign	Biotite gneiss and amphibole gneiss within the Charlotte belt

Symbols

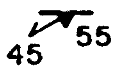


Contact between Carolina slate belt (C.S.B.) greenschist metamorphic belt with sedimentary and volcanic textures and Charlotte belt (C.B.) amphibole metamorphic belt without sedimentary or volcanic textures.

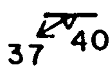


Fault, dashed where inferred, querried where speculative

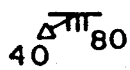
Bedding (S_B)



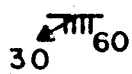
First foliation (S_1) and first generation fold axis (F_1)



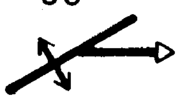
Second foliation (S_2) and second generation fold axis (F_2)



Third foliation (S_3) and third generation fold axis (F_3)



Fourth foliation (S_4) and fourth generation fold axis (F_4)



Flint Hill Anticlinorium third generation fold axial plane with F_3 synoptic axis

CB7-83 Sample locality referred to in the text

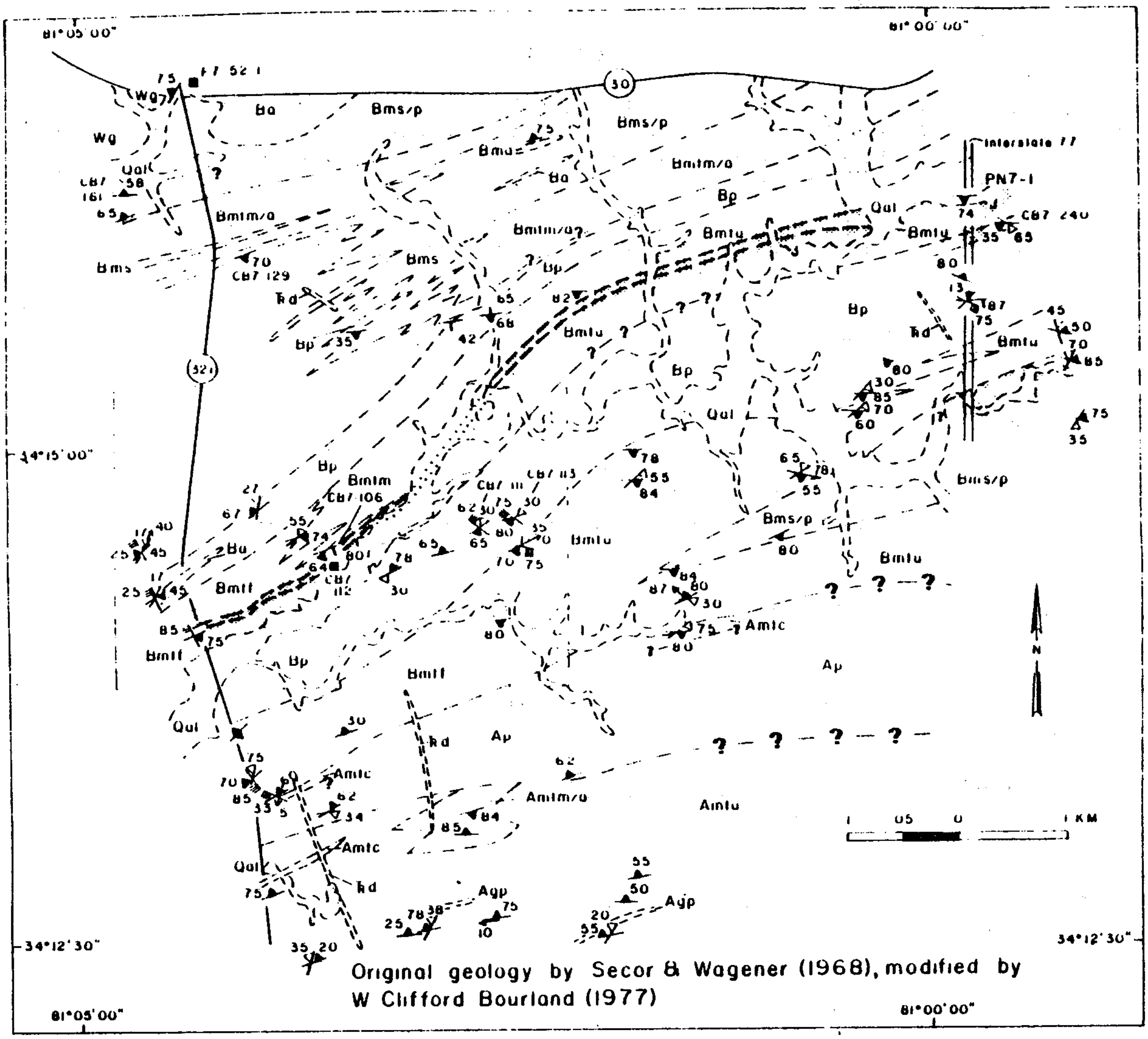


Figure 2 Geologic map of the Carolina slate belt southeast of the Winnsboro intrusive complex

EXPLANATION

Map Units

Quaternary	Qal	Quaternary alluvium
Triassic	TR(?)d	Triassic (?) diabase dike
Carboniferous	Wg	Winnsboro coarse granite
Late Precambrian-Cambrian	Bma	Metaarenite
	Bms	Metasiltstone
	Bms/p	Interlayered metasiltstone and phyllite
	Bp	Phyllite
	Ba	Massive amphibolite
	Bmtm/a	Mafic metatuff and massive amphibolite
	Bmtm	Mafic metatuff
	Bmtf	Felsic metatuff
	Bmtu	Mafic and felsic metatuff undifferentiated
	Amtc	Crystalline metatuff
	Amtm/a	Mafic metatuff and amphibolite
	Amtu	Mafic and felsic metatuff undifferentiated
	Agp	Graphitic phyllite
	Ap	Phyllite

Map Symbols

— — Contact dashed where approximate, short dashed where inferred, querried where doubtful, dotted where covered.

B, 76	Bedding foliation	(S_B)		
80	First foliation	(S_1)		F_1 axis
25	Second foliation	(S_2)		F_2 axis
34	Third foliation	(S_3)		F_3 axis
85	Fourth foliation	(S_4)		F_4 axis
CB7-123	Sample locality			

Ductile cataclastic deformation (shaded) and brittle cataclastic deformation (heavy dashed line)

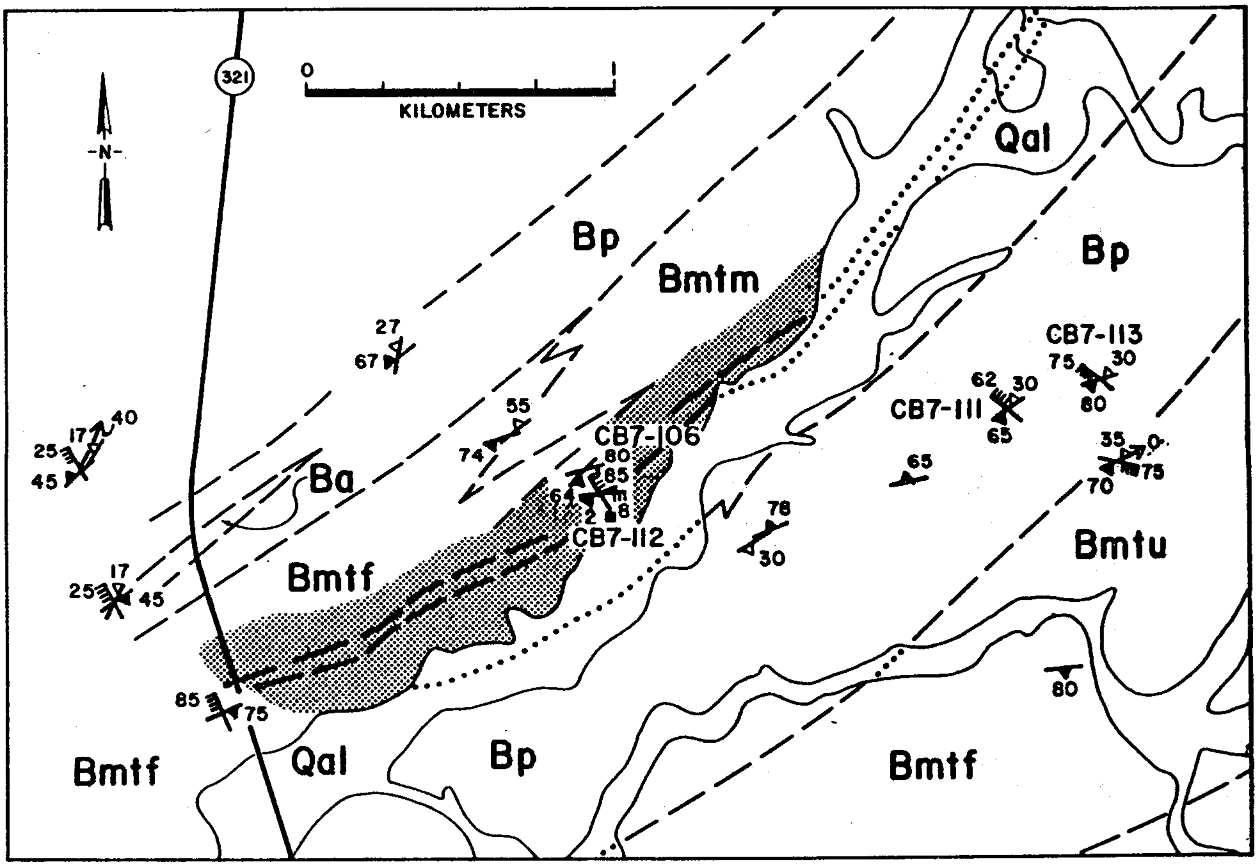


Figure 2a. Detail of structure and stratigraphy along the Cedar creek Fault within insert on figure 2.

Previous work by Secor and Wagener (1968) divided the Carolina slate belt of central South Carolina into the Wildhorse Branch, Persimmon Fork, and Richtex formations. Unit A includes the same rocks as the Wildhorse Branch formation. Unit B, however, combines the Persimmon Fork and Richtex formations into a single map unit. Secor and Wagener implied that the phyllites of the Persimmon Fork formation were pyroclastics, and those of the Richtex formation were epiclastics. However, in the field there is no clear distinction between the physical and compositional characteristics of phyllites of epiclastic and pyroclastic origins. Without such a distinction, the boundary between the Persimmon Fork and Richtex formations becomes unclear. In addition, no unconformity between any of the predominately volcanic and nonvolcanic layers has been observed. Thus, the southern map area can only be divided into two recognizable units, A and B (figure 2).

Unit A

Unit A is comprised of five lithologies. The most abundant lithology in Unit A is a green tuffaceous rock (Amtm, figure 2) that consists of muscovite, chlorite, quartz, plagioclase (albite), epidote, and sulfides. A light gray graphitic phyllite (Agp, figure 2), usually in layers less than four meters thick, is interlayered with the green tuffaceous rocks. The graphitic unit has at least 15% modal percent graphite and can have up to 35% modal percent graphite accompanied by muscovite, quartz, plagioclase, and epidote. Also interlayered with the tuff layers are mafic layers (Amtm/a, figure 2) which contain chlorite, plagioclase, quartz, epidote, and scattered actinolite. North of the tuffaceous and mafic lithologies is a muscovite-chlorite-quartz-plagioclase phyllite with a small amount (2 percent) of graphite, which is interlayered with thin felsic tuffaceous layers of a composition similar to that of the phyllite (Ap, figure 2). Crystal tuffs (Amtc, figure 2), which vary from 4-20 meters thick, are composed of plagioclase and quartz phenocrysts in a matrix of quartz, muscovite, and plagioclase, and are interlayered with the phyllite unit near the boundary of Units A and B.

Pyroclastic debris in the felsic metatuffaceous layers of Unit A (Amtu and Amtm/a, figure 2) consists of crystal and lithic fragments (Secor and Wagener, 1968). Thickness of the tuff layers varies from 3-30 meters and is gradational into chlorite-muscovite phyllitic units. Size of pyroclastic fragments varies from 7-20 mm in length, and in hand specimen the clasts appear to be poorly sorted.

Unit B

The central portions of figure 2 are comprised of two maps units: (1) mafic and felsic lapilli metatuff (Bmtu) and (2) muscovite rich phyllites (Bp). They are interlayered, and have gradational contacts. Mafic metatuffs are more prevalent than felsic metatuffs. Movement within the tuff unit along the Cedar Creek fault (see section on cataclastic deformation) may have caused a repetition of the tuff-phyllite sequence, complicating an estimate of the thickness of tuffaceous and phyllitic rocks.

Pyroclastic debris in the tuffaceous layers is composed of lithic, crystal, pumice, and vitric(?) fragments. Lithic and crystal fragments are the most abundant types of debris. Fragments range from 6-50 mm in length and fall within the lapilli size classification of Fisher (1966). Pyroclastic fragments comprise 40-80 percent of the rocks, with local variations.

In the felsic metatuffs (Bmtf, figure 2) pyroclastic debris consists of crystal fragments of euhedral to anhedral plagioclase and plagioclase with quartz inclusions and pumice fragments which have been recrystallized into very fine-grained quartz-albite clasts. Two amygdyloidal bombs, 12 and 20 cm in diameter with quartz-plagioclase-chlorite filled amygdules, were found in the felsic tuffs near the Cedar Creek fault.

Mafic metatuffs (Bmtm, figure 2) have plagioclase and amphibole phenocrysts in a chlorite-epidote-quartz matrix. Other dark, very fine-grained clasts which occur in the mafic tuff may be either vitric fragments or pumice fragments.

Numerous thinly layered phyllitic units (Bp, figure 2) are interlayered with and gradational into tuffaceous units. The phyllites, in contrast to the tuffaceous units, are well sorted and commonly show bedding planes. To the north, the phyllites are interlayered with and gradational into metasiltstones (Bms), metasandstone (Bma), and layered amphibolites (Ba).

Phyllitic units are composed of 70-90 modal percent muscovite, 10-30 modal percent quartz and minor albite. Biotite-muscovite phyllites are found north of the Cedar Creek fault in the direction of increasing metamorphic grade.

Quartz-rich siltstones and sandstones (Bms and Bma, figure 2), interlayered and gradational with the phyllites, occur in the northern portion of the southern map area. These lithologies average 60-90 modal percent quartz, and 15-20 modal percent muscovite and biotite, with accessory plagioclase, epidote and/or amphibole. The siltstones and phyllites in

Unit B are the equivalents of the meta-arenites (ms and mg) of Wagener (1970) (figure 1). Laminated microgneisses and aphanitic fine-grained rocks described by Wagener (1968) north of the southern map area may be the recrystallized equivalents of the siltstones in a region of higher grade metamorphism. Sedimentary features such as cross-bedding, load casts, and ripple marks have been reported in the siltstones and phyllites by Secor and Wagener (1968).

Layered and massive amphibolites (Bmtm/a and Ba, figure 2) are interleaved with metasiltstones and phyllites along the southeastern and eastern margins of the Winnsboro complex, and are equivalent to the mafic volcanics (vs) of Wagener (1970) (figure 1). These amphibolitic units occur along the border of the Carolina slate belt and Charlotte belt in an area of northerly increasing metamorphic grade and are discussed as Charlotte belt lithologies. Since the siltstones and amphibolites are intercalated, no stratigraphic or structural discontinuity is meant to be implied by this contact.

Origin of Units A and B

Unit A is apparently a series of marine volcanic tuffs and mafic flows (Secor and Wagener, 1968). Interlayered within the sequence are lenses of carbonaceous mudstones. The graded bedding and abundance of pumiceous fragments in the metatuffaceous layers favors a subaqueous environment where the original pyroclastic fragments could gravitationally settle out (Fiske, 1968 and 1969).

Unit B may have formed in a basin near active volcanism, probably in a marine environment similar to Unit A (Fiske, 1968). Within Unit B there are pumice-rich layers gradational with phyllitic layers similar to those of Unit A. The phyllitic units, although similar in appearance and modal composition throughout Unit B, may have had several different origins. Laminated phyllites interlayered with the tuffaceous layers may be ash fall units which settled out along with the fragmental tuffaceous debris. Other phyllites, which in some cases are also laminated, occur near the tuffaceous units and are gradational into siltstones and sandstones. These phyllites may be epiclastic mudstones, possibly reworked from subaerially exposed volcanic units. Siltstones and sandstones which have well developed sedimentary features are epiclastics and, as Secor and Wagener (1968) indicate, may be turbidites. The mafic rocks which are intercalated with the siltstones, sandstones, and mudstones throughout Unit B are interpreted to be volcanic flows. Overstreet and Bell (1965) hypothesized that the amphibolite units on the eastern margin of the Winnsboro complex are basaltic or andesitic flows, possibly injected by dacitic and gabbroic dikes. Unit B, therefore, probably formed in a basin where marine pyroclastic debris could accumulate synchronously along with epiclastic shales, siltstones, and sandstones, and basaltic flows. At some later time or synchronously, the sequence may have been injected by dacitic and gabbroic dikes (Overstreet and Bell, 1965).

Charlotte Belt Lithologies

Several relationships between the structure, metamorphism, and stratigraphy of the Carolina slate belt and Charlotte belt can be implied from previous work and this study. First, there is no stratigraphic discontinuity between the two belts; similar sequences interpreted to be interlayered volcanics and sediments can be found in both belts (Secor and Wagener, 1968), and a continuous sequence of rocks of volcanic origin was observed across the contact of the belts. Second, metamorphic grade gradually increases toward the core of the Flint Hill Anticlinorium (figure 1). Third, the chronology of structural deformation observed in the Carolina slate belt is apparently the same as that observed in the Charlotte belt.

The following lithologies occur in the northern map area northwest of the Winnsboro complex (figure 3) and west-southwest of the Winnsboro complex, South Carolina (figure 1). Rocks in this area have been regionally metamorphosed and multiply deformed, such that determining the original sedimentary structures and compositions is difficult or impossible. For this study, the Charlotte belt is divided into compositionally layered and unlayered intrusive lithologies.

Layered Lithologies

Amphibolite gneisses north and southwest of the Winnsboro complex (figures 1 and 3) are comprised of hornblende gneiss, hornblende-tremolite-actinolite gneiss, hornblende-biotite gneiss, and thin layers of chlorite schist. The major mineral constituent of these layers is a pleochroic blue-green hornblende or hornblende partially replaced by tremolite-actinolite. In some samples, relict gabbroic textures are preserved as a pattern of finely distributed opaque inclusions which are not destroyed when the preexisting pyroxene was reacted to hornblende. Plagioclase (An 20-40), epidote, quartz and titanite are also present in limited amounts.

Overstreet and Bell (1965) described the amphibole gneisses as equivalents of basaltic-andesitic flows, and the less mafic, layered

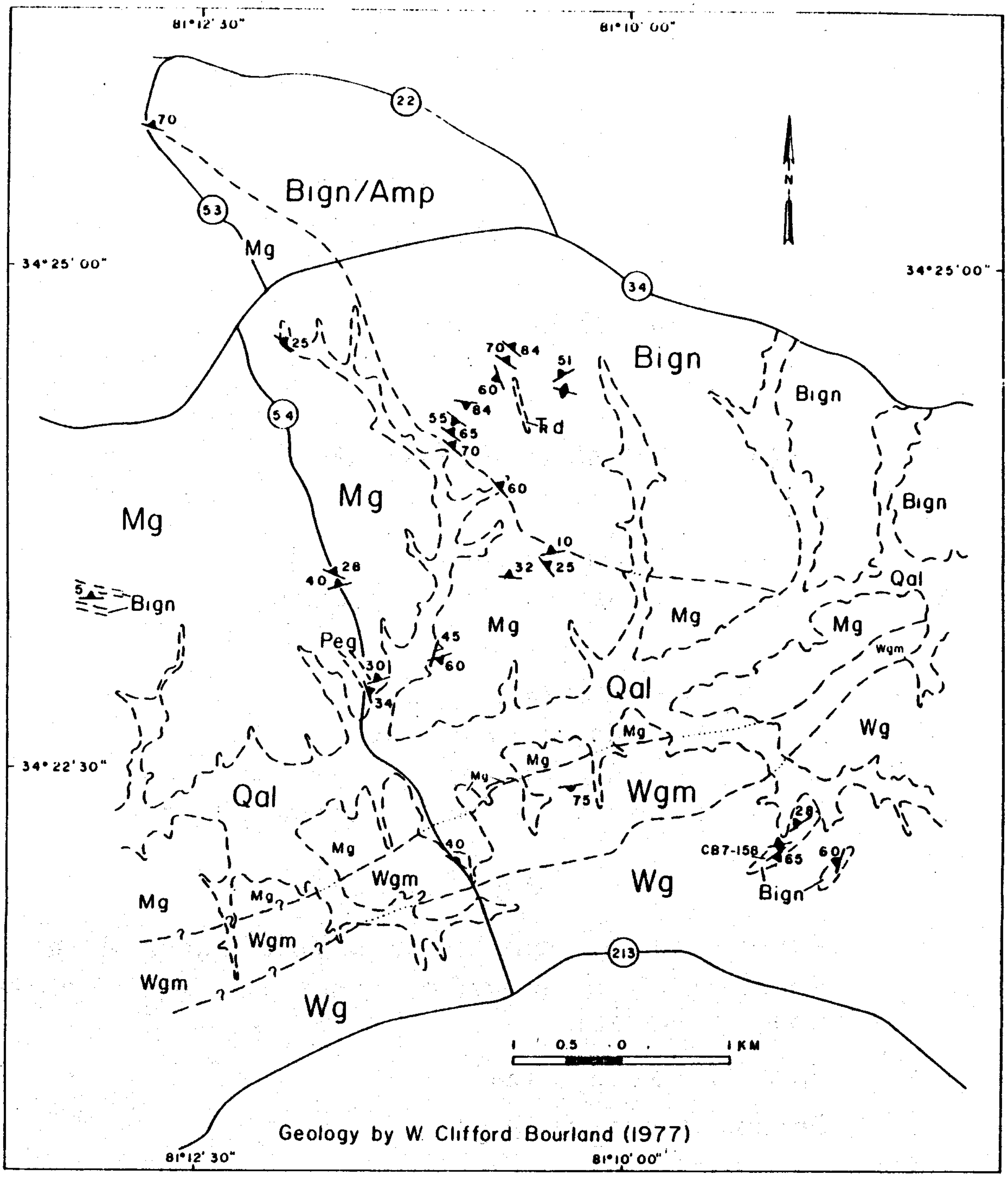


Figure 3 Geologic map of the Charlotte belt adjacent to the northern border of the Winnsboro intrusive complex.

EXPLANATION

Map Units

Quaternary	Qal	Quaternary alluvium
Triassic	TR(?)d	Triassic (?) diabase dike
Carboniferous	Wg	Winnsboro coarse granite
	Wgm	Winnsboro mafic granite
Early Paleozioc	Peg	Pegmatite
	Mg	Metagranite foliated
	Bign	Biotite gneiss
	Bign/Amp	Biotite gneiss and amphibolite

Map Symbols

— — — ? ········ Contact dashed where approximate, short dashed where inferred, querried where doubtful, dotted where covered.

34 First foliation (S_1)

78 Second foliation (S_2)

CB7-345 Sample locality

12 Igneous foliation

amphibolites were interpreted to be intercalated graywackes and mafic tuffs. However, some of the amphibolite gneisses in this study have intrusive textures and their contacts are discordant to the surrounding gneisses. Therefore, at least the massive amphibolites appear to be of intrusive rather than extrusive origin.

Biotite gneiss, which is interlayered with the amphibolite, consists mainly of plagioclase (An 20-30?), microcline, and quartz in varying amounts with 30 modal percent or less biotite and lesser muscovite, chlorite or amphibole (hornblende), epidote, and possible clinozoisite. Biotite gneiss is intermixed with a migmatitic zone on the border of the foliated metagranite (figure 3).

Biotite schist (not shown as a distinct map unit on figure 3), which has a mineralogy similar to biotite gneiss, except that it contains more than 30 modal percent biotite, occurs with biotite gneiss near migmatitic zones around the northern parts of the Lebanon metagranite (figure 3) and intermixed as xenoliths in the Winnsboro granite. The xenoliths subsequently developed contact metamorphic mineralogy which consists of quartz, plagioclase, brown biotite, cordierite, spinel, garnet, and andalusite or fibrolitic sillimanite (CB7-158, F7-52-1, F7-63, figure 1). Minor biotite schist also occurs elsewhere in the biotite gneiss.

Muscovite schist and sillimanite quartzite occur on the northwest and southwest margins of the Winnsboro complex (Farrar, 1977). Muscovite schist is composed of 70 modal percent green muscovite, 25-30 percent quartz and small amounts of fibrolite (Farrar, 1977, CB7-82 figure 1). The sillimanite quartzite is composed of 60 modal percent quartz and nearly 40 modal percent sillimanite in 6-8 mm long blades. The present mineralogy of these units reflects the effects of contact metamorphism.

The layered Charlotte belt lithologies may correlate with some of those in the Carolina slate belt (Secor and Wagener, 1968). South and southwest of the Winnsboro complex, muscovite-quartz phyllites and tuffaceous lithologies of the Carolina slate belt are progressively metamorphosed into the biotite and amphibole gneisses of the Charlotte belt which are intercalated with the Lebanon metagranite. There does not appear to be a stratigraphic or structural break in the sequence from the Carolina slate belt to the Charlotte belt.

Intrusive Lithologies

Ultramafic intrusives occur throughout the Charlotte belt (Overstreet and Bell, 1965), postdating the layered lithologies and either synchronous with or postdating the metagranites. An ultramafic dike-like body occurs in the northern traverse (CB7-175, figure 1). The mineralogy of the body is anthophyllite, talc, chlorite, and tremolite. Another ultramafic body occurs near Jenkinsville, South Carolina, (CB7-64, figure 1) and contains serpentine, chlorite, clinoamphibole, and clinopyroxene (?). Both bodies are derived from the regional metamorphism of ultramafic intrusives.

A large body of foliated metagranite, herein named the Lebanon metagranite, occurs north of the Winnsboro complex (figure 3) and is composed of microcline, quartz, plagioclase (An20?), muscovite, and biotite, with accessory apatite and zircon. The most distinctive characteristic of the metagranite is the foliation which is defined by microscopic and mesoscopic flattened quartz and feldspar and aligned muscovite and biotite grains.

There is a discordant contact between the biotite gneiss and the foliated granite north of the Winnsboro complex (figure 3). Migmatitic zones occur on the border between the metagranite and biotite gneisses. As this contact is approached, increasing amounts of foliated and unfoliated pegmatites are found. The Lebanon metagranite could have formed in place as an anatectic melt, but if the granite was intruded from below, the presence of migmatites indicates that the country rocks were hot enough at one time for partial melting to occur.

DEFORMATIONAL FEATURES

In the following descriptions, S-surfaces are pervasive and non-pervasive planar features such as schistocity, crenulation cleavage, and layering caused by metamorphic differentiation (modified from Turner and Weiss, 1963). S_B, original bedding, is not an S-surface but is a planar feature observed in the Carolina slate belt. S_0, compositional layering, is a planar feature in the Charlotte belt where S_B has not been observed. Igneous flow foliation is restricted to the area of the Winnsboro intrusive complex, and was formed much later than the regional foliation. Table 1 explains the use of all symbols for structural elements in the two map areas and their relationships to deformation and metamorphism.

Table 1 Relationship of deformational, structural, and metamorphic elements in the Carolina slate belt and Charlotte belt rocks around the Winnsboro intrusive complex.

D_n Deformational Event	M_1 thermal regional metamorphic peak; Mc-contact metamorphism; Mr_1 retrograde metamorphism	S_n planar elements; L_{nxm} linear elements; F_n folds; f_n fractures	Age (million years, m.y.)	Comments
Original deposition or metamorphic compositional layering		S_B Bedding; S_0 compositional layering	Late Precambrian-Early Paleozoic (Overstreet & Bell, 1965)	
D_1	M_1	S_1, L_{Bx1}; F_1	Pre-Winnsoboro granite 301±4 m.y. (Fullagar, 1971)	S_1 is generally parallel to S_0 in belts. S_1 is a pervasive NE-striking slaty cleavage. Possibly the origin of ductile movement along the Cedar Creek fault (?) was during this event.
D_2	Cooling stage of M_1	S_2, L_{1x2}; F_2	Pre-Winnsboro granite 301±4 m.y. (Fullagar, 1971)	S_2 is a nonpervasive NE-striking crenulation cleavage. F_2 folds are the dominant structure of the area and fold the metamorphic isogrades and refold the F_1 axes. Possible continuation of ductile deformation along the Cedar Creek fault.

Table 1 (continued)

D_3	Cooling stage of M_1	S_3, F_3, L_{1x3}	Pre-Winnsoboro granite 301±4 m.y. (Fullagar, 1971); Definitely postdates S_1 and S_2	S_3 is a nonpervasive NE-striking cleavage rarely found mesoscopically in this area (Secor, personal communication, 1977). F_3 folds may have formed large wavelength open folds with near vertical axes, such as the Flint Hill anticlinorium.
D_4	Cooling stage of M_1	S_4, F_4, L_{1x4}	Probably Pre-Winnsboro granite 301±4 m.y. (Fullagar, 1971) Definetely postdates S_1, S_2, and S_3	S_4 may be a crenulation cleavage which generally strikes NW; however a NW-NE striking conjugate pair has been observed. S_4 folds are open folds with slightly NW-plunging axes.
D_5	Mc	Flow foliation	301±4 m.y. (Fullagar, 1971)	Contact metamorphism has produced contact aureole 1.0 km to 1.25 km wide that reached cordierite hornfels facies.

Table 1 (continued)

D_6	Mr	f_1	Post 301±4 m.y (Fullagar, 1971); possibly Mesozoic	Brittle fracturing of earlier ductile textures associated with later stages of movement along the Cedar Creek fault. Zeolite mineralization along fractures.
D_7		S_5, F_5	Post-Cretaceous	S_5 is a fracture cleavage axial planar to folds, which folded Carolina slate belt and Coastal Plain lithologies (Howell and Zupan, 1974)

Structural Elements of D_1

The first regional deformational event (D_1) is identified by a pervasive foliation, S_1. S_1 is defined megascopically and microscopically by the planar orientation of platy and prismatic minerals, which represent the highest grade metamorphic assemblage (M_1).

Orientation of S_1 for the Carolina slate belt and Charlotte belt may vary because of subsequent fold events (figure 4a-d). Poles to S_1 foliations for the Carolina slate belt are represented in figure 4a. These poles to S_1 are distributed in a girdle which indicates that the S_1 foliations have been folded. The poles to Charlotte belt S_1 foliations are shown in three pi-diagrams according to geographic location and lithologic type. Three separate girdles varying from northeast to northwest trending are indicated (figure 4b-d).

Small, tight, nearly isoclinal, asymmetric F_1 folds with steep to vertical refolded axes can be seen in both belts.

Structural Elements of D_2

The S_2 foliation formed very soon after S_1, but during a separate regional deformation (D_2, table 1). S_2 is nearly parallel to S_1 in both mesoscopic and microscopic occurrences in both the Carolina slate belt and Charlotte belt. In addition there is no difference in metamorphic grade between S_1 and S_2. S_2 may have developed shortly after the peak of metamorphism, but before regional temperatures or pressures changed significantly. Poles to S_2 foliations for both the Carolina slate belt and Charlotte belt are shown in figure 5a.

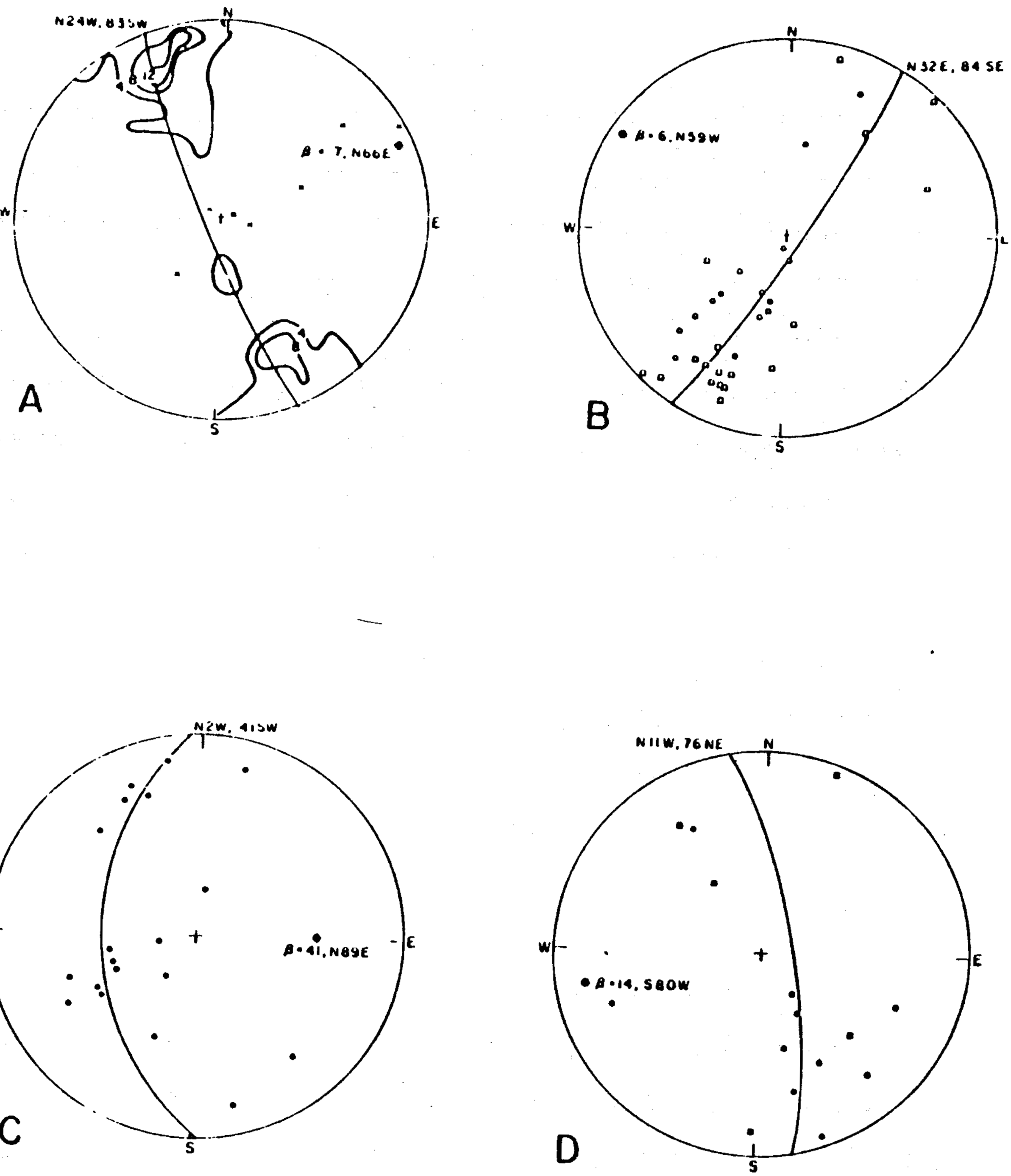


Figure 4. Poles to S_1 foliations for: A) Carolina slate belt (60 poles), x=F_1 fold axes. B) Charlotte belt lithologies north of the Winnsboro complex, O=metagranite, ▢ =biotite and amphibolite gneiss. C) Charlotte belt lithologies west and southwest of the Winnsboro complex. D) Xenoliths and migmatites within the Winnsboro complex, ■ =migmatitic zones, ● = zenoliths.

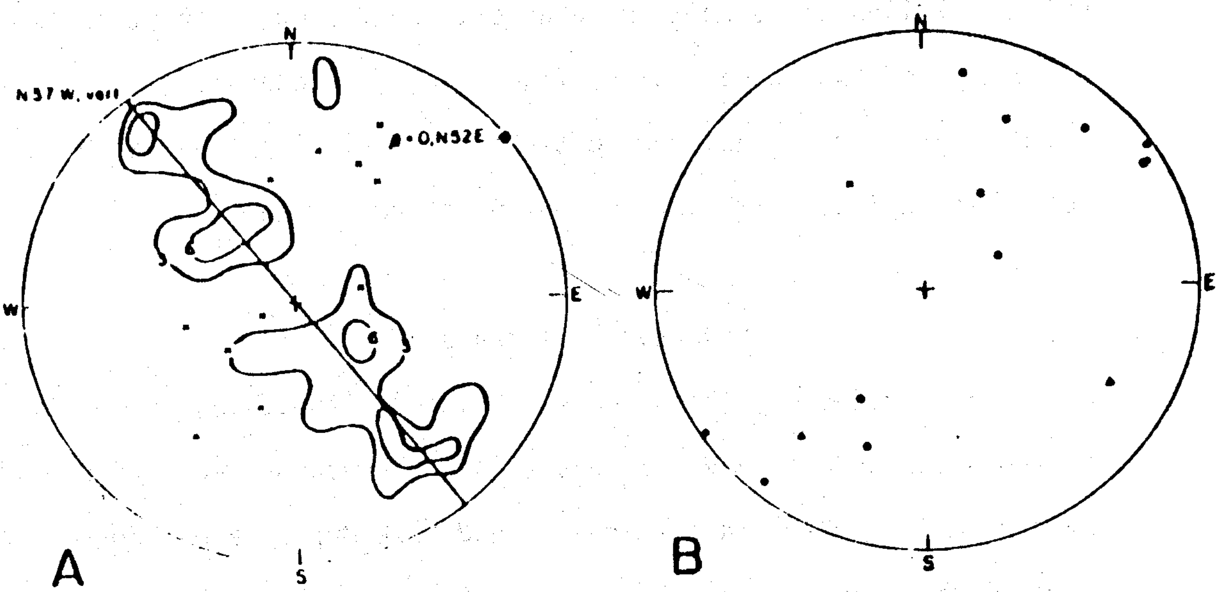


Figure 5. Poles to S_2 foliations, Carolina slate belt and Charlotte belt combined, (40 poles) $x=F_2$ fold axes. B) Poles to S_4 foliations, ▲ =conjugate pair, $x=F_4$ fold axis.

Mesoscopic F_2 folds occur in both belts and always fold S_1, but may or may not display an S_2 axial plane foliation. Poles to S_1 foliations in the Carolina slate belt and Charlotte belt show a variation in trend and plunge of F_2 synoptic axes (figure 4a-d). Generally, F_2 in outcrop can be characterized as open to tight flexural slip folds with shallow- to steeply-plunging, northeast to southwest trending axes.

Structural Elements of D_3

The S_3 cleavage, which formed during D_3 (table 1), is poorly defined in the areas under study. S_3 was first observed by Secor (personal communication, 1977) in the area around Lake Murray about 50 km southwest of this study area. S_3 is a northeast striking cleavage that cuts across S_1 and S_2, and has refolded F_2 in the Cedar Creek fault area (CB7-112, figure 2b).

F_3 includes mesocopic open to close folds with northeast striking axial surfaces and northeast plunging axes, (0, N52E) as is indicated by the F_3 synoptic axis in figure 5a. However, in outcrop it is very difficult to distinguish F_3 from F_2.

Macroscopic F_3 folds may be responsible for the folded contact pattern between the Carolina slate belt and Charlotte belt in the Central Piedmont around the Winnsboro complex. S_1 clearly dips to the north, north of the Winnsboro complex and south, south of the complex. Also F_2 axes plunge northwest north of the Winnsboro complex and plunge southwest of the complex. Poles to S_2 are clearly folded about a northeast axis (figure 5a). It appears that the present study areas are on the limbs of a large F_3 anticlinorium, herein referred to as the Flint Hill anticlinorium. Figure

6 shows a distribution of poles to S_1 within the area from north of Gayden's Creek fault to the northern boundary of the Dutchman's Creek gabbro, which define a possible F_3 fold axis (25, N69E). On Overstreet and Bell's (1965) map the same vicinity was shown as a folded amphibolite unit. The folds in the Lake Murray spillway (Secor, personal communication, 1977) and near Chester, South Carolina may also be F_3 generation folds.

Structural Elements of D_4

S_4 is a nonpervasive regional foliation best preserved in phyllites in the Carolina slate belt as kink planes and conjugate kink bands (figure 5b). S_4 is a northeast- to northwest-trending set of kink features, observed refolding S_3 foliations. The kink folds and conjugate kink planes indicate a later low temperature type of deformation and therefore may represent a separate deformational event, D_4.

F_4 is a poorly defined folding event in the Carolina slate belt. Generally, F_4 can be described as asymmetrical open to close folds that have variable axes. F_4 folds are found with both northeast- and northwest-striking axial surfaces and as conjugate pairs. Commonly these folds have a well developed fracture parallel to the axial surfaces.

Structural Elements of D_5 and D_6

Structural elements of D_5 are igneous flow foliation and possible movement or shouldering aside of the country rock as the Winnsboro granite was emplaced. Elements of D_5 and contact metamorphism are discussed by Farrar (1977).

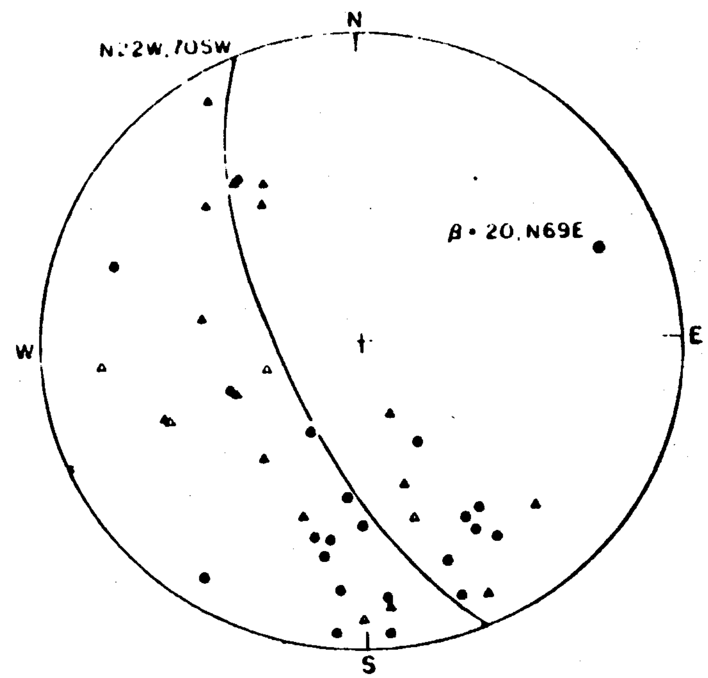


Figure 6. Poles to S_1 foliations redistributed on the limbs of the Flint Hill Anticlinorium, ● =south limb of fold, ▲ =north limb, △ =north limb, north of Gaydens fault (figure 1).

D_6 is a brittle fracturing event discussed in the section on cataclastic deformation in the discussion of the Cedar Creek fault. The primary structural feature of this event was faulting and fracturing of old ductile cataclastic zones, which may have occurred during Mesozoic uplift (Bourland, 1976; Bobyarchick, 1976; and Duke Power Co., 1976).

Structural Elements of D_7

S_5 and F_5 have been observed outside the area of this study, and are included here only for the completeness of the tectogenesis. S_5 and F_5 have been observed 116 km to the northeast near Cheraw, South Carolina (Howell and Zupan, 1974) and along the borders of the Pageland granite. These same structural elements may be present in the Lake Murray Spillway approximately 50 km to the southwest.

S_5 is a northeast striking, vertical fracture cleavage axial planar to F_5. F_5 are open, long-wavelength (greater than 40 meters) folds that have folded the Carolina slate belt and the overlying Coastal Plain sediments. Zupan (personal communication, 1978) indicates that these folds could be as young as Eocene (50 m.y.). These structural features probably represent a structural deformation event (D_7) during uplift.

Cataclastic Deformation

There is a northeast trending zone of ductile cataclastic deformation, interpreted to be a fault, along the southeast border of Winnsboro complex (figure 2). The fault forms a lense-shaped structure that may be a part of a larger fault zone mapped by Secor and

Wagener (1968), and is one of several northeast-trending lineaments south of the Winnsboro intrusive complex (Trask and others, 1977). This fault may also be part of the Eastern Piedmont fault system (Hatcher and others, 1977).

Ductile features such as fluxion structure, dislocated chips of country rock, and zones of very fine-grained material lacking fluxion structure, indicate the presence of a fault zone. The rocks within the zone are mylonites and ultramylonites as defined by Higgins (1971). Within the area of study no brittle fractures were observed to be associated with the fault zone.

The early mylonitic features of the fault zone formed prior to the intrusion of the Winnsboro granite. A groundmass of biotite, muscovite, and quartz is well aligned in a plane of cataclastic foliation which forms the fluxion structure in the fault zone. The contact metamorphic minerals (biotite, garnet, cordierite, and andalusite) have grown across this plane of cataclastic foliation. Therefore, the cataclastic texture of the groundmass formed prior to the contact metamorphism which occurred about 301 $\pm$ 4 m.y. (Fullagar, 1971).

A second fault zone, approximately 1.0 km wide, trends northeastward across the central portions of figure 2. This fault, herein named the Cedar Creek fault (figure 2), is a splay off from a larger fault (Secor, unpublished data) and is part of a major system of lineaments 300 km long which crosses South Carolina (Trask and others, 1977). This lineament and fault system although not shown by Hatcher and others, 1977, is part of the Eastern Piedmont fault system which they defined.

Like faults of the Eastern Piedmont system (Hatcher and others, 1977), and the region around Lake Murray and the Clouds Creek granite (Secor and Snoke, 1977), in particular, the Cedar Creek fault has an early ductile mylonitic zone that dips steeply to the southeast and a brittlely fractured zone that is almost vertical and transects the mylonitic zone. The ductile mylonitic zone is shown as a shaded area on figure 2, and the brittle zone is enclosed by the dashed lines on the interior of the mylonitic zone. There are two localized mylonitic zones south of the Cedar Creek fault along the eastern border of figure 2, which may or may not be part of the Cedar Creek fault system.

The direction of movement and net slip of the Cedar Creek fault is impossible to determine given the limited exposure in this area. The apparent dip of the fault is steeply to the southeast.

In rocks of the Cedar Creek fault zone, platy and prismatic crystals have recrystallized, forming a cataclastic layering. This cataclastic layering was subsequently deformed by what appear to be F_2 folds. The trace of the fault is parallel to S_1 foliations inside and outside the ductile zone, and therefore, the ductile cataclastic zone appears to be cogenetic with S_1. In addition, the metamorphic grade is the same inside and outside the ductile zone, which indicates there were no sharp differences in temperature or pressure between the fault and surrounding country rock.

Sheared garnets were found in the plane of S_1 in the cataclastic zone on the northeast edge of the map area (Nystrom, personal communication, 1978; PN7-1, figure 2) and were apparently formed during ductile mylonitization. The sheared garnets probably represent the peak metamorphic assemblage in this unit. Euhedral garnets lacking inclusions have also been found in these rocks. However, it is unknown whether they represent a separate generation of garnets or continuous crystallization of garnets during and after mylonitization.

Therefore, S_1 is parallel to the trace of the ductile zone inside and outside the zone, and the minerals aligned in S_1 represent the highest grade of metamorphism. S_1 is folded both outside and inside the ductile zone by what appear to be F_2 folds. These lines of reasoning lead to the conclusion that the ductile cataclasis occurred synchronously with the intense S_1 shear stress during D_1.

Brittle deformation within the Cedar Creek fault is outlined within the ductile mylonitic zone on figure 2 and is the sixth deformation event (D_6, Table 1). Mineralized fractures, nearly vertical, cross the cataclastic foliation. The fracture zones indicate one or more periods of brittle deformation (figure 2, and table 1; f_1 is the designation for mineralized fractures). Fractures are nearly vertical and are of two types; one filled with epidote-quartz and the second by quartz and sulfides (m_1, table 1, represents the retrograde mineralogy found in the fractures). The two types have not been observed to intersect and are hypothesized to be of approximately the same age. Both types of fractures, because they cross the mylonitic texture, are younger than the ductile mylonitic zone.

Stilbite laths were found in disoriented arrays filling local fractures in blastomylonites (CB7-106 and CB7-112, figure 2), in the center of the brittle zone. Zeolites have been found in fractures along other faults in the Eastern Piedmont fault system (Duke Power Co., 1976; Bobyarchick, 1976; Bourland, 1976) of Triassic age, and have been attributed to retrograde metamorphism after brittle stages of movement. Exact timing of the brittle movements in the Cedar Creek system is unknown except that the movement occurred after ductile mylonitization. The presence of stilbite localized in the center of the brittle zone may indicate a period of retrogression accompanying the later stage of brittle movement, possibly during a Mesozoic(?) uplift.

REGIONAL METAMORPHISM (M_1)

The grade of regional metamorphism (M_1) for the Piedmont of Central South Carolina was described by Secor and Wagener (1968) as varying systematically from greenschist facies in the Carolina slate belt to middle amphibolite facies in the Charlotte belt. Metamorphism was synchronous with the formation of S_1, and S_1 and the metamorphic isograds have been refolded. The boundary between the Carolina slate belt and Charlotte belt has been folded by the Flint Hill anticlinorium (figure 1) in such a way that a section of high grade Charlotte belt rocks jut into the Carolina slate belt. In the central South Carolina Piedmont there is evidence of only one regional metamorphic event, prior to the minimum 300 m.y. age (Fullagar, 1971) of the unmetamorphosed Winnsboro granite.

Lithologies of the Carolina slate belt are greenschist grade, poorly recrystallized, and retain original volcanic and sedimentary textures and compositions. Mafic lithologies are composed of chlorite, albite, epidote, and minor actinolite, biotite and opaques. Felsic lithologies contain quartz, muscovite, albite, and minor amounts of chlorite, graphite, epidote and opaques. Biotite in the felsic lithologies is more common north of the Cedar Creek fault.

On the southern and southeastern borders of the Winnsboro complex along the boundary between the Carolina slate belt and Charlotte belt the rocks are in the epidote-albite-amphibolite facies. The amphibolites in this area define a transition zone between the low grade and high grade belts. The amphiboles start at a lower grade as actinolite, then in the transition zone there is a zoned amphibole of hornblende and actinolite-tremolite, and finally in the Charlotte belt, unzoned hornblende.

Ultramafics which occur with the amphibolites are also in the epidote-albite-amphibolite facies. Ultramafic dikes to the north of the Winnsboro complex (figure 1, CB7-175) have an anthophyllite-tremolite-chlorite-talc assemblage. The ultramafic to the south (figure 1, CB7-64) contains hexagonal crystals of forsterite altered to serpentine (antigorite) with an inner core of clinopyroxene-iron oxide-chlorite(?). Both assemblages can be formed at the moderate temperatures and pressures of the epidote-albite-amphibolite facies or lower amphibolite facies (Johannes, 1969).

Previous authors have described the regional grade of metamorphism for the Charlotte belt of central South Carolina as kyanite-sillimanite subfacies, amphibolite facies (Wagener, 1973; Secor and Wagener, 1968; Overstreet and Bell, 1965). The highest grade metamorphism found in this study is sillimanite facies found in the area around the Winnsboro complex within the core of the Flint Hill anticlinorium. Sillimanite, reported by Wagener (1970), occurs in sillimanite-muscovite quartzites and schists (CB7-83; figure 1) and in xenoliths reported by Farrar (1977). Xenoliths from the northern borders of the Winnsboro complex contain cordierite-spinel pseudomorphs of sillimanite(?). The occurrence of sillimanite-bearing lithologies indicates temperatures and pressures within the core of the Flint Hill anticlinorium of at least $600^{o}C$ and 4-6 kb (Richardson, et al., 1969).

The highest grade regional metamorphism is restricted to the area around the Winnsboro complex and can be differentiated from the contact metamorphism (Farrar, 1977). Juxtaposition of the high grade lithologies next to the Carolina slate belt lithologies probably occurred during F_3, D_3, when the Flint Hill anticlinorium was formed.

CONCLUSION

The Carolina slate belt of Central South Carolina is a low grade, multiply-deformed, metamorphosed sequence of interlayered tuffs, siltstones, and massive volcanics. There are no recognizable stratigraphic unconformities in the area under study. The formational boundaries recommended by Secor and Wagener (1968) are confusing in the absence of stratigraphic markers and the presence of a continuous sequence of interlayered sedimentary and volcanic lithologies; therefore, formational boundaries are not implied in this study.

The Charlotte belt is an interlayered and intercalated sequence of amphibolites, biotite gneisses, metamorphic granites, and ultramafic dikes. Regional metamorphic grade reached sillimanite subfacies in the core of the Flint Hill anticlinorium (F_3), and cooled to greenschist facies on the limbs of the fold.

Both the Carolina slate belt and Charlotte belt have been involved in a complex history of multiple structural deformations. At least three and possibly four regional foliations were formed during or after the peak of regional metamorphism. During the D_1 event the metamorphic minerals were aligned in the plane of S_1. F_2 folded S_1 and an axial plane foliation S_2 has formed. S_3 is axial planar to F_3 macroscopic and mesoscopic folds, which refold and fold S_1 and S_2. The fourth event is a weaker nonpervasive fold event formed during a period of lessened temperatures and pressures. A fifth post intrusive event may have affected the area but was not observed.

Two zones of ductile deformation occur in the Carolina slate belt area studied. The largest zone, the Cedar Creek fault, may have been a zone of ductile deformation during the first regional structural deformation, and has since been reactivated as a zone of brittle deformation possibly during Mesozoic uplift.

At about 300 m.y. (Fullagar, 1971), the Winnsboro complex intruded the core and southern limb of the Flint Hill anticlinorium which apparently controlled the shape and level of emplacement of the Winnsboro complex.

REFERENCES CITED

Bobyarchick, A. R., 1976. Tectogenesis of the Hylas zone and eastern Piedmont near Richmond, Virginia (M.S. Thesis): Virginia Polytechnic Institute and State University, Blacksburg, 168 p.

Bourland, W. C., 1976. Tectogenesis and metamorphism of the Piedmont from Columbia to Westview, Virginia along the James River (M.S. Thesis): Virginia Polytechnic Institute and State University, Blacksburg, 113 p.

Duke Power Co., 1976. Duke Power Compnay Catawba nuclear station, final report on brecciated zones.

Farrar, S. S. and Becker, S. W., 1976. Winnsboro plutonic complex: Evaluation and targeting of geothermal energy resources in the Southeastern United States (Progress Report), Blacksburg, Virginia Polytechnic Institute and State University. VPI&SU-5103-2.

______________, 1977. Winnsboro plutonic complex: Evaluation and targeting of geothermal energy resources in the Southeastern United States (Progress Report), Blacksburg, Virginia Polytechnic Institute and State University. VPI&SU-5103-4.

Fiske, R. S., 1968. Subaqueous pyroclastic flows in the Ohanapecosh Formation, Washington: Geol. Soc. America Bull., 74, p. 391-406.

________________, 1969. Recognition and significance of pumice in marine pyroclastic rocks: Geol. Soc. America Bull., 80, p. 108.

Fisher, R. V., 1966. Rocks composed of volcanic fragments and their classification: Earth Science Review, no. 1, p. 287-298.

Fullagar, D. D., 1971. Age and origin of plutonic intrusions in the Piedmont of the Southeastern Appalachians: Geol. Soc. America Bull., 82, p. 2845-2862.

Hatcher, R. D., Howell, D. E., and Talwani, P., 1977. Eastern Piedmont fault system: speculations on its extent: Geol., 5. p/ 636-640.

Higgins, M. W., 1971. Cataclastic rocks: U. S. Geol. Survey Professional Paper 687, 97 p.

Howell, D. E. and Zupan, A.-J. W., 1974. Evidence for post-Cretaceous tectonic activity in the Westfield Creek area north of Cheraw, South Carolina: Div. of Geology, S. C. State Development Board. Geologic Notes, 18, no. 4, p. 98-105.

Johannes, W. 1969. An experimental investigation of the system $MgO-SiO_2-H_2O-CO_2$: American Jour. Sci., 267, p. 1083-1104.

Overstreet, W. C. and Bell, H. III, 1965. The crystalline rocks of South Carolina: U. S. Geol. Survey Bull., 1183, p. 1-42.

Richardson, S. W., Gilbert, M. C., and Bell, P. M., 1969. Experimental determination of kyanite-andalusite-sillimanite equilibra; the aluminum silicate triple point: Am. Jour. Sci., 267, p. 259-272.

Secor, D. R. and Wagener, H. D., 1968. Stratigraphy, structure, and petrography of the Piedmont in central South Carolina: Div. of Geology, S. C. State Development Board, Geologic Notes, 12, no. 4, p. 67-84.

Secor, D. T., and Snoke, A. W., 1977. Stratigraphic and structural relationships, Carolina slate belt, Central South Carolina: Geol. Soc. America Abs. with Prog., 9, p. 183.

Trask, N. J., Rowan, L. C., and Krohn, M. D., 1977. Lineament map of parts of Virginia, North Carolina, and South Carolina: U. S. Geol. Survey Open File Map 77-434, plate 1.

Turner, F. J., and Weiss, L. E., 1963. Structural analysis of metamorphic tectonites: McGraw-Hill Book Co., New York, 545 p.

Wagener, H. D., 1966. Coarse grained sillimanite-quartz rock associated with the Winnsboro granites: Div. of Geology, S. C. State Development Board, Geologic Notes, 10, no. 4, p. 47-49.

__________________, 1968. Notes on metamorphic rocks of the eastern Piedmont of South Carolina, Winnsboro area: Div. of Geology, S. C. State Development Board, Geologic Notes, 12, no. 2, p. 25-29.

__________________, 1970. Geology of the southern two-thirds of the Winnsboro 15-minute quadrangle, South Carolina: Div. of Geology, S. C. State Development Board, MS 17, 34 p.

__________________, 1973. Petrology of the adamellites, granites, and related metamorphic rocks of the Winnsboro quadrangle, South Carolina: The Citadel Monograph Series, No. X, 75 p.

RECONNAISSANCE AND PETROGRAPHY OF THE PAGELAND PLUTON

by

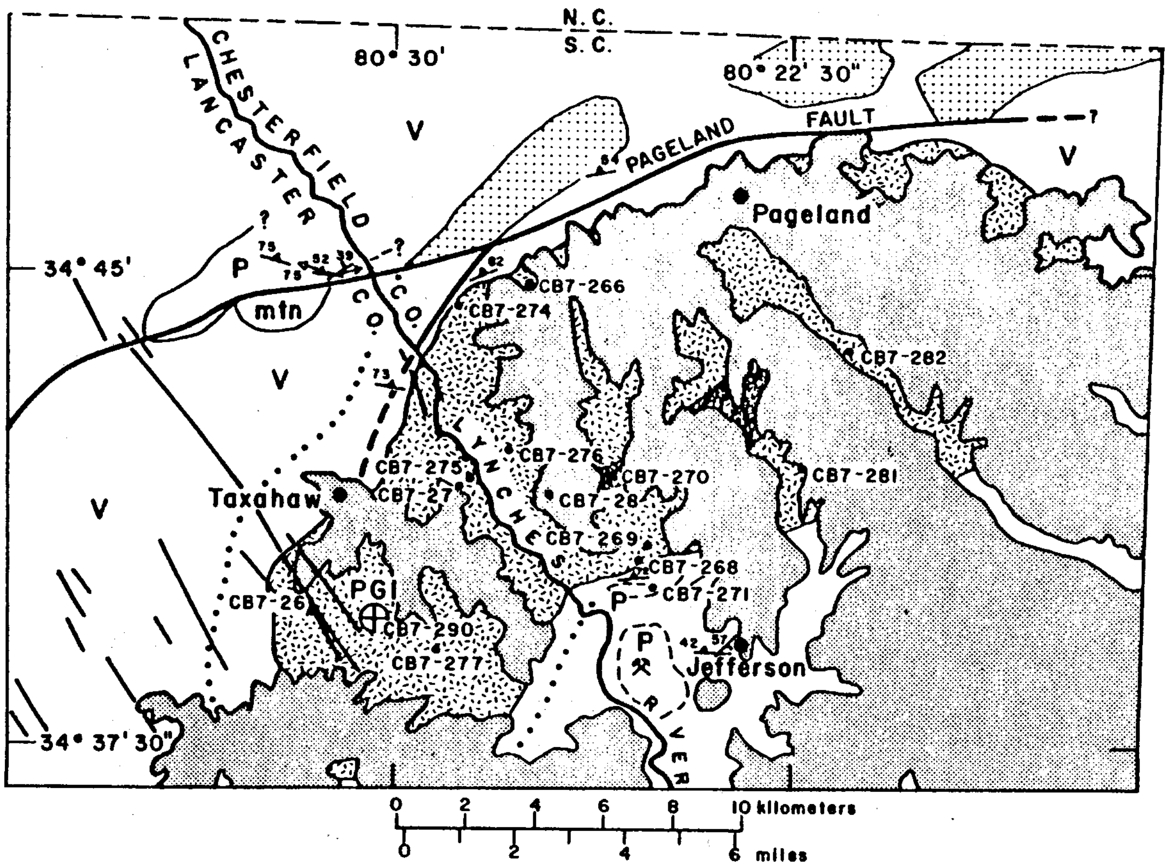
W. C. Bourland

INTRODUCTION

The exposed Pageland granite is part of a kidney-shaped pluton located in the northeastern Piedmont of South Carolina (Figure 1) with only 30 percent of the pluton exposed as a result of the Coastal Plain cover. The pluton is a coarse-grained porphyritic granite which intruded Carolina slate belt rocks (Bundy, 1965). Recent studies of the stratigraphy in and surrounding the pluton have been conducted by Nystrom (1967; 1976, work in progress), Bundy (1965), Bell and others (1974), and Butler and Howell (1977). Gravity studies on the Pageland and other central and northern South Carolina granites were conducted by Bell and Popenoe (1976).

The Pageland pluton has a lobate gravity anomaly with two well defined lows (Bell and Popenoe, 1976). The northwest lobe has no surface exposure and is separated from the main exposures of granite by the Pageland fault (Butler and Howell, 1977). Gravity profiles by Bell and Popenoe (1976) indicate that the contacts of the exposed portions of granite are steeply inward-dipping.

This study briefly describes the tectonic setting of the pluton, and mineralogy of the granite complex, and the extent of contact metamorphism. A discussion of the Pageland drill core # (PG-1) is given in another section of this report.



EXPLANATION

- COASTAL PLAIN SEDIMENTS
- ~ UNCONFORMITY ~
- TRIASSIC BASIN SEDIMENTS
- ~ UNCONFORMITY ~
- MEDIUM TO COARSE GRAINED MONZOGRANITE
- FINE GRAINED GRANODIORITE
- mtn METATONALITE
- P CAROLINA SLATE BELT PHYLLITE
- V CAROLINA SLATE BELT VOLCANICS
- ⊕ DRILL HOLE PGI
- • SURFACE SAMPLE LOCALITIES
- ⚒ BREWER MINES
- ····· POSSIBLE EXTENT OF CONTACT METAMORPHISM
- DIABASE DIKE

Figure 1. Geologic map of the Pageland granite and the surrounding Carolina slate belt compiled from Butler and Howell, 1977.

CAROLINA SLATE BELT LITHOLOGIES SURROUNDING THE PAGELAND PLUTON

The most common lithologies surrounding the Pageland granite are felsic and mafic metavolcanics (Butler and Howell, 1977). The felsic metavolcanics are primarily rhyolitic to dacitic flows and layers of pyroclastics. Felsic metavolcanics are intercalated with mafic metavolcanics and possibly some thin layers of epiclastics. The mafic metavolcanics are massive to layered amphibole-biotite rich rocks, possibly andesitic or basaltic flows (Butler and Howell, 1977).

Near the contact with the Pageland granite the mafic volcanics are composed of: quartz, plagioclase, epidote, amphibole, biotite, and along the edge of the granite some pyroxene and garnet occur in place of the epidote and biotite and less amphibole is found (Bundy, 1965). Felsic volcanics near the granite contact may or may not have a hornfels texture and commonly contain quartz, plagioclase, microcline, biotite, chlorite, and opaques, and rarely hornblende and epidote.

Apparently overlying the metavolcanics is a sedimentary sequence of mudstones or shales now metamorphosed to phyllites and siltstone or sandstone layers metamorphosed to quartzites. A similar epiclastic and volcanoclastic interlayering was observed around the Winnsboro complex (see Winnsboro section of this report for detailed petrographic and lithologic descriptions).

The rare phyllites within the contact aureole are finely laminated, well foliated hornfels rocks composed of quartz, plagioclase, biotite, cordierite, microcline(?), and muscovite. Bundy (1965) reported the presence of 0.25-inch garnet porphyroblasts in phyllites containing cordierite; however, no garnet was found during this study.

Phyllites are finely layered with greater than 60 modal percent quartz layers and greater than 60 modal percent muscovite and biotite layers. Minor amounts of plagioclase and epidote are also present. Accessory minerals include calcite, chlorite, and opaques.

Butler and Howell (1977) reported a metatonalite south of the Pageland fault (Figure 1). This unit is similar to the felsic metavolcanics, but apparently intrudes the volcanic sequence.

Both the sedimentary and volcanic sequences have been regionally metamorphosed to greenschist facies. Mafic metavolcanics have a mineral assemblage of hornblende and/or actinolite, plagioclase (albite), quartz, biotite, chlorite, and epidote. The felsic metavolcanics are primarily quartz, plagioclase, biotite, and muscovite. Clasts in the pyroclastics are recrystallized quartz and plagioclase.

STRUCTURE

Folds

Reconnaissance of the structural elements of the Carolina slate belt around the Pageland granite indicates three, or possibly four periods of structural deformation similar to the structural chronology observed in the Carolina slate belt rocks around the Winnsboro complex (see Winnsboro section this report). The first two periods of deformation formed northeast trending separate mesoscopic folds probably equivalent to F_1 and F_2 around the Winnsboro complex. The third deformation, reported by Butler and Howell (1977) as open folding of the metavolcanics and phyllites, is equivalent to the F_3 Flint Hill anticlinorium in the vicinity of the Winnsboro complex.

Approximately 50 km east of Pageland, South Carolina, Howell and Zupan (1974) reported several post-Cretaceous folds and reverse faults. Another group of post-Cretaceous folds can be found in metasediments near the eastern edge of the Pageland granite. These folds are apparently the result of a Tertiary structural deformation (D_7, Table 1, Winnsboro report). These are open, broad wavelength (greater than 40 meters), folds that have axial planar fractures. Clastic dikes either axial planar to, or normal to, the fold axial plane are common in these folds and appear to have formed synchronously with folding. The areal extent of this generation of folding is unknown; therefore, it is not known whether this is a regional tectonic event, or of a local nature.

Faults

The Pageland fault was recognized by Carney and Bundy (1965). As described by Butler and Howell (1977), the Pageland fault forms one boundary of the Crowburg-Wadesboro Triassic basin. A silicified breccia 2-20 m thick occupies the center of the fault zone, and no ductile features have been observed. The amount of displacement on the fault is unknown, but the rocks north of the fault appear to have been downthrown with respect to those south of the fault (Butler and Howell, 1977).

A splay of the Pageland fault was discovered on the western margin of the Pageland complex (Figure 1). The western margin of the Pageland granite in this area is a silicified breccia zone. In the drill core PG-1 a zone of brecciation and zeolitization occur, possibly the result of brittle movement associated with this splay.

PAGELAND GRANITE

The Pageland granite is a 302 $\pm$ 5 m.y. old (Butler and Fullagar, 1975), medium to coarse grained porphyritic biotite-hornblende granite or monzongranite (Streckeisen, 1975, Figure 2). Pink microcline phenocrysts, ranging in size from 0.5 cm to 5.0 cm are the most striking visual characteristic of the granite. Microcline, plagioclase, and quartz occur in nearly equal amounts (Figure 2). Biotite is the most common mafic mineral. Accessory minerals include hornblende, epidote, allanite, titanite, zircon, apatite, opaques, and secondary muscovite. The granite has a weak flow foliation which becomes stronger toward the contacts and where xenoliths are common.

The contact aureole of the Pageland pluton is poorly exposed and therefore the extent of contact metamorphism is uncertain. North of the pluton (south and east of the Pageland fault) the mafic metavolcanics have been recrystallized to amphibolite hornfels facies. As the contact is approached the amount of hornblende increases except where clinopyroxene and garnet are present at the contact with the granite. South of the Pageland pluton the contact aureole extends for 1-2 km into Carolina slate belt phyllites. Approximately 1.5 km south of the pluton (CB7-271, Figure 1) a finely laminated black and gray, well foliated, biotite-cordierite bearing hornfels occurs. Cordierite crystallized in the plane of foliation during contact metamorphism of the biotite which had been kinematically aligned in the plane.

Detailed examination of the cordierite-garnet-biotite assemblages in contact aureoles of the other 300 m.y. old plutons in South Carolina by Speer (personal communication, 1978) has shown that the Winnsboro, Liberty

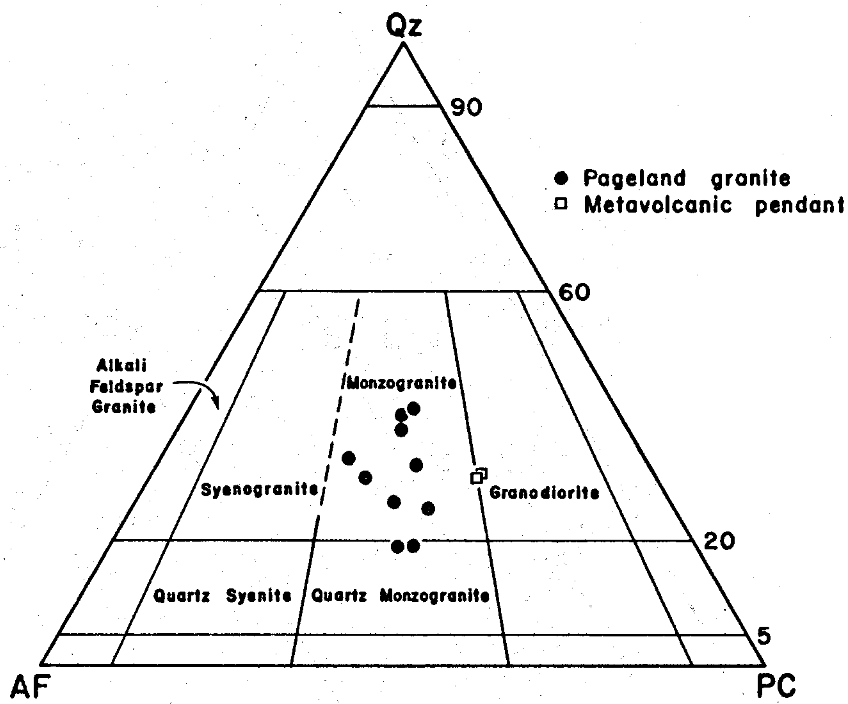


Figure 2a. Quartz-plagioclase-feldspar diagram for the Pageland coarse-grained monzogranite and metavolcanic pendant.

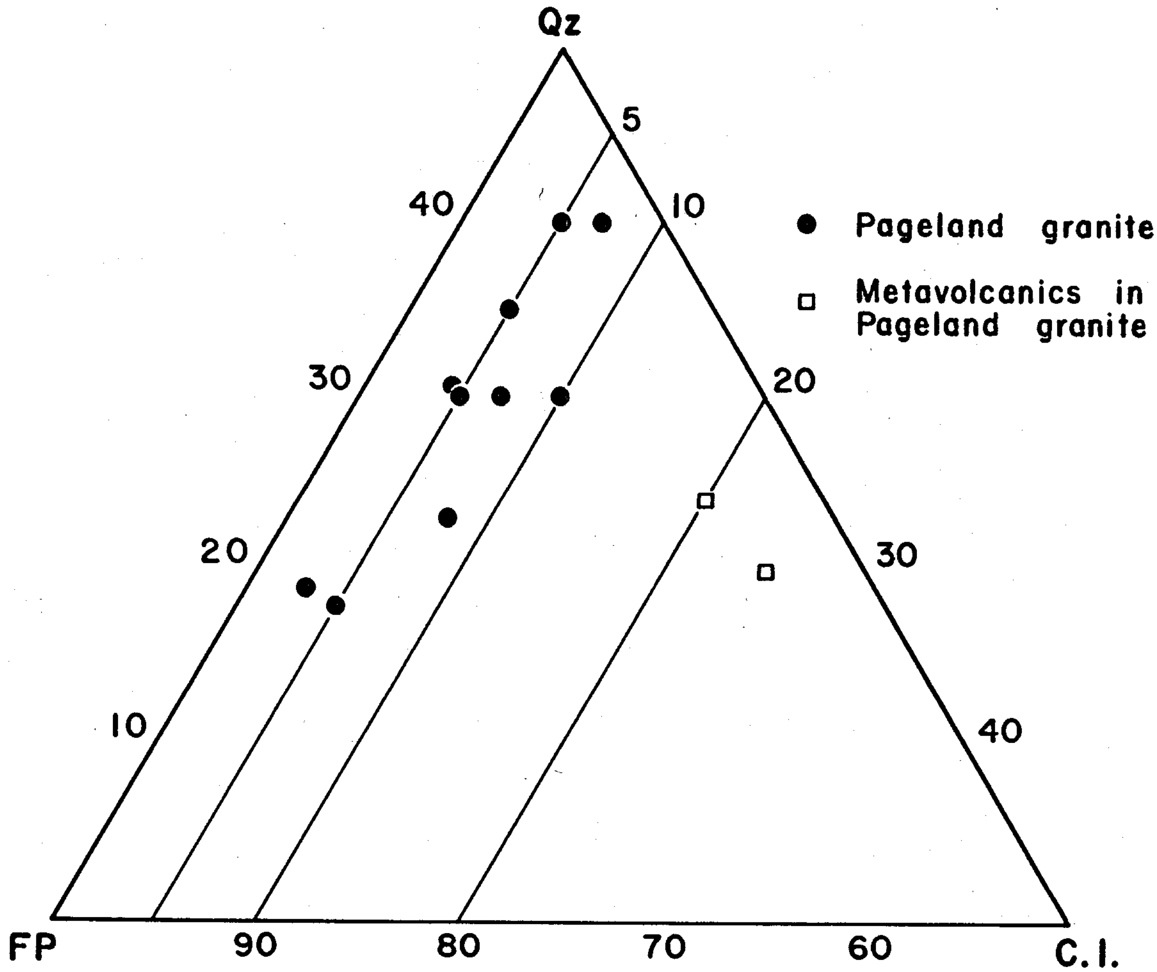


Figure 2b. Quartz-feldspar color-index diagram for the Pageland granite and metavolcanic pendant.

Hill, and Lilesville granites were emplaced as hot (700°C) dry melts at 14 - 16 km. Since the contact aureole of the Pageland granite also contains cordierite-biotite and a cordierite-garnet-biotite assemblage has been reported by Bundy (1960), it is estimated that it, too, was emplaced at approximately 15 km at about 700°C.

In the center of the Pageland granite is a dark gray, fine-grained, biotite-hornblende granodiorite (Figure 2). This granodiorite has a weak igneous flow foliation and many xenoliths, some over a meter long, of Carolina slate belt volcanics. A similar fine-grained granodiorite occurs as xenoliths in the coarse-grained Pageland granite at Forty Acre Rock. Compositionally, the granodiorite is very different from the Pageland coarse-grained granite and other fine-grained phases of 300 m. y. old granites (Figures 2 and 3). Plagioclase is more abundant than microcline or quartz, and is zoned from oligoclase to narrow albite rims. Hornblende and biotite occur in nearly equal amounts, with accessory chlorite, titanite, and epidote. The Rion and fine-grained Liberty Hill have little or no hornblende and biotite, and microcline is more abundant than plagioclase (Farrar and Becker, 1976; Speer and Becker, 1976) (Figures 2b and3). Unlike the Rion and fine-grained Liberty Hill, the Pageland granodiorite is probably not a contemporaneous intruive phase of the main grainte body. Instead, the fine-grained Pageland granodiorite was intruded into the Carolina slate belt lithologies and then itself intruded by the Pageland granite. Perhaps the metatonalite northwest of the Pageland granite is equivalent to the recrystallized fine-grained Pageland granodiorite.

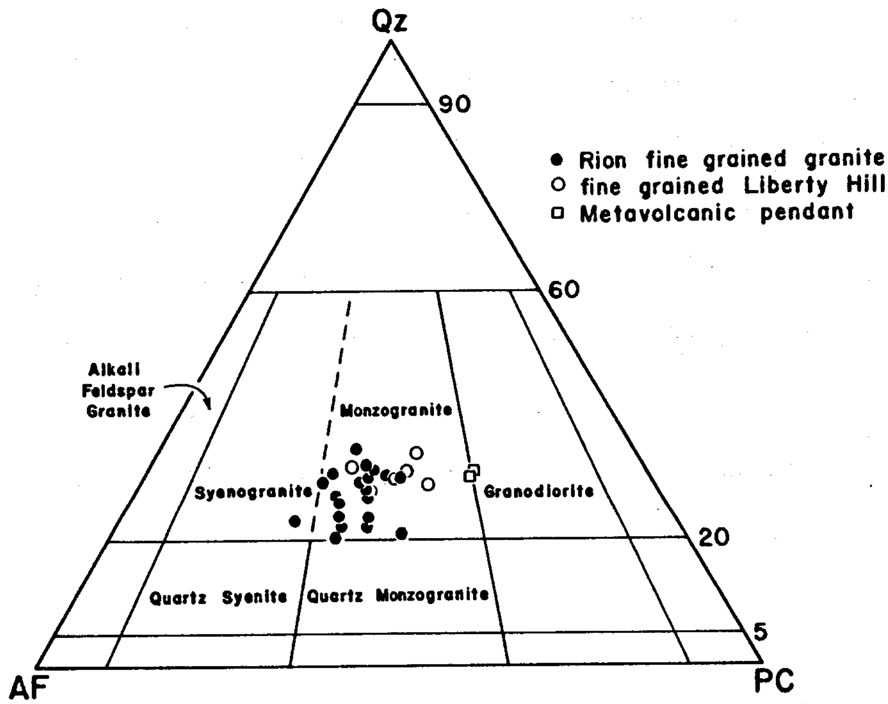


Figure 3. Quartz-plagioclase-potassium feldspar diagram for Rion, Liberty Hill fine-grained monzogranite and the metavolcanic pendant in the Pageland pluton.

PETROGRAPHY OF THE PG-1 DRILL CORE FROM THE PAGELAND GRANITE

The drill core PG-1 was taken from a 694 ft. (210 m) hole in the southwest lobe of the main body of medium-grained Pageland granite (Figure 1). The hole is located over the lower portions of the gravity anomaly for this area. A fault which borders the Pageland granite was not believed to have penetrated the granite body. However, filled fractures can clearly be seen throughout the core, indicating that the fault may extend along the western edge of the granite. Figure 4 shows the combined lithologic and gamma ray log of PG-1, and sample locations for petrography, chemistry, and heat generation.

Petrographically, the Pageland granite in this drill hole is rather homogenous and similar to the Pageland surface samples mentioned in another section of this report. Generally, the prismatic feldspar crystals have no preferred orientation, except in intensely sheared or brecciated zones. Biotite may be aligned in the plane of igneous flow foliation. In the upper 200 ft. (62 m) deuteric alteration of biotite to chlorite and saussuritization of plagioclase occurs. The grain size of the granite begins to change at around 350 ft (115 m) from the medium-grained Pageland granite to the medium- and coarse-grained granite. Near the 350-foot change are interfingerings of medium- and coarse-grained granites. As in the surface samples, xenoliths are rare.

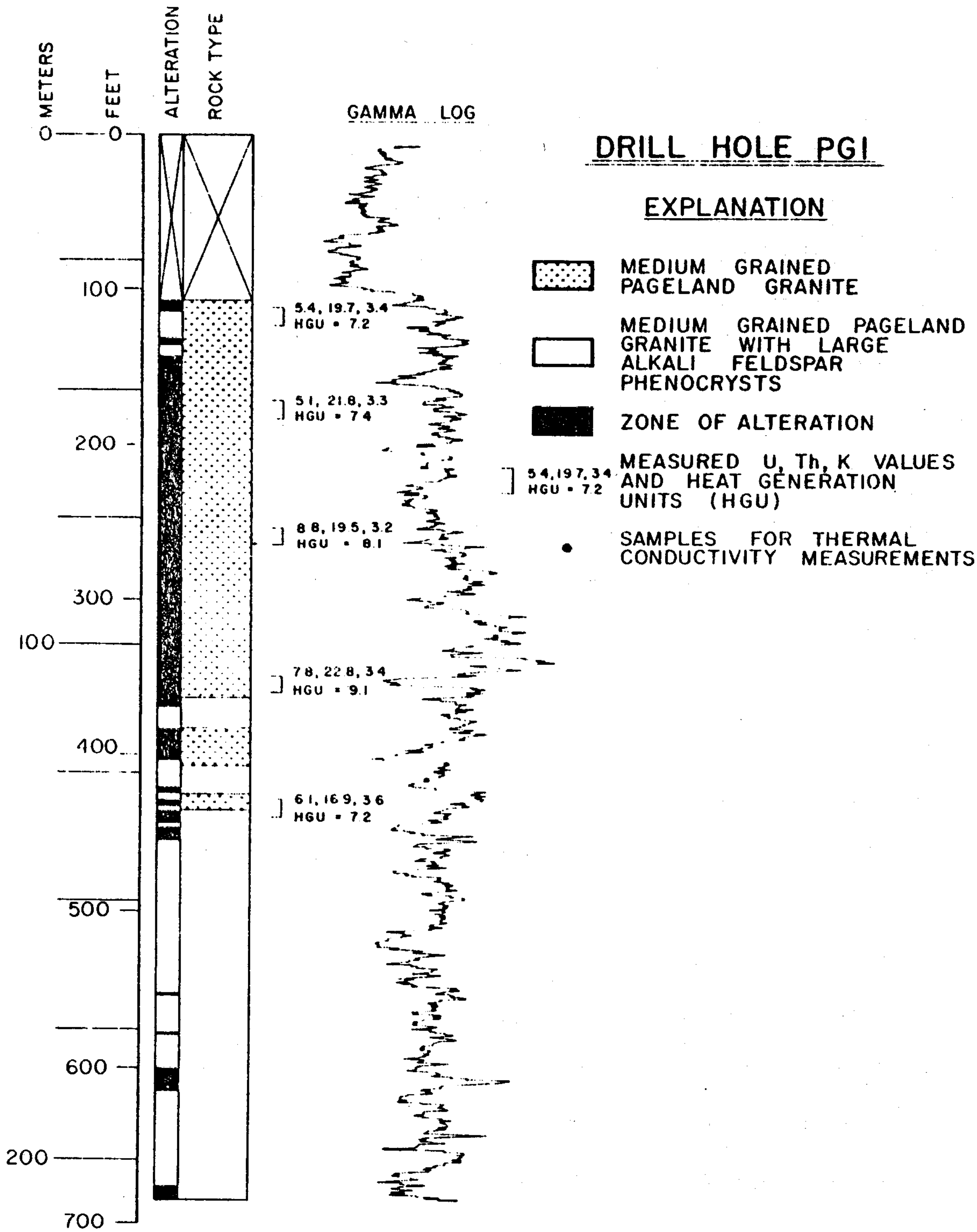


Figure 4. Combined lithologic and gamma ray log for Pageland drill hole PG-1.

Mineralogy of the Pageland granite is the same throughout the core: microperthitic microcline (15-25 mm in diameter), plagioclase zoned from An_{29}-An_5 and unzoned An_{18}, quartz, biotite, and muscovite. Accessory minerals are zircons, allanite, titanite, epidote, calcite (?), apatite, and opaques.

In addition, numerous vertical fractures are filled with zeolites; laumontite and calcite are the most common assemblage. At several depth (in feet) levels (295, 400, 550, 580, 590) the laumontite and calcite are bordered by dark green chlorite and magnetite(?) on the edges of the fractures. Breccia zones (usually less than 3 feet thick) consist primarily of recrystallized quartz and plagioclase with rare microcline sheared along twin planes.

SUMMARY

The porphyritic Pageland granite intruded a metamorphosed and folded sequence of volcanic and epiclastic lithologies approximately 302 ± 5 m.y. ago (Butler and Fullagar, 1975). The Pageland granite is a Late Carboniferous intrusive body like the Winnsboro, Liberty Hill, and Lilesville plutons (Farrar and Becker, 1976; Speer and Becker, 1976). Shape, mineralogy, and texture of the granites are very similar. Apparently, all of the granites were emplaced at approximately the same depth and temperature, in a highly deformed terrane. The cordierite-garnet-biotite-hornfels of the contact aureole indicates that the granite was probably emplaced as a hot dry melt around 15 km if their compositions are similar to those of the Winnsoboro, Liberty Hill, and Lilesville contact rocks (Speer, personal communications, 1978). The pluton was subsequently faulted, and the northwest portion of the pluton has not yet been exhumed. The gravity anomaly associated with the main body of granite indicates that is has a lobate shape with steeply inward dipping contacts.

REFERENCES CITED

Bell, H. III and Popenoe, P., 1976. Gravity studies in the Carolina slate belt near the Maile and Brewer mines, north-central South Carolina: Jour. Res. U. S. Geol. Surv. 4, p. 667-682.

Bell, H. III, Butler, R. S., Howell, D. E., and Wheeler, W. H., 1974. Geology of the Piedmont and Coastal Plain near Pageland, South Carolina and Wadesboro, North Carolina: Carolina Geol. Soc. Fieldtrip Guidebook, S. C. State Devel. Board, Div. of Geol.

Bundy, J. L., 1960. Contact metamorphism in Lancaster County, South Carolina (M.S. thesis): University of South Carolina, Columbia, 61 p.

Butler, J. R. and Fullagar, P. D., 1975. Lilesville and Pageland plutons and the associated meta-rhyolites, eastern Carolina slate belt: Geol. Soc. America, Abst. with Prog. 7, p. 475.

Farrar, S. S. and Becker, S. W., 1976. Winnsboro plutonic complex: Evaluation and targeting of geothermal energy resources in the Southwestern United States (Progress Report), Blacksburg, Virginia Polytechnic Institute and State University. VPI&SU-5103-2.

________, 1977. Winnsboro plutonic complex: Evaluation and targeting of geothermal energy resources in the southeastern United States (Progress Report), Blacksburg, Virginia Polytechnic Institute and State University. VPI&SU-5103-4.

Howell, D. E. and Zupan, A-J. W., 1974. Evidence for post-Cretaceous tectonic activity in the Westfield Creek area north of Cheraw, South Carolina: S. C. State Devl. Board, Div. of Geol. Geologic Notes 18, no. 4, p. 98-105.

Nystrom, P. G., 1967. Geology of the Jefferson N. W. quadrangle (M.S. thesis): University of South Carolina, Columbia, 49 p.

________, 1976. The stratigraphic significance of metamorphosed mafic dikes near Jefferson, South Carolina: South Carolina State Devel. Board, Div. of Geol. Geologic Notes 20, p. 62-72.

Overstreet, W. C. and Bell, H. III, 1965. The Crystalline Rocks of South Carolina: U. S. Geol. Surv. Bull. 1183, p. 1-42.

Speer, J. A. and Becker, S. W., 1976. Liberty Hill Pluton: Evaluation and targeting of geothermal energy resources in the Southeastern United States (Progress Report), Blacksburg, Virginia Polytechnic Institute and State University. VPI&SU-5103-2.

Streckeisen, A., 1975. To each plutonic rock its proper name: Earth-Science Reviews 12, p. 1-33.

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-640-092/524