

ABSTRACT

David R. Sieling. THE GEOLOGY OF PELZER QUADRANGLE, SOUTH CAROLINA. (Under the direction of Dr. David P. Lawrence) Department of Geology, September, 1997.

The Pelzer 7.5' quadrangle, located in the Inner Piedmont of South Carolina, was geologically mapped at a 1:24,000 scale. The rocks were believed to have been emplaced as a nappe (Six Mile nappe) during the Taconic Orogeny. However, subsequent studies divided the quadrangle into Six Mile thrust sheet to the west and the Paris Mountain thrust sheet to the east. The rocks are sillimanite-grade metamorphic rocks including quartz-mica schists, granitic gneisses, biotite gneisses, hornblende-plagioclase gneiss/amphibolites and gabbro-norites. The metamorphic grade was defined by the presence of sillimanite in quartz-mica schists and of metamorphic clinopyroxenes in amphibolites. The coexistence of sillimanite and granitic veins, seams, and pods predict a metamorphic temperature of 650-680°C and a pressure of 5.5 - 6.5 kilobars (or approximately 20 km in depth). The rocks have been through three, possibly four, deformation events including the Taconic, Acadian, Alleghenian, and possibly Penobscottian orogenies. The deformation has created three primary fold styles which, from oldest to youngest, include: isoclinal folds, open synform and antiform folds, and chevron folds. The main penetrative foliation commonly strikes east of north with moderate dips to the east and west, and was produced either in the late Taconic or early Acadian. Several shear zones including one large zone (Grove Creek Shear Zone) trend

northeast through the quadrangle. The Grove Creek Shear Zone, which can be up to 1 km across, indicates Alleghenian dextral movement defined by asymmetric augen and attenuated fold limbs. Some shear zones are truncated by other shear zones, indicating at least two episodes of shear. Thrust faults show northwest transport during reactivation of the Six Mile thrust sheet in the Alleghenian orogeny. This thrust separates rocks of similar lithologies, metamorphic grade and fold styles. Thus, it does not form a major lithologic and tectonic boundary, but is a minor fault within the Six Mile nappe.

**THE GEOLOGY OF PELZER QUADRANGLE,
SOUTH CAROLINA**

A Thesis

presented to

the Faculty of the Department of Geology

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Geology

by

David R. Sieling

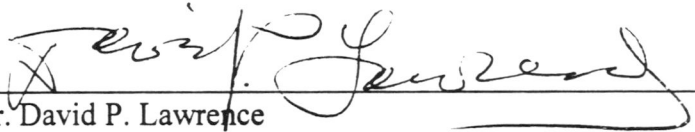
September, 1997

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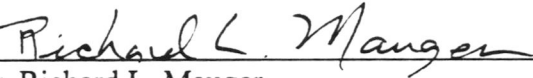
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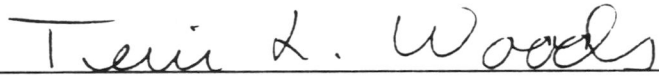
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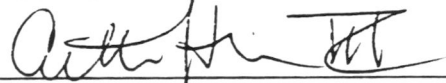
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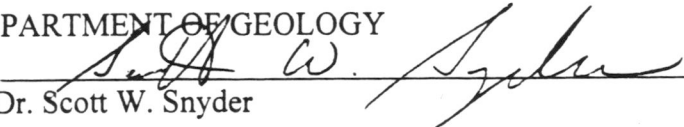
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ACKNOWLEDGMENTS

This project was funded and assisted by the USGS EDMAP Project, the South Carolina Geological Survey, and the Department of Geology, East Carolina University.

I would like to my thesis advisor, Dr. David P. Lawrence. I have never met a person so willing to help in a student's education. Even with my constant questions and frequent office visits, his patience never wore thin. Thank you for your knowledge and wisdom, it will not soon be forgotten. I would also like to thank my committee members, Dr. Terri L. Woods, Dr. Richard Mauger, and Arthur H. Maybin III for their tremendous contribution to this manuscript.

My parents deserve more praise than I could possibly give. Never a bad word, nothing but encouragement, I am so very lucky to have you on my side. Thank you for always being there for me. As for my friends, thanks, you know who you are.

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INTRODUCTION

This study of the Pelzer quadrangle, South Carolina focuses on geologically mapping an area of the Inner Piedmont at the 1:24,000 scale. The goal was to use the detailed geologic data from the Pelzer quadrangle to clarify the lithology, structure, and metamorphic grades associated with past deformation. Furthermore, the results are compared with other studies of the Inner Piedmont in order to assess the local geology and its regional significance.

LOCATION OF THE STUDY AREA

The Pelzer quadrangle is located in northwestern South Carolina approximately 10 miles south of the city of Greenville. The northeast corner of the quadrangle is latitude 34° 45' 00" N, longitude 82° 22' 30" W (Figure 1). The study area is within the Inner Piedmont (Inner Piedmont terrane of Horton and Zullo, 1991) of South Carolina as defined by Overstreet and Bell (1965) (Figure 2).

TECTONIC HISTORY OF THE INNER PIEDMONT

The rocks of the Inner Piedmont began forming approximately 700 Ma (million years ago) as sediment prisms along the edges of the opening Iapetus Ocean (Higgins and others, 1989). These rocks were subsequently lithified, deformed and metamorphosed along with Middle Proterozoic Laurentian basement and cover rocks during the Taconic orogeny. Although Penobscottian orogenic evidence is found in the piedmont of northern

Figure 1. Location map of the Pelzer quadrangle within northwestern, South Carolina.

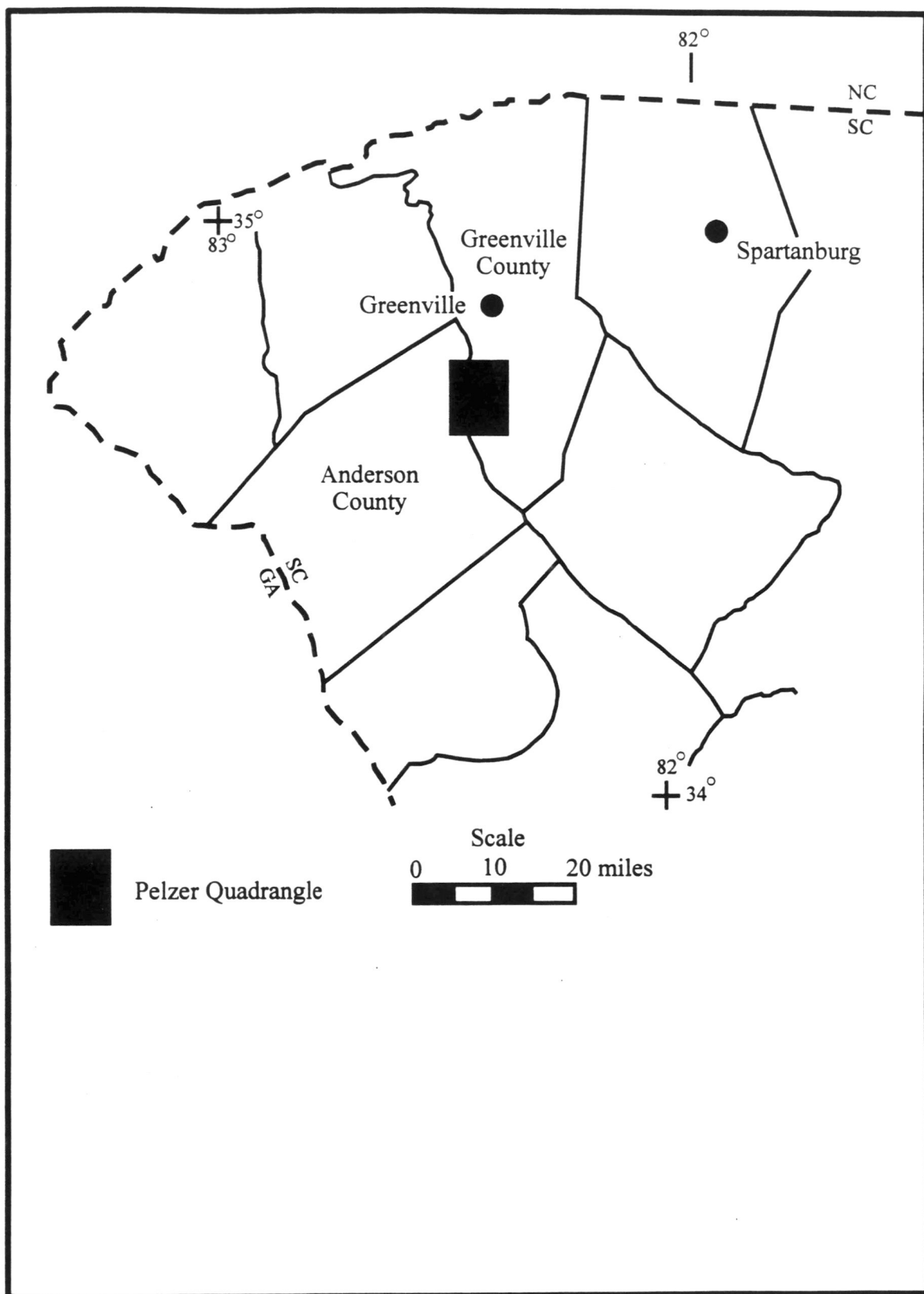
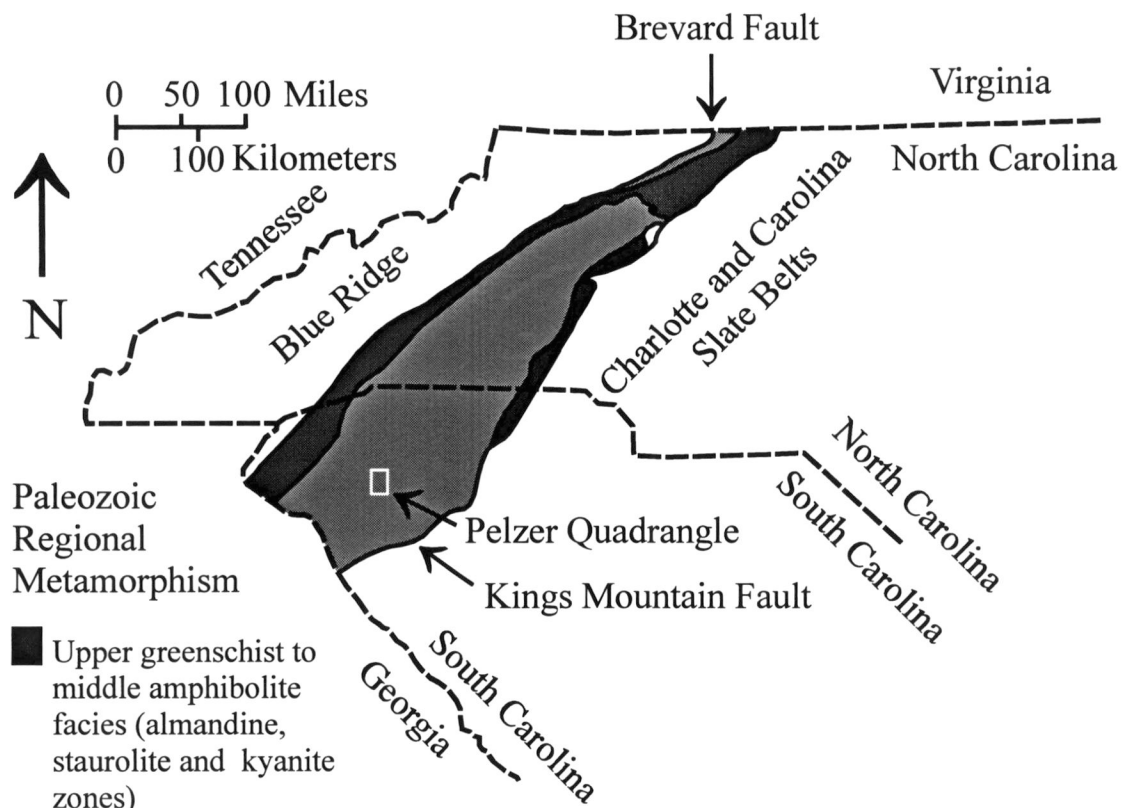


Figure 2. Map depicting the location of the Pelzer quadrangle in the Inner Piedmont as defined by Overstreet and Bell (1965).



The Inner Piedmont of North and South Carolina

Virginia, this pre-Taconic event has yet to be identified in the Inner Piedmont of South Carolina.

Approximately 600 Ma, the Iapetus Ocean began to close, eventually initiating the Ordovician Taconic compressive orogeny (Higgins and others, 1989). This event was presumably responsible for the crystalline thrust sheet/nappe emplacement of the Inner Piedmont in South Carolina (Figure 3). The highest grades of metamorphism were apparently achieved during the Taconic orogeny.

Devonian deformation and metamorphism, possibly associated with the Acadian orogeny, have also been recognized in the Inner Piedmont. However, this deformation is somewhat younger than the Acadian orogeny in the northern Appalachians (Horton and McConnell, 1991).

The final orogeny occurred in the late Paleozoic (Alleghenian) when Laurentia and Gondwanaland collided producing Pangea. The Alleghenian orogeny initiated thrusting and dextral strike-slip motion in the Inner Piedmont (Horton and McConnell, 1991).

PREVIOUS WORK

The Pelzer quadrangle had not previously been mapped in detail. Previous work, both local and regional, includes: Butler (1991), Horton and others (1991), Horton and McConnell (1991), Nelson and others (1987), Bramlett and Griffin (1978), Griffin (1974a), Griffin (1974b), Griffin (1972), Koch (1968), and Overstreet and Bell (1965). The only published geologic map (Nelson and others, 1987) of the region is shown in

Figure 3. Schematic cross section of nappes within the South Carolina Inner Piedmont.
Modified from Hatcher and Hooper (1992).

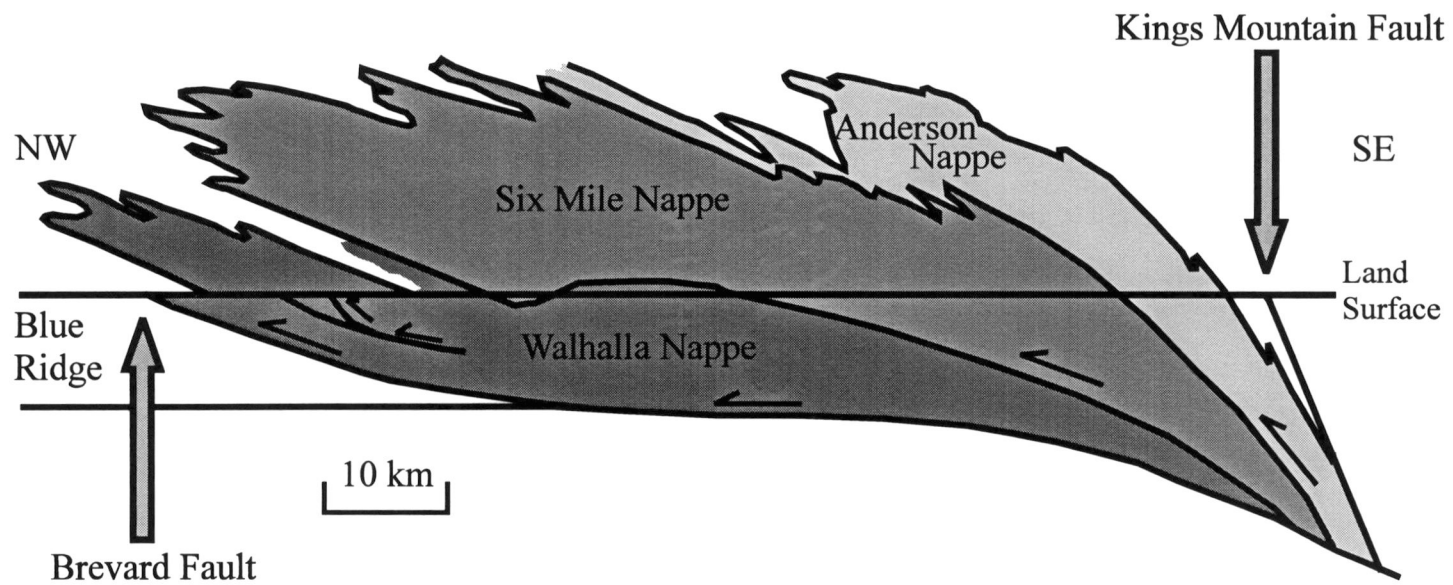


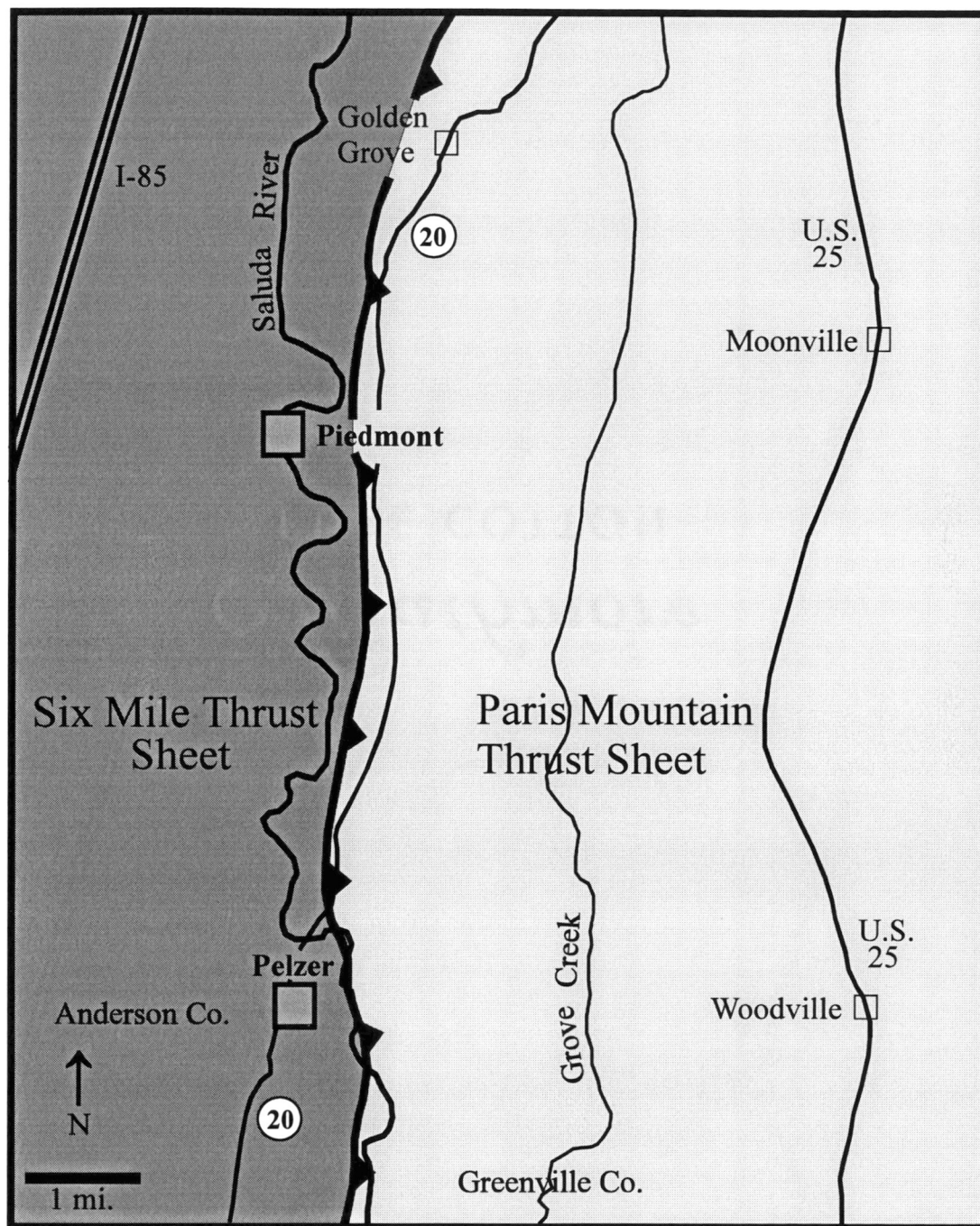
Figure 4. This map shows a thrust contact between the lower Six Mile thrust sheet and the upper Paris Mountain thrust sheet. Thus, Nelson and others (1987) created two thrust sheets out of a region that was originally shown as the Six Mile nappe by Griffin (1969b).

Nelson and others (1987) describe the Six Mile thrust sheet as resting on top of the Chauga-Walhalla thrust complex and containing many rock types including (in order of decreasing abundance) mica schist, red-weathering biotite schist, sillimanite schist and gneiss, amphibolite, various gneisses, that can be porphyroblastic, felsic gneiss, metagraywacke, and some manganiferous schist (Nelson and others, 1987).

The proposed Paris Mountain thrust sheet lies over the Six Mile thrust sheet (Nelson and others, 1987). It is predominately sillimanite facies metamorphic rocks including garnet-sillimanite schist and sillimanite-bearing felsic gneiss. Other rock assemblages include metasiltstone, quartzite, a marker bed of garnet-quartz granulite, and amphibolite in small amounts on the western edge of the thrust sheet. Nelson and others (1987) also state that half of the thrust sheet's volume is granite. The structure and geochemistry of the granite are unstudied.

Griffin (1969b), based on detailed mapping in the western portion of the Inner Piedmont, described the Six Mile thrust sheet as a nappe which flowed westward over the Walhalla nappe during the middle to late Paleozoic orogenies. He described the metamorphic grade within the nappes as almandine-amphibolite facies and the lithologies as muscovite-biotite schist, biotite gneiss, and biotite schist. Isoclinal recumbent folds

Figure 4. Tectonic map of the Pelzer quadrangle modified from the 1:250,000 tectonic map of the Inner Piedmont by Nelson and others (1987).



are the oldest folds within the nappe and were followed by upright synforms and antiforms (Griffin, 1969b).

METHODS

Field work included mapping the Pelzer quadrangle to the 1:24,000 scale, obtaining rock samples for geochemical analysis, thin section analysis, structural analysis, and for determination of metamorphic grade. Structural data, including mineral lineations, schistosity and fold axis orientations are assessed using Wulff net equal angle summary techniques. Laboratory work included identification of minerals and metamorphic grade using petrography and geochemistry. Eleven samples from the quadrangle were analyzed by Fusion-ICP-AES and Fusion-ICP/MS for 10 major oxides and 50 minor trace elements. These analyses helped determine the protoliths for several amphibolites, granitic gneisses and schists.

LITHOLOGIES

The rocks of the Pelzer quadrangle are predominately schists and gneisses of the Inner Piedmont Core (Griffin, 1974b). They are deeply weathered and crop out in streams and on steep hillsides where soil erosion is rapid. Minor occurrences of other lithologies including gabbro-norites, amphibolites/hornblende-plagioclase gneisses, granitic veins, seams and pods, pegmatites and rare quartzite layers were noted throughout the quadrangle (Plate 1).

A conventional stratigraphy was impossible to determine because of extensive weathering, small to poor outcrops, extensive folding of several styles, units that gradually grade into one another, and the lack of top and bottom indicators. Griffin (1974b) states that complex folding and local tectonic slides in the Inner Piedmont of South Carolina make along-strike correlation uncertain. He also states that extensive migmatization can completely transform the original character of the country rock.

Griffin (1974b) indicates that the rocks from the Six Mile nappe include biotite gneiss, mica schist, granitoid gneiss, and amphibolite. He also claims that garnetiferous and magnetiferous quartzite, coarse- to medium-grained calc-silicate rocks, and gabbros commonly occur in small units.

While mapping this quadrangle, some difficulties were encountered in differentiating between various units. Typically, rock units grade into one another (over significant distances) so that a sharp geologic contact is uncommon. Also, the rocks in the quadrangle are extensively weathered. The weathered material from different bedrock

units may look exactly the same (the weathered schistose portion of biotite gneiss appears just like the weathered quartz-mica schist). Making the task more daunting, the units are tabular and typically interlayered at small scales. However, recognition of specific units was only slightly successful hence, most of the map units (Plate 1) are interlayered combinations of two or possibly three lithologies.

My mapping in the quadrangle has recognized most of the previously described Six Mile nappe rock types (which may or may not contain garnet and sillimanite) including: coarse- to very coarse-grained biotite gneisses, quartz-mica schists, granitic gneisses, amphibole-plagioclase gneisses which can grade into amphibolites, gabbro-norites, diorites, mafic hornfelses and quartzites. Griffin's (1974b) description of the Six Mile nappe lithologies conform well to those that I have found.

QUARTZ-MICA SCHISTS

Outcrop Description

The quartz-mica schist is a well-foliated, pervasive rock type occurring as thin to massive tabular units throughout the quadrangle. These tabular units may be 30+ meters thick, but typically they are 3 to 14 meters thick. Commonly, the quartz-mica schist is in concordant contact with other lithologies described below except for the small gabbro-norite bodies which appear to be plutonic. The intrusive contact between the quartz-mica schist and gabbro-norite was not directly examined.

The units weather to a deep, maroon-red color and fresh samples have a more silver-reddish color (Plate 2). Readily weathered and eroded, quartz-mica schist was only found in road or railroad cuts and in stream beds. The schist consistently has a layered appearance with discreet layers of micas and and/or sillimanite interspersed with more quartz-rich layers (Plate 3). Because of the high metamorphic grades, granitic veins, seams and pods are pervasive in the schists and form discrete bands and pods parallel to the main foliation. These granitic rocks are often boudinaged.

The best outcrops of the quartz-mica schist are seen in the road- and railroad-cuts on the east side of South Carolina route 20 in the center of the quadrangle and in the storm water drainage gully in front of Flat Rock Church.

Petrographic Description

The quartz-mica schist is medium- to coarse-grained and composed primarily of muscovite, biotite, sillimanite and quartz; accessory minerals include apatite, chloritoid, epidote, opaques, chlorite and garnet (Appendix). Garnet can be pervasive in some of the schists. It usually has a porphyroblastic texture and makes up to 15 percent of some samples. Graphite was seen in some hand samples.

The amount of sillimanite in a schist sample can vary from a few needles to entire layers (Plate 3). It commonly forms euhedral, elongate, wedge-shaped needles that are often broken into small segments along the length of the crystal (Plate 4). However, very fine-grained sillimanite (almost fibrolite) occurs commonly in most schists. Intimately

Plate 2. Typical outcrop of quartz-mica schist showing the distinctive weathering color.



Plate 3A and B. Two photomicrographs of quartz-mica schists indicating the variability of the mineralogy, texture, and distribution of minerals within the unit. The long dimension of the photomicrographs is 2.9 mm.

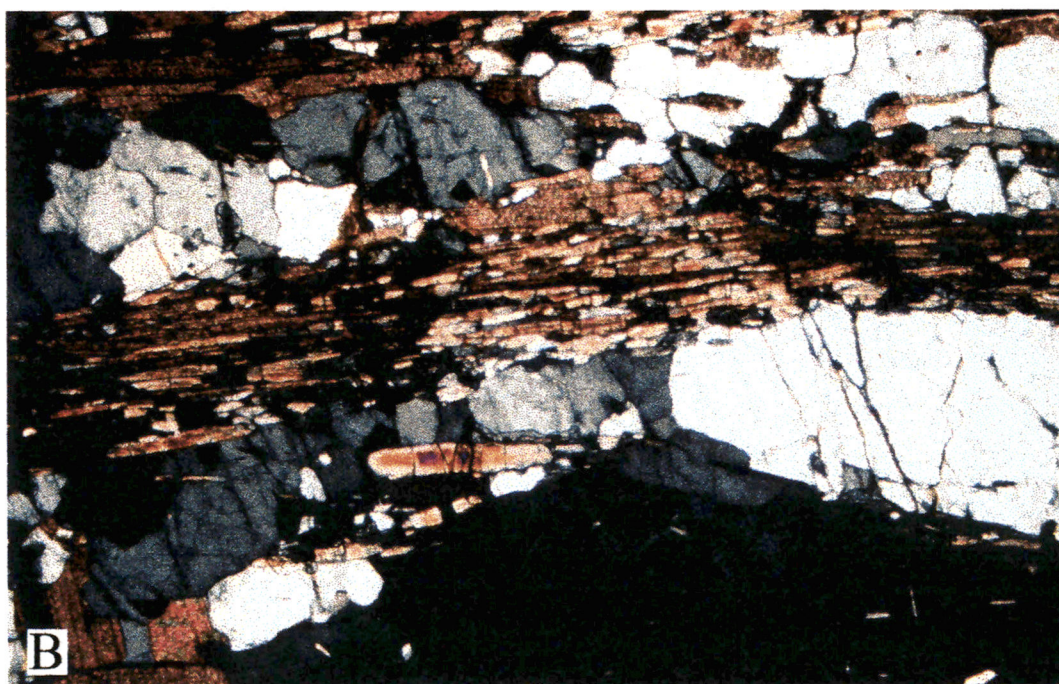
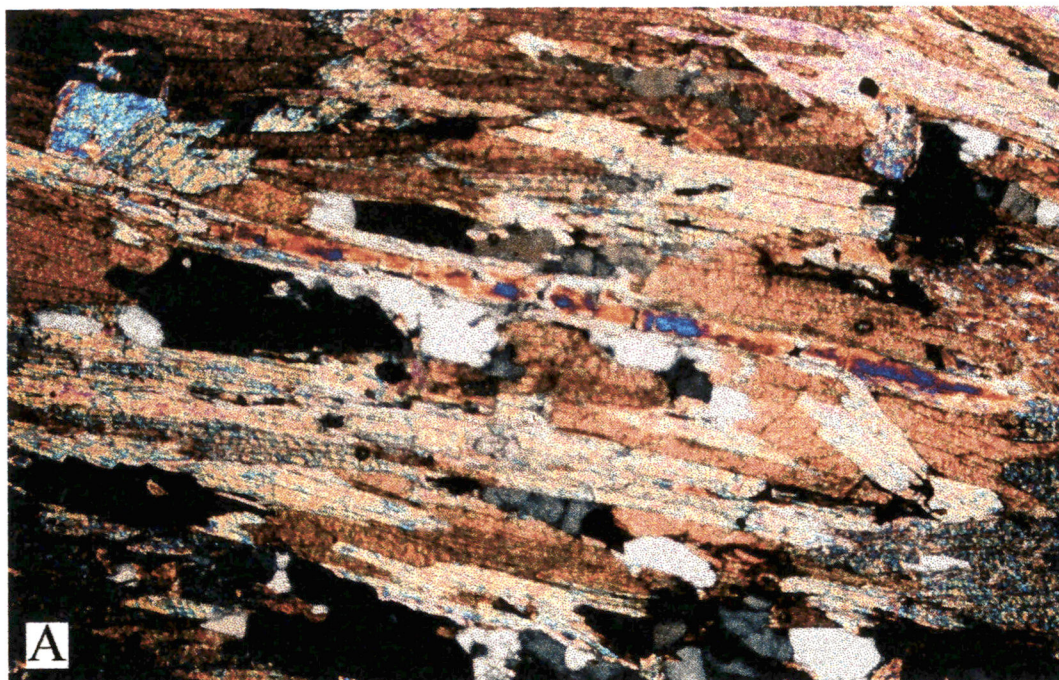
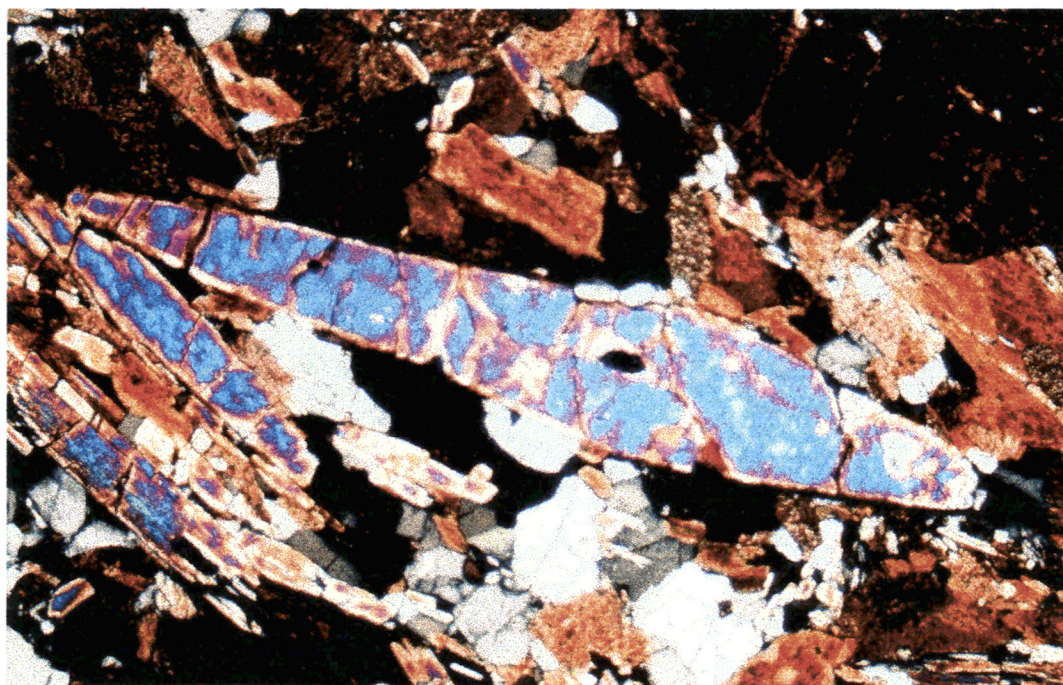


Plate 4. Photomicrograph of a typical boudinaged sillimanite grain in quartz-mica schist.

Large sillimanite grain is 2.5 mm long.



associated with muscovite, sillimanite usually occurs within layers of muscovite and grows parallel to the main foliation. The needles are usually the longest mineral grains in the thin section and are often visible in hand sample.

The porphyroblastic garnets are anhedral to euhedral and are often cracked and decomposed along the crack surfaces (Plate 5). Chlorite growth is extensive in some garnet fractures. Biotite often replaces the garnets partially or wholly leaving a biotite pseudomorph after garnet (Plate 6). Often with the shortest dimension perpendicular to foliation, the garnets are sometimes skeletal and commonly surrounded by biotite or chlorite.

The muscovite and biotite are subhedral to euhedral and, with quartz, make up more than half of the quartz-mica schist. Rarely bent or warped, these micas define the main penetrative foliation along with the sillimanite and define the color of the hand sample. Cross micas do occur but were uncommon (Plate 7). The quartz has an undulose extinction and grains often have the shortest dimension perpendicular to foliation.

GRANITIC GNEISSES

Outcrop Description

The granitic gneisses are typically poorly foliated, often lineated, fine- to medium-grained and generally grayish-white in fresh samples (Plate 8). Commonly, these tabular granitic gneiss layers are in contact with quartz-mica schist and

Plate 5. Photomicrograph of a quartz-mica schist containing a garnet that is decomposing along cracks. The long dimension of the photomicrograph is 2.9 mm.



Plate 6. Photomicrograph of garnet in quartz-mica schist partially replaced by biotite and minor amounts of chlorite. The long dimension of the photomicrograph is 2.9 mm.

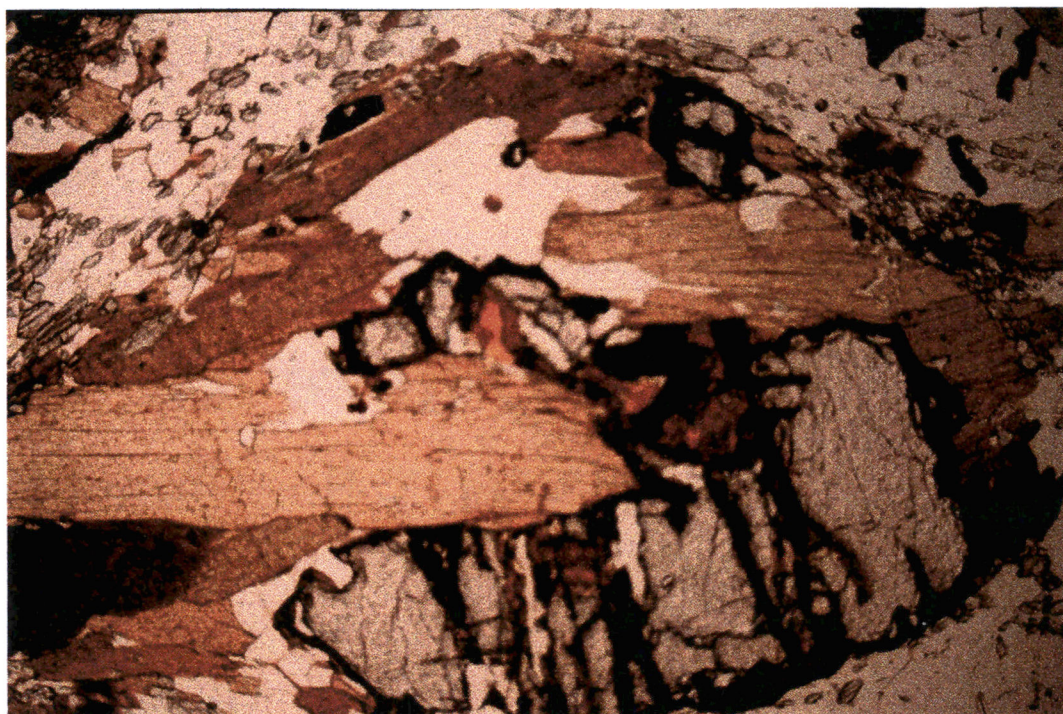


Plate 7. Photomicrograph of quartz-mica schist showing a muscovite grain cutting across the main foliation that trends from right to left. The long dimension of the photomicrograph is 2.9 mm.

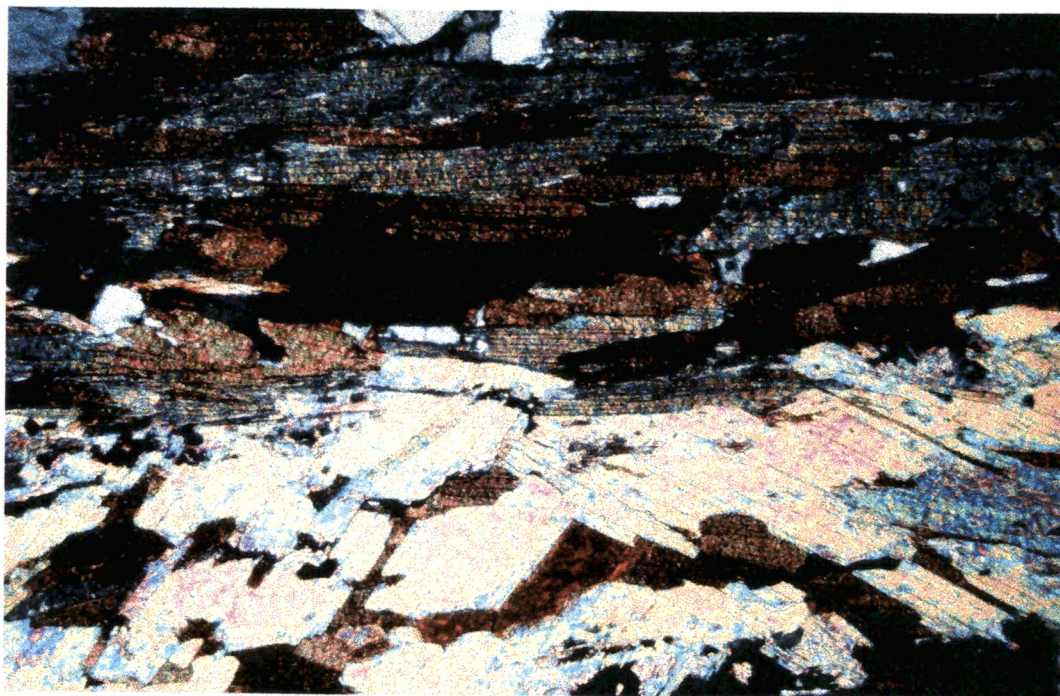


Plate 8. Photograph of typical granitic gneiss outcrop. Note moderately plunging open synform and antiform folds.



amphibolites/hornblende-plagioclase gneisses. These layers can be 30 meters or more thick but typically are much thinner, 3 to 6 meters.

In more weathered samples, the oxidation of biotite imparts a light yellow color to surrounding plagioclase, quartz and potassium feldspar grains. Most often, the rock is granoblastic but can have banding, spotting, and linear fabrics including mineral elongation. Often, this lithology includes more biotite-rich fine- to medium-grained gneiss and augen granitic gneisses.

Plate 9 illustrates the difference between the granitic gneisses and the biotite gneisses. The biotite gneisses are typically much coarser grained than the granitic gneisses and contain more biotite.

The granitic gneisses crop out well in streams, gullies, on hillsides, and in road-cuts. This unit can be interlayered with the quartz-mica schist and it crops out well where the quartz-mica schist does not. Often, valley walls tend to become steeper when cut through this gneiss. Good outcrops occur in the southern portion of Grove Creek where the gneiss is exposed in the cut banks of the incised meanders.

Petrographic Description

The granitic gneisses are composed of quartz, plagioclase (typically oligoclase-andesine), potassium feldspar (typically microcline), biotite and muscovite (Plate 10) (Appendix). Accessory minerals include skeletal, prograde, clinozoisite, sillimanite, metamict allanite (in biotite), apatite, zircon and opaques. The garnets are skeletal

Plate 9. Photograph of biotite gneiss (group A) and granitic gneiss (group B).



Plate 10. Photomicrograph of a typical granitic gneiss. The long dimension of the photomicrograph is 2.9 mm.



indicating rapid growth (Spry, 1969). Biotite is the most distinctive mineral, imparting a “salt and pepper” look to the rock and partly defining a faint mineral stretching lineation that typically occurs in the gneisses east of the Saluda River. Grain sizes tend to be smaller within sheared rocks.

The quartz grains have undulose extinction and some plagioclase grains show albite twins that terminate to points (strain twins). Myrmekite textures are evident. Biotite imparts a poor foliation in thin section and quartz is slightly elongated and flattened imparting a poor schistosity.

Zircon was rare. However, the few grains observed showed morphologies that are rounded rather than euhedral. The crystal shape was distinctive, but sharp terminations were not apparent (Plate 11).

AMPHIBOLITES AND HORNBLende-PLAGIOCLASE GNEISSES

Outcrop Description

Amphibolites and hornblende-plagioclase gneisses occur in the quadrangle as minor pods and interlayers (Plate 1) and are typically black or very dark gray; they may have a salt and pepper appearance (Plate 12). Often, an outcrop will have a brown weathering rind that penetrates a few millimeters. The interior of a sample is generally fresh and unweathered.

Plate 11. Photomicrograph of rounded zircon grains in granitic gneiss. The long dimension of the zircon grains is 0.2 mm.

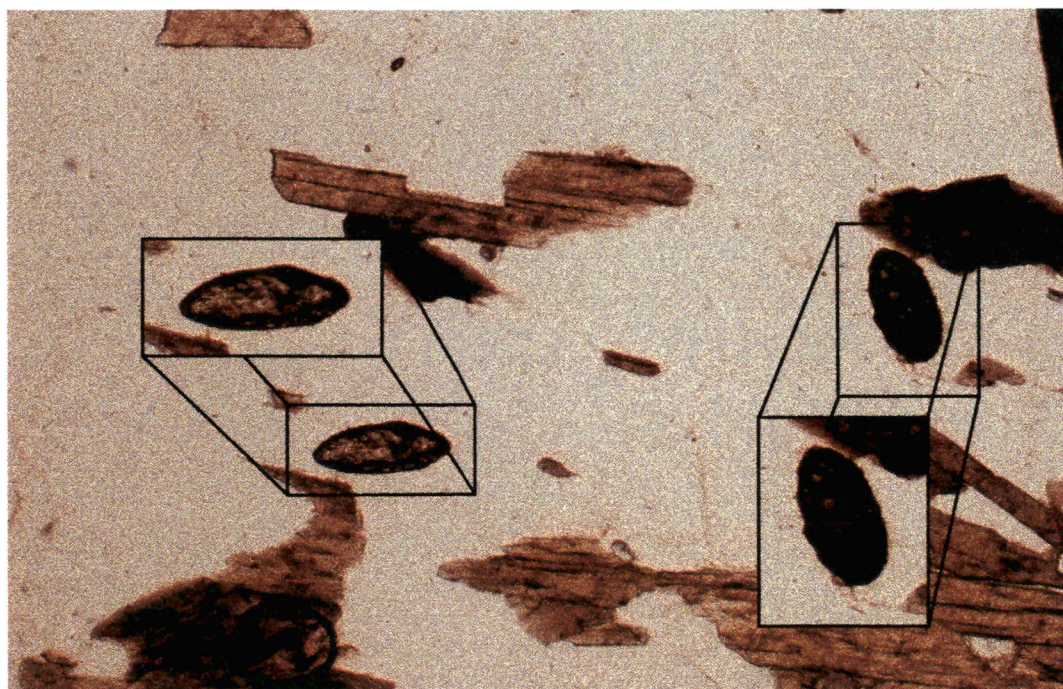


Plate 12. Photograph of a typical hornblende-plagioclase gneiss/amphibolite residual boulders.



The units are usually thin tabular layers (0.5 - 3 meters thick) but larger pods of non-concordant amphibolites can cover larger areas. These units are commonly in contact with the quartz-mica schist, biotite gneiss, and granitic gneiss.

The amphibolites and hornblende-plagioclase gneisses crop out well in streams as pavement outcrops and residual boulders occur along the trend of the unit. Amphibolites and hornblende-plagioclase gneisses are widespread, but they can not be correlated between neighboring streams.

The samples have a slight schistosity because of parallel alignment of the stubby amphibole grains. They often contain quartz veins and pegmatite veins.

Petrographic Description

The samples are medium-grained, granoblastic, equigranular and composed of amphibole, plagioclase (typically andesine), biotite, quartz, and rare clinopyroxene with accessory amounts of apatite and opaques (Plate 13) (Appendix).

The amphibole grains are typically medium-grained (some a little larger), drab olive-green in plane polarized light, subhedral to euhedral, well cleaved, highly pleochroic and normally the largest mineral grains in a sample. Exsolution in the clinopyroxenes is common. Some plagioclase twins are strain bent and quartz has undulose extinction. Biotite in a sample increases with proximity to a quartz vein.

Plate 13. Photomicrograph of a typical amphibolite/hornblende-plagioclase gneiss. The long dimension of the photomicrograph is 2.9 mm.



GABBRONORITES

Outcrop Description

The medium-grained, non-metamorphosed gabbronorites found within the mafic complex (Plate 1) are often dark with a salt and pepper appearance imparted by the clinopyroxene and plagioclase laths. These rocks typically form spheroidal, residual boulders that have a brown weathering rind that often breaks off in curved fragments (Plate 14). The boulders are best found in river valleys and on steep hillsides. Often, the gabbronorites occur as rounded boulders up to 3 meters in diameter across scattered across fields, flood plains, and hillsides. This unit appears to be of plutonic origin and was intruded into quartz-mica schists and granitic gneisses.

Petrographic description

The gabbronorite is composed of plagioclase (typically labradorite), clinopyroxene, occasionally orthopyroxene, amphibole and quartz with some traces of opaques and biotite (Plate 15) (Appendix). The plagioclase is typically lath shaped; an amphibole rim can often be seen around the clinopyroxenes (Plates 15 and 16). The gabbronorites contain no olivine. The crystals are randomly oriented with a granoblastic texture.

Plate 14. Photograph of typical gabbro-norite residual boulder. Large boulder is 1 meter across.



Plate 15. Photomicrograph of a typical gabbro-norite. The long dimension of the photomicrograph is 2.9 mm.

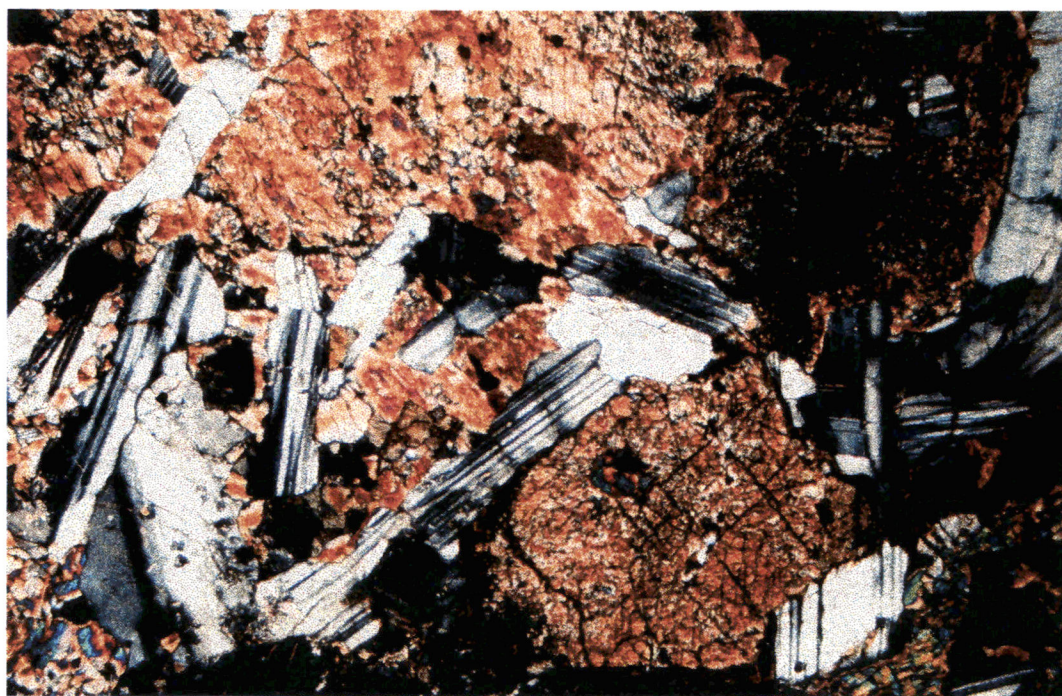
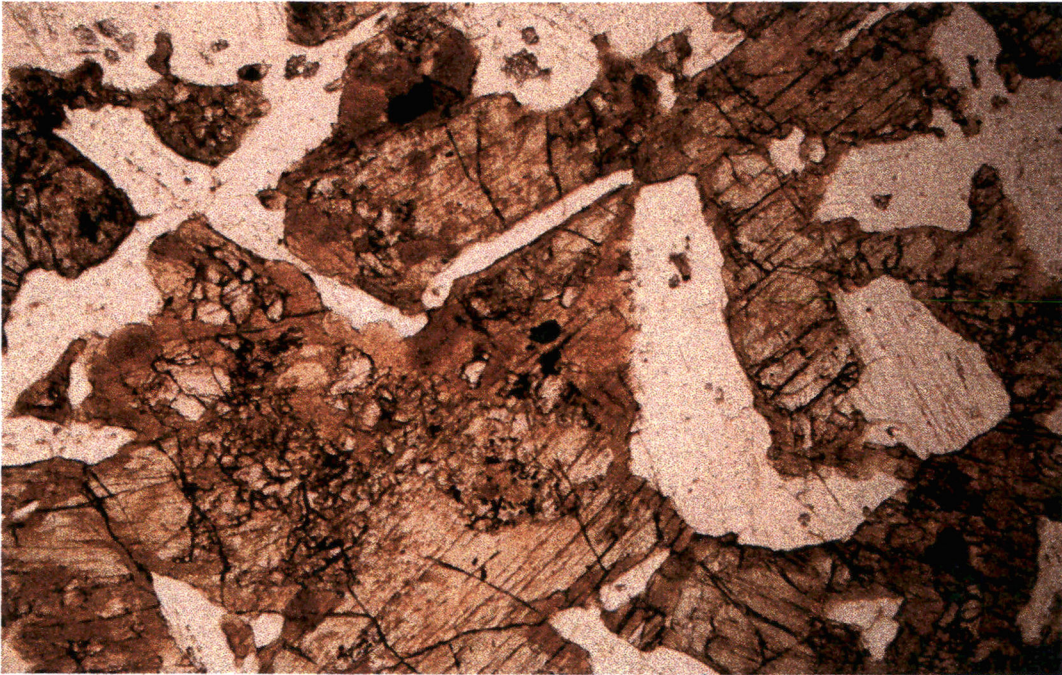


Plate 16. Photomicrograph of a typical gabbro-norite showing the light brown amphibole rim encompassing the clinopyroxene grains. The long dimension of the photomicrograph is 2.9 mm.



BIOTITE GNEISS

Outcrop Description

The biotite gneisses are generally coarse- to very coarse-grained, homogeneous, banded, or augened rocks that cover large regions of the western half of the quadrangle and to a lesser extent the east (Plate 1). This coarse grain size helps differentiate it from the granitic gneisses that are typically fine- to medium-grained (Plate 9). However, the grain size can be drastically reduced in shear zones.

This gneiss is black and white in hand specimen and tends to form rust-red clayey soils. Weathered, schistose gneisses are difficult to differentiate from weathered quartz-mica schist (Plate 17).

This unit forms the thickest layers in the quadrangle, up to 40+ meters thick (Plate 18). It is typically interlayered with thin layers of quartz-mica schist and amphibolite/hornblende plagioclase gneiss.

The gneissic bands are usually alternating quartzofeldspathic layers and biotite-dominated mica schist layers. The banding can be 1 mm to 30-40 cm thick and can change character rapidly from banded to homogeneous (Plate 19).

The biotite gneisses crop out well in streams, on steep hillsides and in some road-cuts. Good outcrops can be seen along Hurricane Creek on the western border of the quadrangle (Plate 20). The interlayering of the unit may also be expressed in the microtopography of some fields (Plate 21).

Plate 17. Photograph of a typical weathered, banded biotite gneiss saprolite outcrop.



Plate 18. Photograph of biotite gneiss in the south wall of the Vulcan Lakeside quarry approximately 1.5 km north of the field area. The layering shown in these rocks (indicated by the red line) represents the strike and dip of the average schistosity for the region. These layers probably occur as isoclinal fold limbs within the Six Mile nappe. Truck in the lower right is approximately 5 meters high.



Plate 19A and B. Photographs A and B show how the biotite gneiss lithology varies in texture. In photograph A, the gneiss shows a distinctive banding. In photograph B, the gneiss has a less banded, more homogeneous texture (lens cap for scale). Both photographs are of samples from the Vulcan Lakeside quarry, 1.5 kilometers north of the field area.



Plate 20. Typical outcrop of biotite gneiss as a shoal on Hurricane Creek. The location is near the western edge of the quadrangle.



Plate 21. Photograph of the microtopography caused by differential erosion within the biotite gneiss unit. The quartzofeldspathic layers hold up the low ridges while, the micaceous portions create the topographic lows.



Petrographic Description

The biotite gneiss is a granoblastic to schistose rock that is coarse- to very-coarse grained and contains (in order of decreasing abundance) quartz, plagioclase (typically oligoclase-andesine), biotite, microcline, muscovite, sillimanite, chlorite and rutile (Plate 22). Microcline and sillimanite were not found in the same thin section. The minerals in the homogenous biotite gneiss are typically randomly oriented but can sometimes exhibit a weak schistosity. Quartz generally has an undulose extinction and plagioclase often shows strain twinning. Occasionally, biotite will be slightly warped and bent. The biotite and microcline are subhedral to euhedral while the muscovite and the plagioclase are anhedral to euhedral. The quartz is anhedral. Typically muscovite grew in two distinct sizes, fine- and coarse-grained. Ribboned quartz parallel to the main foliation is not uncommon and segments have often recrystallized (Plate 23).

OTHER MINOR LITHOLOGIES

Granitic veins, seams and pods

Granitic veins, seams and pods were pervasive throughout the quadrangle and are typically contained in the quartz-mica schists. Often, the granitic rocks occur as pods and small layers within the quartz-mica schists parallel to the main foliation. The granitic rocks were generally medium- to coarse-grained, quartzofeldspathic, igneous-textured

Plate 22. Photomicrograph of a homogenous coarse-grained biotite gneiss. The long dimension of the photomicrograph is 2.9 mm.

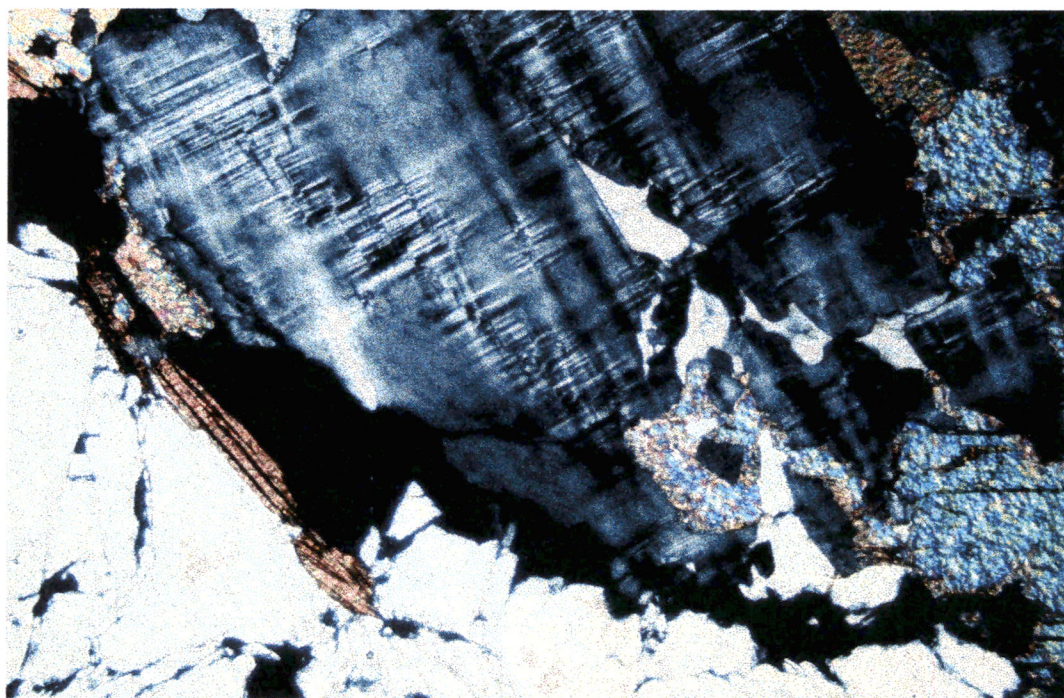
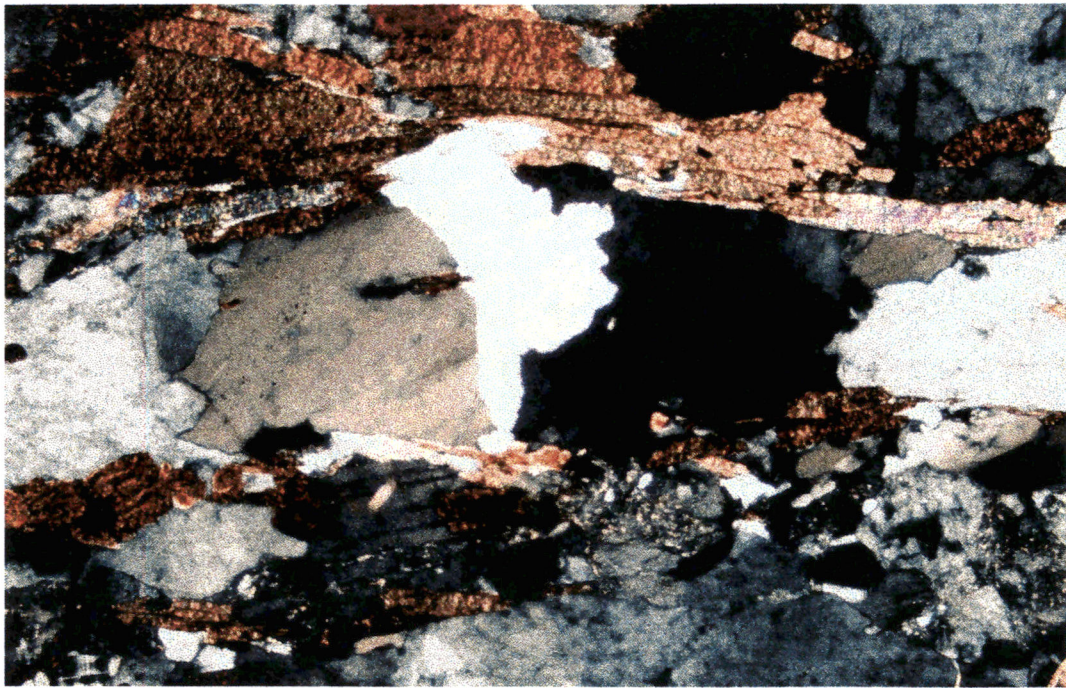


Plate 23. Photomicrograph of biotite gneiss showing strain recovery in a stretched quartz grain. Quartz is stretched parallel to foliation. The long dimension of the photomicrograph is 2.9 mm.

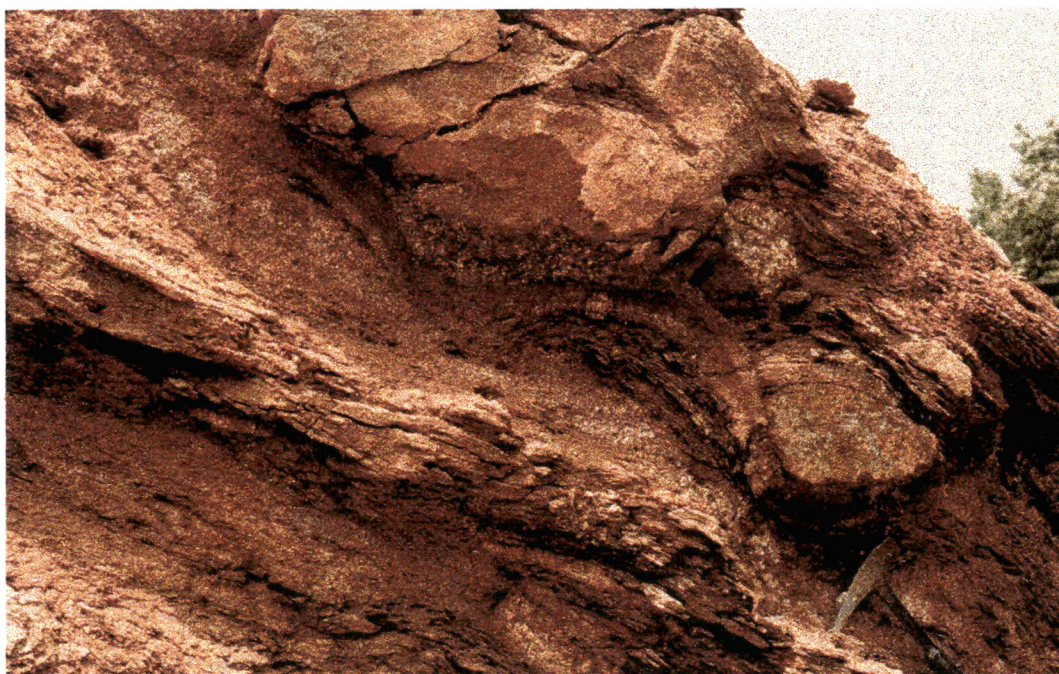


rocks that had a high resistance to weathering, often supporting schist outcrops. The layering was often boudinaged and typically stretched east-west (Plate 24).

Pegmatites

Pegmatites occur as intrusions on a small scale. Characteristically, the pegmatites are resistant to weathering and often create waterfalls on small streams or form outcrop in valleys where none would be expected. Feldspar crystals can be 5-6 cm long, garnets can range from 1 to 5 mm, quartz crystals up to 3 cm, and muscovite “books” up to 7 cm in width. The pegmatites appear to have a slight layering defined by dominant quartzofeldspathic sections. Occasionally, the pegmatite looked as if it contained asymmetric augen.

Plate 24. Photograph of quartz-mica schist containing boudinaged granitic sill (above hammer head). Photograph is taken looking directly north.



STRUCTURE

The rocks of the Pelzer quadrangle have a complex and long deformation history including three (possibly four) orogenies resulting in a complex series of foliations, gneissosities, layers, lineations, folds, faults, and shear zones. Structural data from the quadrangle include measurements of schistosity, gneissosity, lineations, and fold axis orientations. Since compositional layering, gneissosity and schistosity are parallel to subparallel, these measurements will be grouped together under the title “schistosity”.

FOLDS

The three fold styles within the Pelzer quadrangle are isoclinal folds, open, broad synform and antiform folds and asymmetric chevron folds. The sequence of these fold styles elsewhere in the Inner Piedmont is uncertain. Past investigations of the folds in the Inner Piedmont has yielded a variety of fold styles and deformation events.

Griffin (1969b) believed that “the primary stratification surfaces were gradually brought through each successive stage of a fold by a continuous deformation over a long interval of time. Increasing temperature and confining pressure, as well as increases in water pressure, with accompanying recrystallization serve to enhance the extreme elongation and attenuation of the primary fold limbs, resulting in tectonic slides and boudinage”. Griffin (1969b) also stated that “resistance of overlying rock mass served to redirect the stress field causing extension of the primary folds in a subhorizontal position. This continuing flow against this resistance to this forward horizontal pressure resulted in

a superposition of secondary low amplitude folds. As the plasticity of the fold decreased, probably in response to decreasing temperature, slip cleavage was superimposed on all pre-existing foliations, producing crenulated folds.” Each fold style will be discussed below.

Isoclinal Folding

The isoclinal folds are rarely seen in hand sample and are uncommon in the field. Fold axis orientations generally trend north-south, but the one fold axis measurement gave a trend of N60W with a plunge of 20 degrees to the north (Figure 5).

A hand sample, Plate 25, shows isoclinal folding in which the main penetrative foliation is parallel with the fold axial plane. A close inspection of the sample reveals the isoclinal fold may be isoclinally folded, indicating two separate isoclinal folding events (Plate 25). Due to lack of exposure and inadequate thin section expression, it is difficult to resolve the timing between these two fold events without ambiguity.

Griffin (1969b), based on his detailed studies near this field area, stated that recumbent isoclinal folding is the basic structural style and is the oldest fold event. Tull (1979), using data from the Inner Piedmont from North Carolina to Alabama, states the first phase of folding is isoclinal, commonly recumbent and is accompanied by an axial planar metamorphic foliation. He also states that these folds are broadly syn-metamorphic.

Figure 5. Equal angle Wulff net plot of fold axis orientations. Diamonds represent isoclinal folds, circles represent open synform and antiform folding, and triangles represent chevron folding.

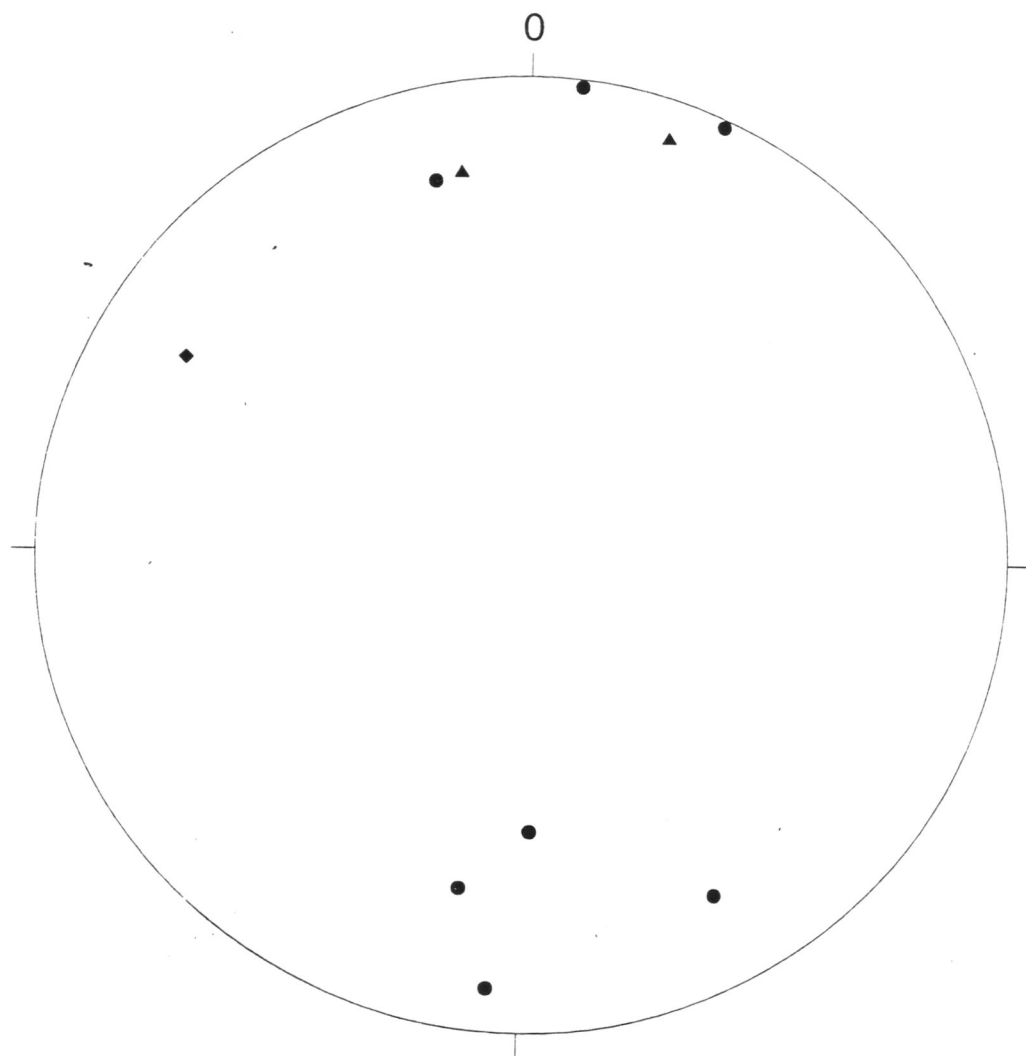
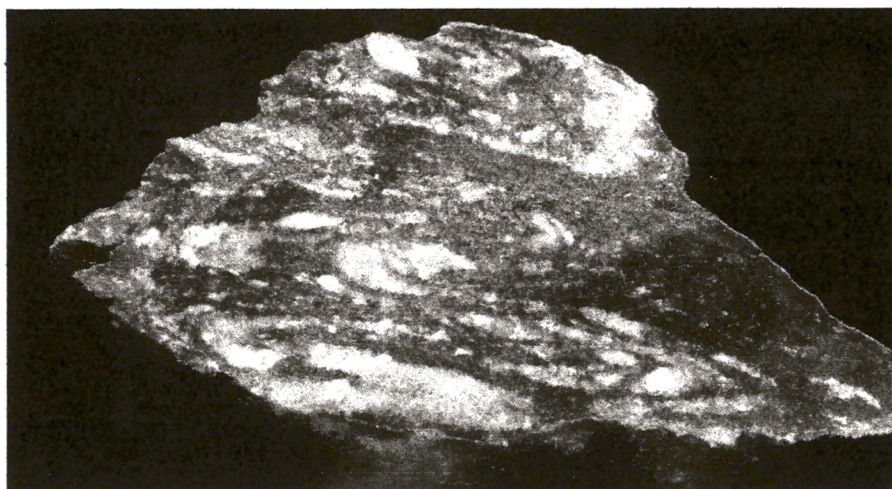


Plate 25. Scanned image of a slabbed biotite gneiss showing isoclinal fold style.

Schistosity is parallel to the fold limbs and fold axial plane. Rock sample is approximately 8 cm long.



Open Synform and Antiform Folding

The most data about folds come from the open, broad, cylindrical synform and antiform folds that occur throughout the field area (Plate 26). These folds typically have wavelengths greater than 5 meters and amplitudes of 0.5 meters. The majority of the fold axis orientations trend north-south with moderate plunges in both directions (Figure 5) (Plate 8). Evidence from the field, as well as hand samples, suggests that the isoclinal folds were warped by this gentle folding (Plate 18). These later-phase folds commonly exert the dominant control over outcrop pattern of mappable stratigraphies (Tull, 1979).

Chevron Folding

The chevron fold style is prevalent throughout the quadrangle and the folds deform the original penetrative foliation created with the isoclinal folds. The folds are usually small, with a maximum amplitude and wavelength of a few centimeters; and they are most common in quartz-mica schists and schistose portions of the banded biotite gneisses (Plate 27). This chevron folding is well expressed in photomicrographs as polygonal folds (Plate 28).

Fold axis orientations tend to be north-south and have a shallow to moderate plunge to the north and south (Figure 5). Griffin (1969b) claimed that continuing work has brought to light small asymmetric folds, or mesoscopic crinkles, formed at a few localities by widely spaced shear surfaces intersecting the primary foliation, probably a slip cleavage.

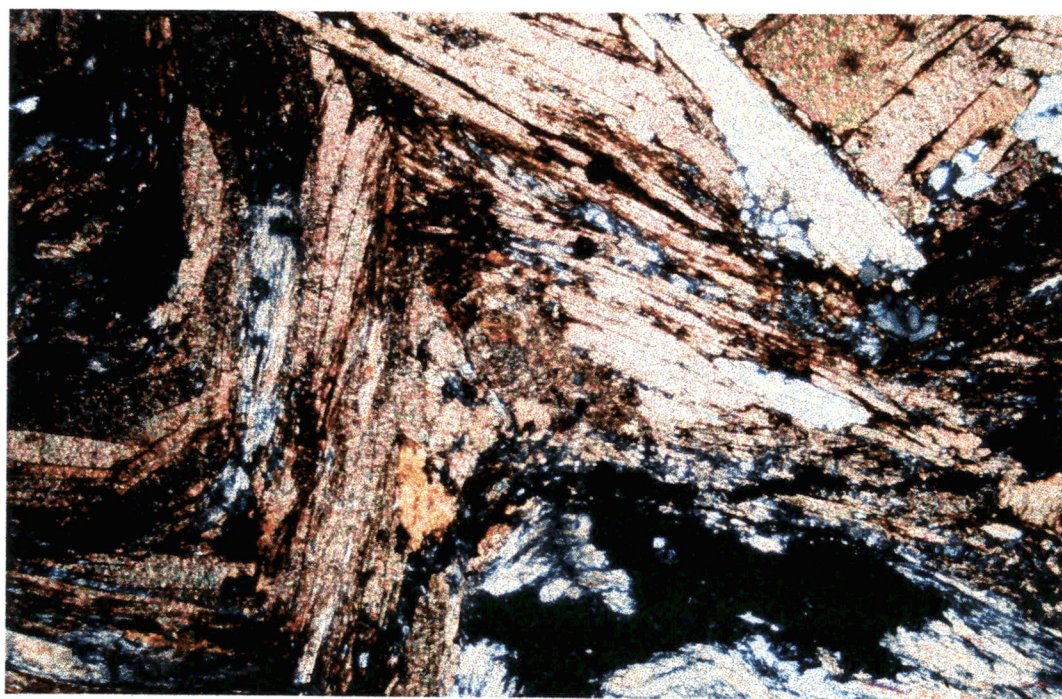
Plate 26. Photograph of open synform and antiform folding in biotite gneiss. Hammer head is resting on fold axis of anticline.



Plate 27. Scanned image of a thin section showing the chevron fold style in a quartz-mica schist. Thin section is 46 mm in long dimension.



Plate 28. Photomicrograph of a chevron fold from the thin section in Plate 27. The long dimension of the photomicrograph is 2.9 mm.



SCHISTOSITY

The “schistosity” of the rocks includes foliations, gneissosities and layering within the rocks in the study area. Most measurements were made of the foliation in schistose portions of schists and gneisses. Bramlett and Griffin (1978), who have worked close to the Pelzer quadrangle, state that foliations are probably parallel or subparallel to bedding. They infer this relationship because the foliation generally parallels the zig-zag recumbent/reclined fold pattern of compositional layering. Thus, all measurements including foliation, gneissosity and layering parallel the schistosity.

Griffin (1969b) also states that stream directions are controlled by schistosity and joints. This is true in the Pelzer quadrangle where most major rivers and creeks run north-south following the main schistosity strike while smaller tributaries run east-west following the dip direction of the schistosity. Plate 29 shows Grove Creek flowing east down schistosity dip in granitic gneiss.

Three hundred and twenty-five schistosity orientations were plotted on an equal angle Wulff net to generate the pole to plane diagram represented in Figure 6. This figure shows a spread of poles girdling the center of the Wulff net. This east-west band represents a predominately north-south strike of schistosity. The east-west spread probably represents the dispersion of schistosity caused by the open synform and antiform folds.

The strike directions, shown on a rose diagram (Figure 7), indicate that the average strike of schistosity is N5E-N10E. If this schistosity was intimately associated

Plate 29. Photograph of Grove Creek flowing east; stream channel follows the schistosity dip in the bedrock. Waterfall is one meter high.

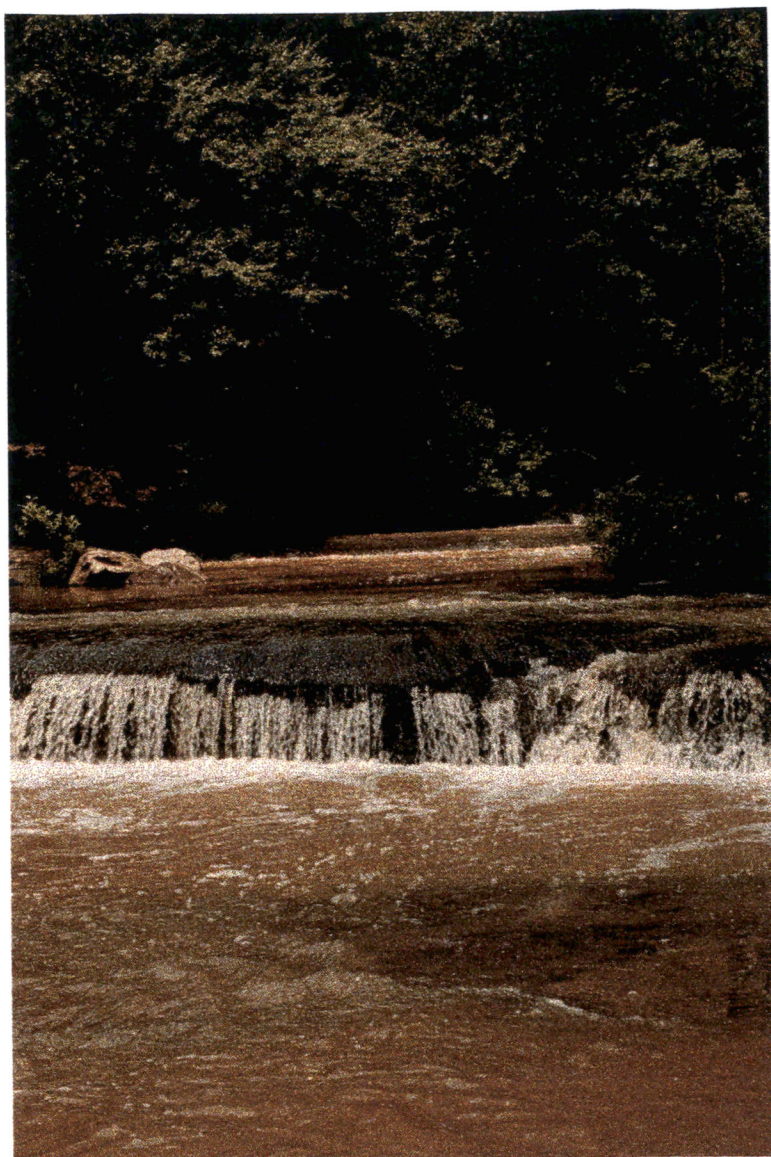


Figure 6. Equal angle Wulff net plot of 325 schistosity orientations (pole to plane).

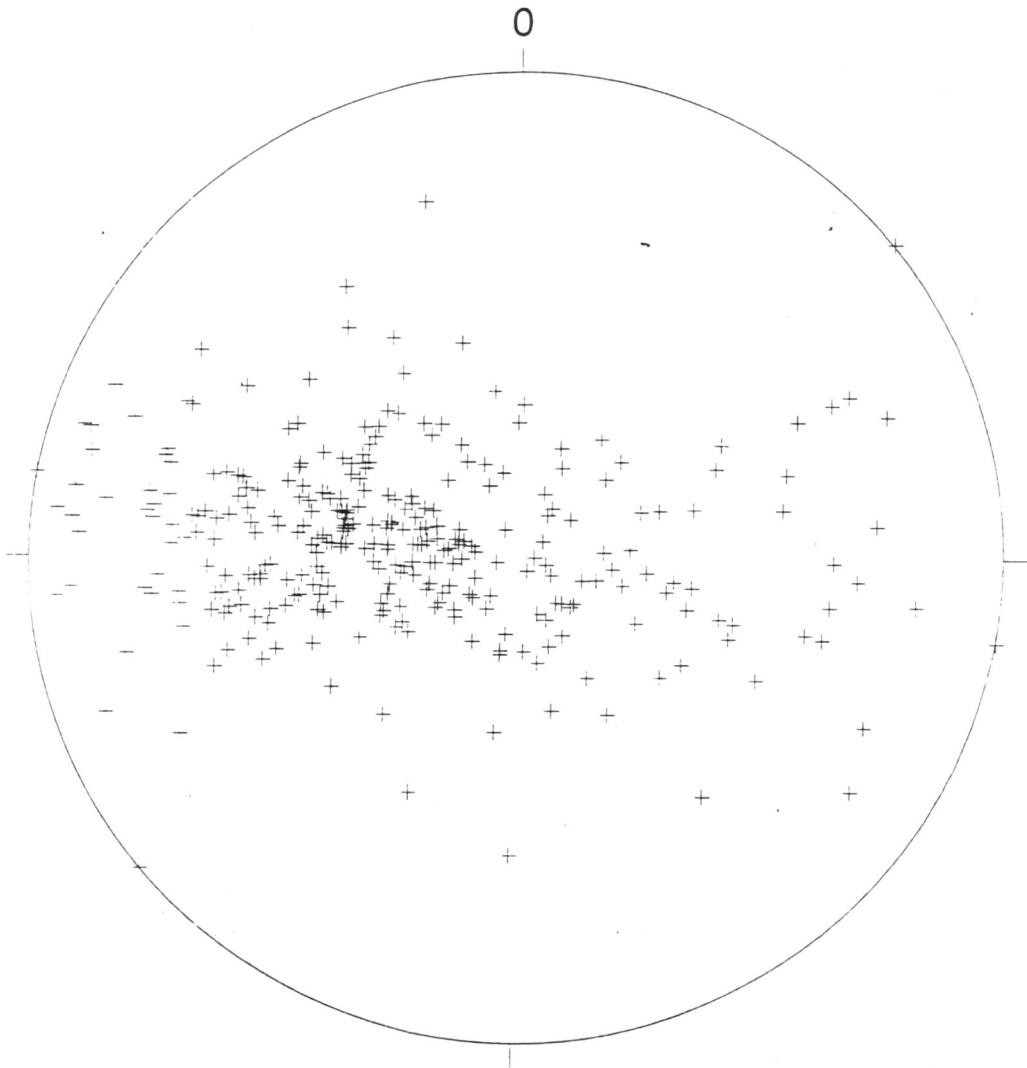
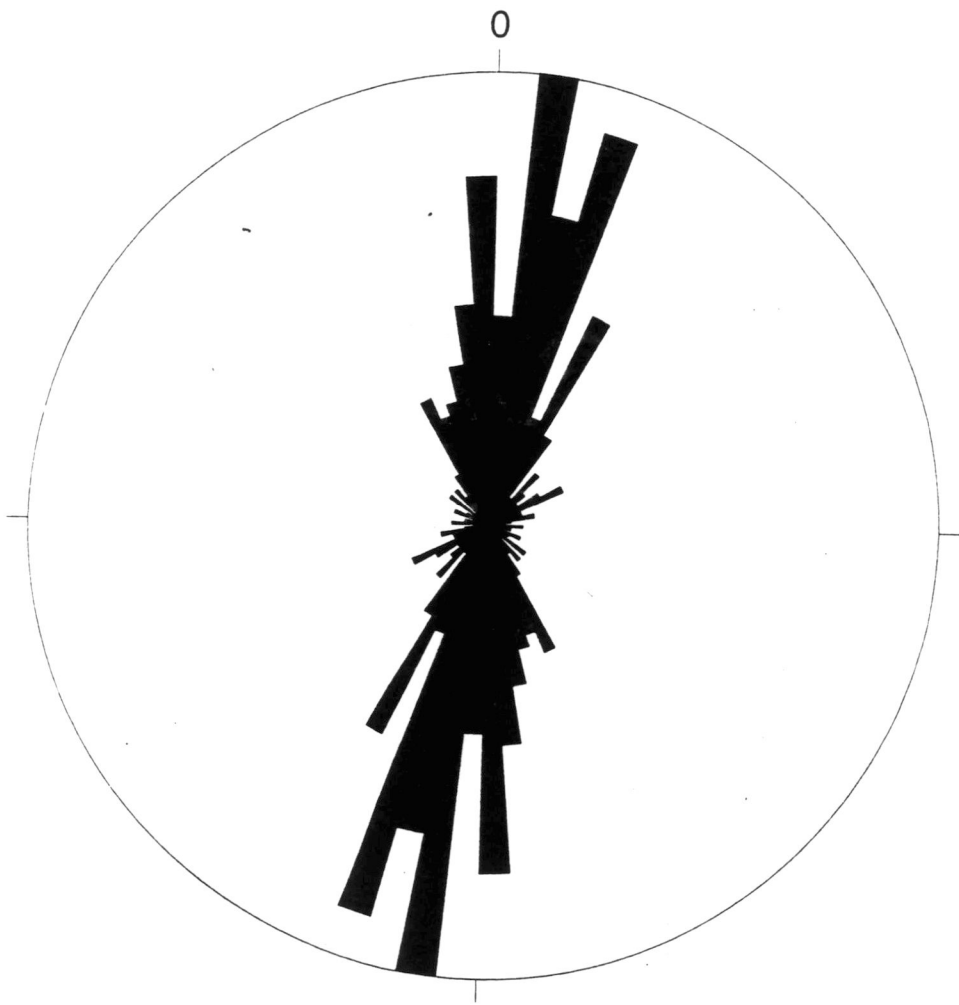


Figure 7. Rose diagram representing the 325 schistosity strike orientations.



with the isoclinal folds, this strike direction suggests a just north of west transport direction for the Six Mile nappe.

The dip directions, shown on a second rose diagram (Figure 8), indicate a strong trend for east dipping schistosity orientations that may represent the eastward dip of layering and isoclinal fold limbs in the Six Mile nappe (Figure 3).

The area of most dense schistosity data (Figure 9) shows an average orientation of N10E, 40 SE. This orientation may represent the average main penetrative foliation developed during the isoclinal folding. This average statistical schistosity may well represent the present orientation of the isoclinal fold limbs and the main penetrative foliation of Six Mile nappe (Plate 18). The less dense areas most likely represent the gentle warping of the main penetrative foliation by the later fold styles.

LINEATIONS

Twenty-nine mineral lineations are plotted on the equal angle Wulff net shown in Figure 10. Typically, biotite in the granitic gneisses and sillimanite in the quartz-mica schists were measured for their lineations. The majority of the lineations trend N10E to N20E and have low plunges (Figures 10 and 11).

Whether or not these mineral lineations formed fold axially or were produced by shearing, is debatable. The good correlation of the mineral lineations and the shear zone orientations gives strong evidence that the lineations were produced by shearing.

However, most fold axis orientations also have northeast trends. Therefore, the lineations

Figure 8. Rose diagram representing the 325 schistosity dip orientations.

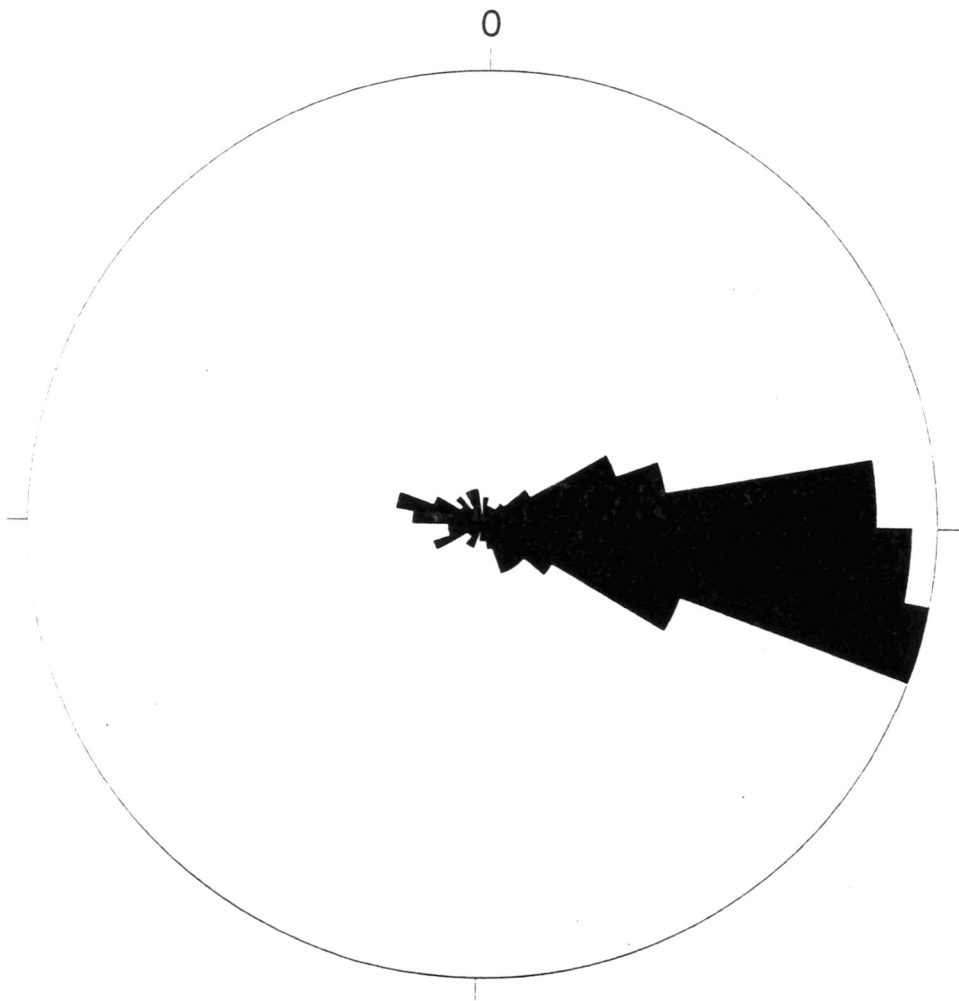


Figure 9. Density plot of the 325 schistosity orientations shown in Figure 6. The statistical density high (black shaded area) is approximately N10E, 40SE. Contour interval is 1%.

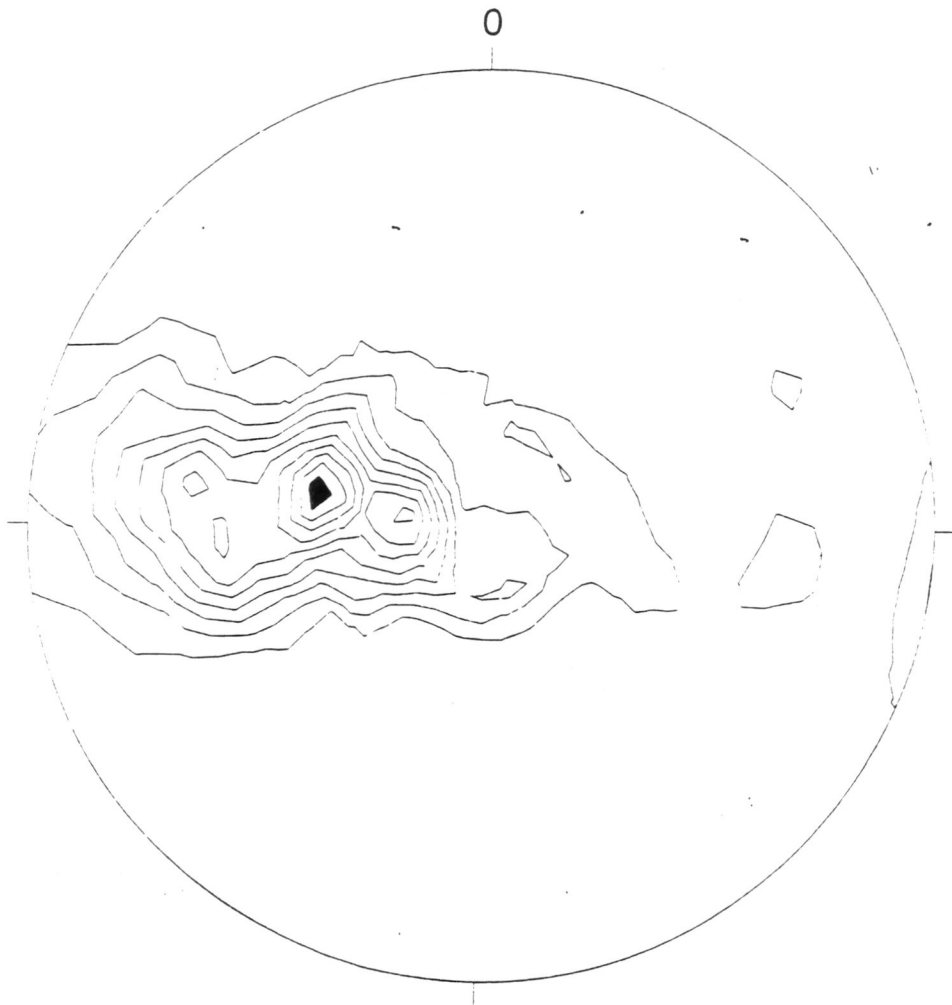


Figure 10. Equal angle Wulff net plot of 29 mineral lineations.

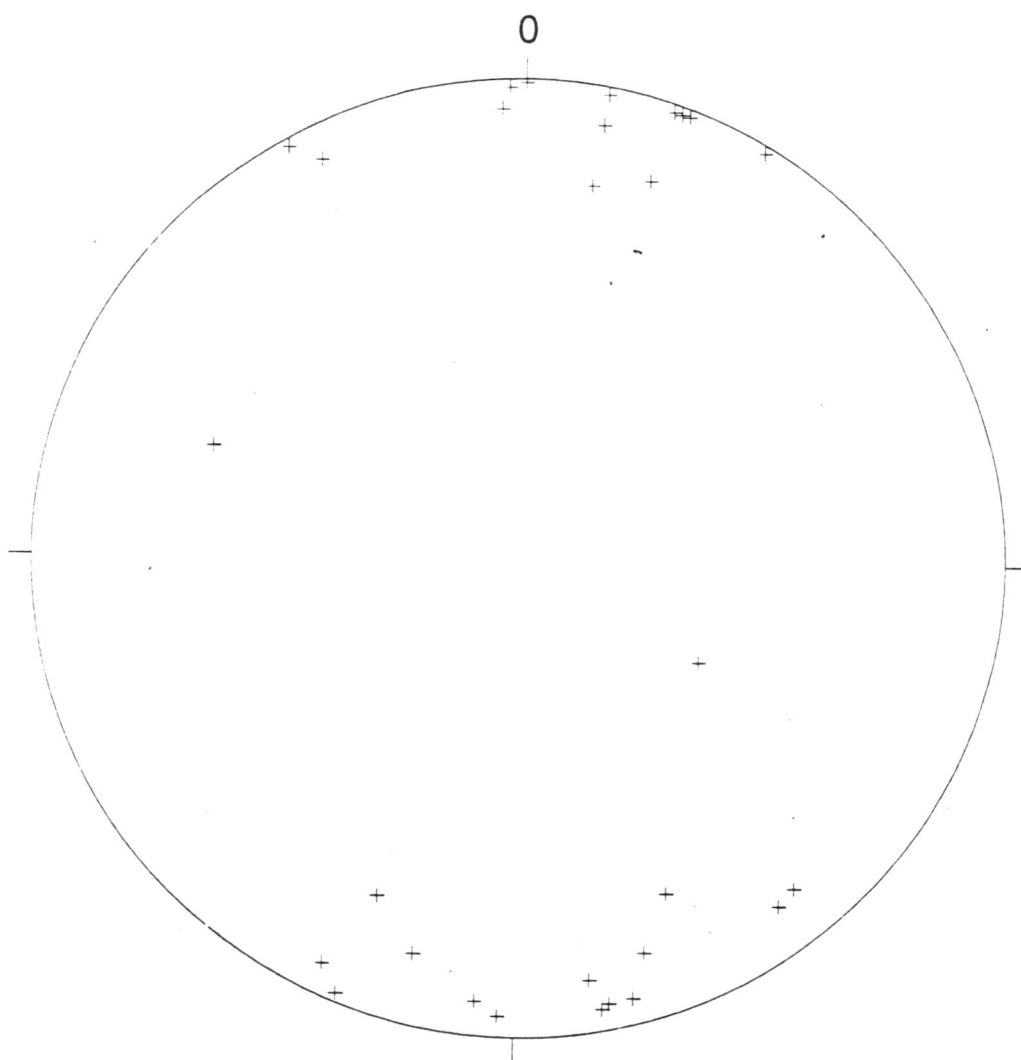
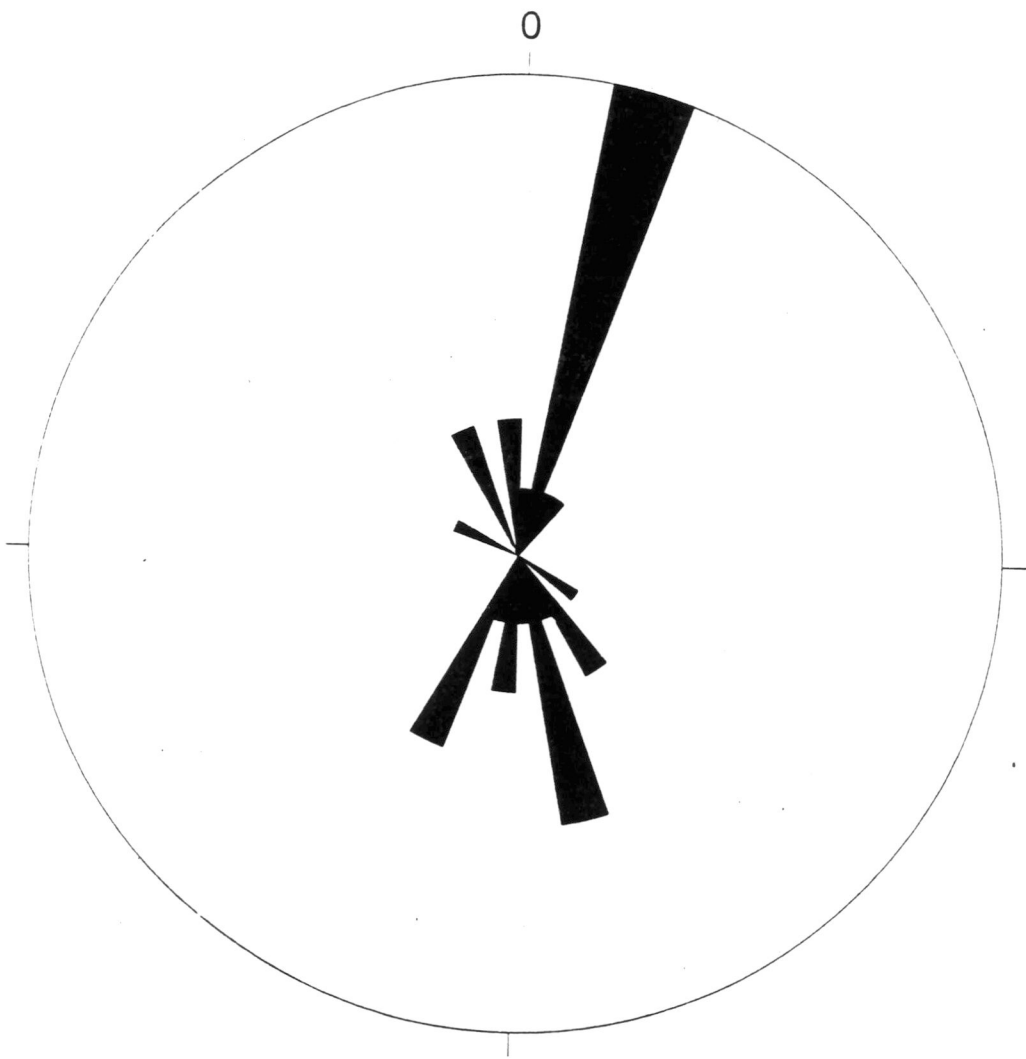


Figure 11. Rose diagram representing 29 mineral lineation orientations.



could be a product of shearing and/or folding. The biotite lineations in the granitic gneiss were probably caused by shearing and the elongate sillimanite grains probably grew with the long dimension parallel to the fold axis.

THRUSTING AND SHEARING

A thrust fault and a shear zone are located within the Pelzer quadrangle. The Grove Creek Shear Zone is located in the eastern half of the quadrangle (indicated by shear symbols) and trends north-south (Plate 1). A thrust fault was located just east of the Saluda River and also trends north-south. Nelson and others (1987) defined this fault as the contact between the Paris Mountain and Six Mile thrust sheets.

The Grove Creek Shear Zone and Other Shearing

The Grove Creek Shear Zone (GCSZ) contains protomylonites, mylonites, lineated granitic gneisses, and lineated hornblende-plagioclase gneisses. Shear is probably the cause of some unusually small grains sizes in rocks at such a high metamorphic grade. The rocks within the shear zones were very resistant to weathering and erosion (Plate 30). Other outcrops of sheared rocks are located throughout the quadrangle (Plate 1).

Simpson and Schmid (1983) state that within many shear belts, mylonitic gneisses contain larger and relatively flow-resistant grains, commonly referred to as porphyroclasts, within a more ductile and fine-grained matrix. Most of the rocks within the shear zone appear to have been sheared biotite gneisses. This relationship between

Plate 30. Photograph of a waterfall created by resistant rock of the Grove Creek Shear Zone. Photograph is taken looking directly west. Shear zone trends north-south.



shear and protolith is well expressed in Plate 31 where biotite gneiss gets “sucked” into a north-south trending shear zone. Shear in the GCSZ was represented well in the gneisses and poorly represented as “mica fish” and S/C fabrics in the quartz-mica schist, suggesting a similar shear history, but less residual and textural expression in the schists.

Displacement across the shear zone was difficult to determine. Simpson and Schmid (1983) claim that by studying the geometry of a shear zone margin, and deflected marker horizons, it is possible to determine not only the sense of displacement, but also the amount. However, larger shear zones, such as the Grove Creek Shear Zone, often lack well define margins and offset markers. This latter scenario seems to be the case in the Pelzer quadrangle.

Shear direction was also difficult to determine. Most asymmetric augen looked as if they had undergone dextral motion while a few looked as if they had been through sinistral motion. This disparity may be a direct result of non-affine flow within the shear zone. Simpson and Schmid (1983) state that in large shear zones, shear is commonly not simple shear; the flow across a large shear zone may not be equally distributed. If the flow occurred in discrete bands across the shear zone, local indicators can give misleading shear directions even though the overall shear direction may be consistent. However, the shear zone does appear to give a consistent last dextral movement (Plate 32).

A good example of this difference in flow is shown in Plate 33. The euhedral grains in the mylonite have been deformed less than the asymmetrical grains. This indicates a disparity in the flow between the bands containing the different augen

Plate 31. Photograph of banded biotite gneiss in a north-south trending shear zone. Scale is 18 cm long.

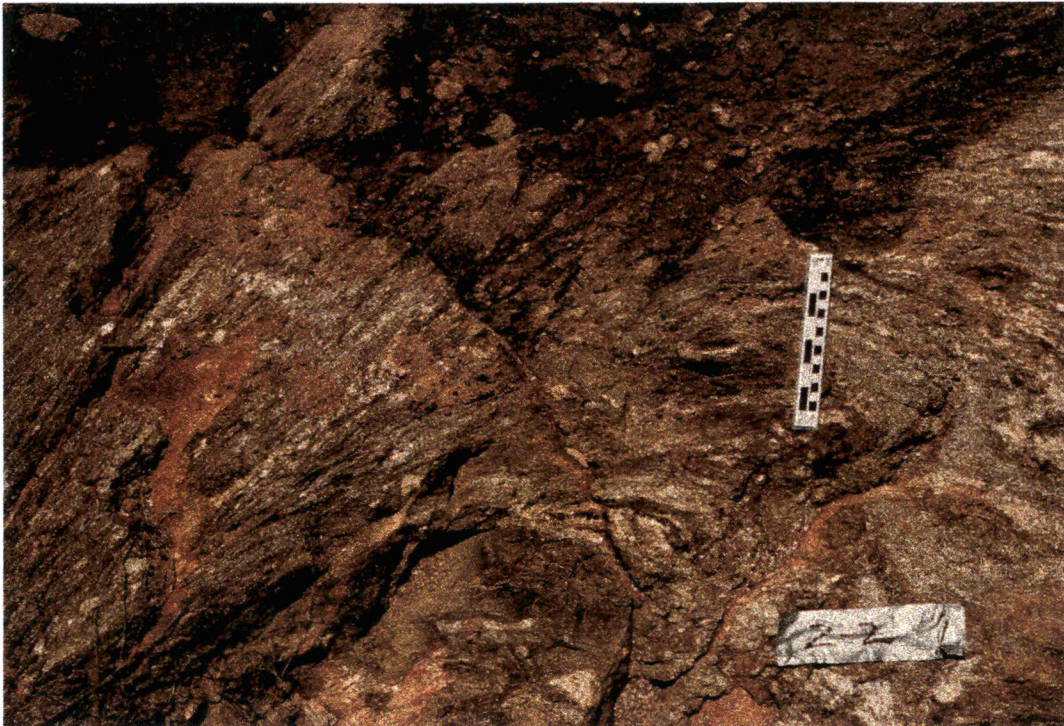


Plate 32A and B. Photographs A and B depict dextral shear within the Grove Greek Shear Zone. Photograph A shows a dextrally sheared augen (see blue arrow).

Photograph B shows a fold nose within the shear zone that has become attenuated and transported right relative to the limb indicating dextral shear (blue arrow connects limb and fold nose). Arrow in photograph B is 15 cm long.

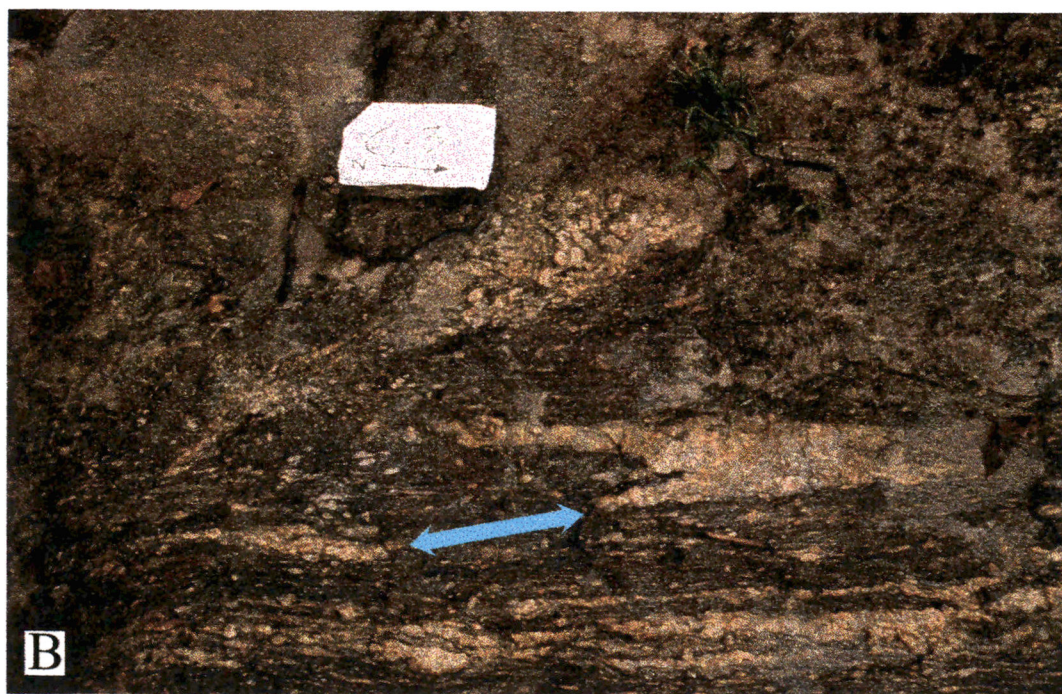
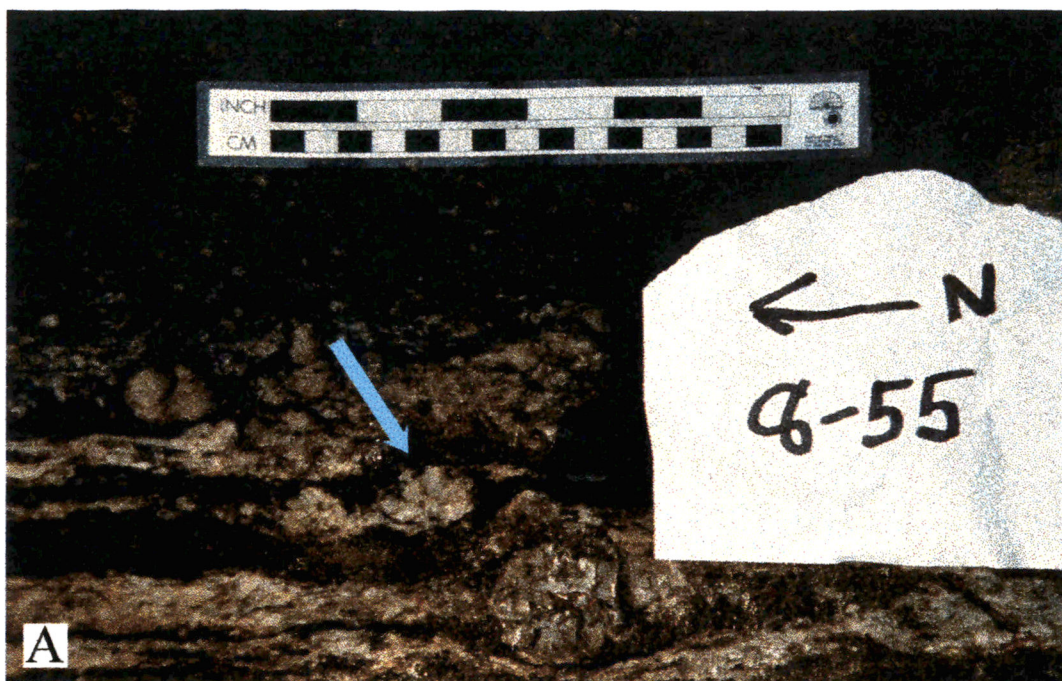
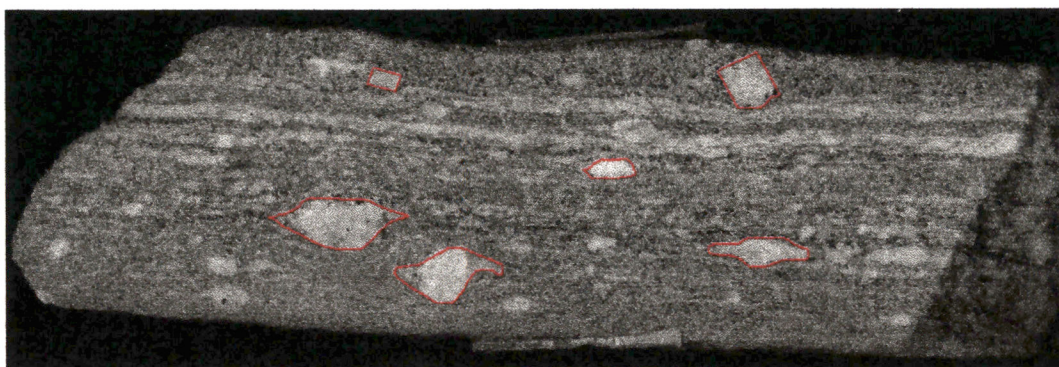


Plate 33. Scanned image of slabbed mylonite showing dextrally sheared augen and euhedral porphyroclasts in the top of the sample. Rock is 9 cm long



morphologies. However, most asymmetric grains do express dextral shearing. The differential flow in this sample may be an analogy for the entire shear zone.

Rocks within the shear zone can range from lineated (Plate 34) to mylonitic (Plate 35) and there appear to have been multiple shearing events. Plate 36 shows multiple shearing events. The main north-south augen trend is cut and displaced by a smaller dextral shear zone in a northeast-southwest direction.

Small grain size causes the protomylonites and mylonites to look much darker in hand sample than a coarser-grained rock with the same mineral composition. Granulation of augen within the shear zone can be seen in Plate 37 where grains of microcline are being removed from a larger microcline augen during shearing.

To assess the size and extent of the shear zone, an aeromagnetics map for South Carolina was consulted (Figure 12). A magnetic anomaly is evident over the shear zone. If the magnetic anomaly does represent the shear zone, it appears that the shear zone is truncated north and south of the field area. Henderson and Broome (1989) have used aeromagnetics to identify shear zone lineaments in Canada.

The Thrust Faulting

The thrust faulting in the Pelzer quadrangle was recognized by visible outcrop-scale thrusting, slickensides, and crush microbreccia.

Previously, thrust faults in the Inner Piedmont (except for the Brevard Zone) were not recognized using evidence such as slickensides, mylonites, and/or breccia (Griffin

Plate 34. Photograph of lineated medium-grained granitic gneiss within the Grove Creek Shear Zone. Scale is 18 cm long and trends north-south.



Plate 35. Photograph of a typical mylonite within the Grove Creek Shear Zone. Augen directly above 8 in the label shows dextral shear. Compass shows shear orientation as N10E.

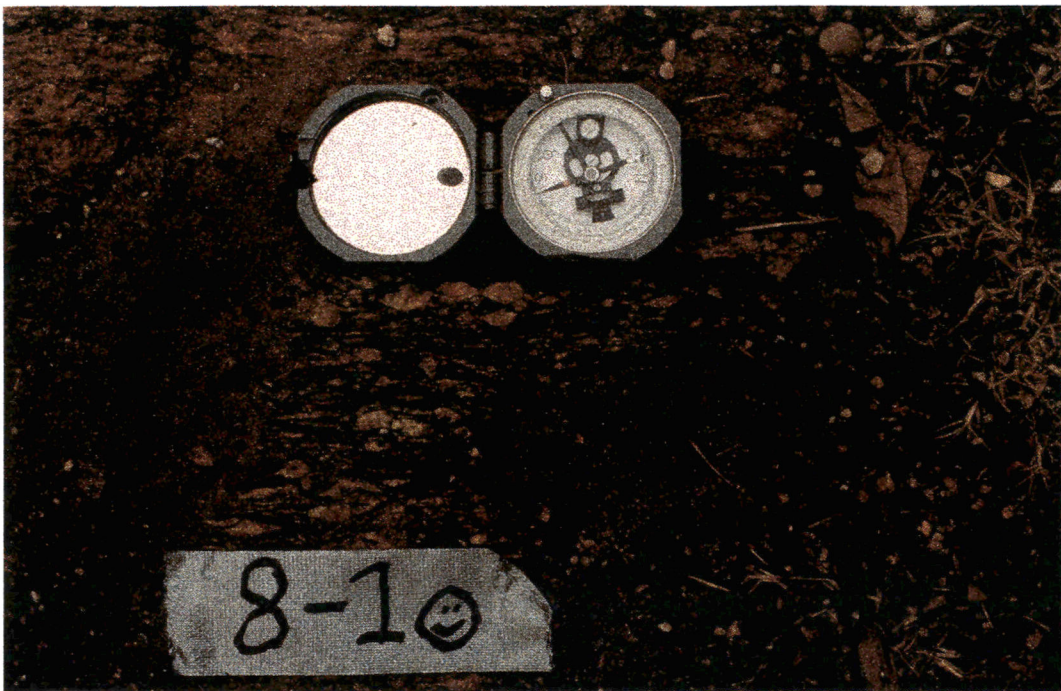


Plate 36. Photograph of a secondary shear zone (red arrow gives orientation) cutting the north-south trending Grove Creek Shear Zone (blue arrow gives orientation). Secondary shear is also dextral indicated by deflection of layering (red line). Label is 15 cm long.

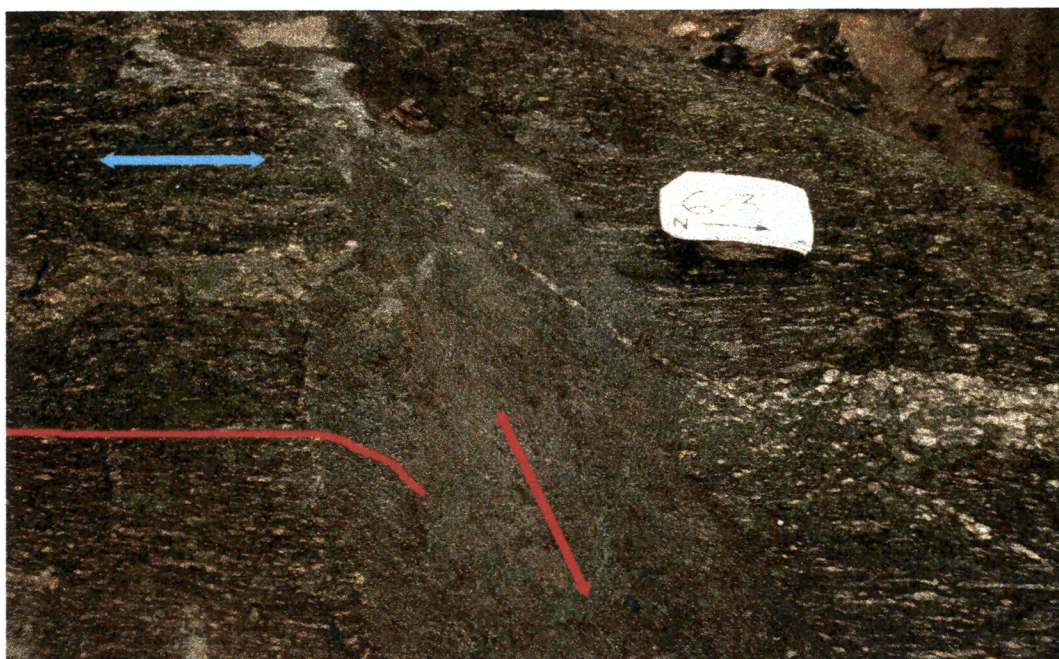
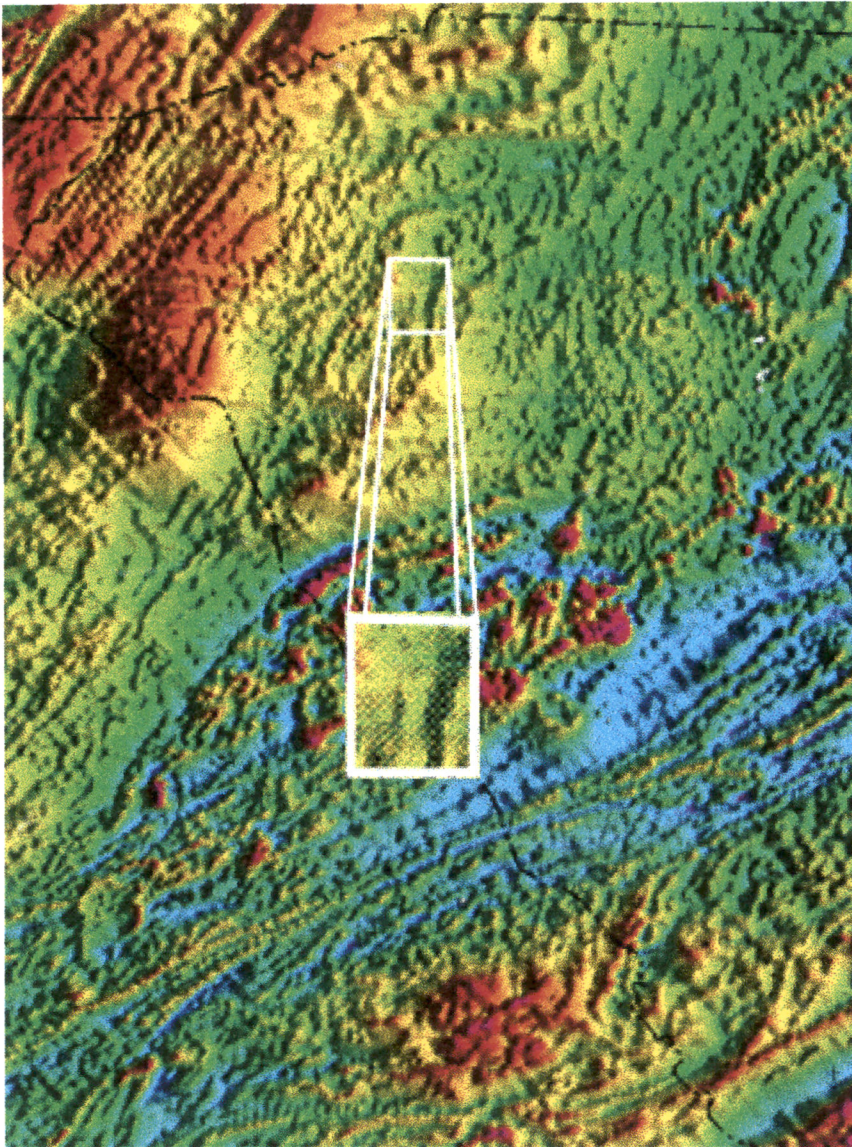


Plate 37. Photomicrograph of a mylonite showing granulation and removal of small fragments from the microcline augen. The long dimension of the photomicrograph is 2.9 mm.



Figure 12. Aeromagnetic map of northwestern South Carolina showing the location of the Pelzer quadrangle. Inset map shows a magnetic anomaly on the eastern border of the quadrangle that may represent the Grove Creek Shear Zone. The anomaly suggests that the shear zone is truncated north and south of the field area. The inset map also shows a magnetic anomaly near the thrust fault (Plate 1). The rocks on each side of this magnetic anomaly (possibly representing the thrust fault) have similar magnetic signatures. Red colors represent a strong positive anomaly. Modified from a map by Zietz and others (1982).



1974b). These faults were first recognized in the Scottish Grampians by Bailey (1910) as a type of fault or nappe slide associated with recumbent folding but usually devoid of fault criteria. The basis for the thrust fault recognition was the dislocation of rock units (Griffin, 1974b). Fleuty (1964) describes nappe tectonic slides a different way, "a slide is a fault formed in close connection with the folding, which is broadly conformable with the major geometric feature (either a fold limb or axial surface) of the structure, and which is accompanied by thinning and/or excision of members of the rock-succession affected by folding." Tobisch and Glover (1971) state that boudinage indicates considerable extension parallel to the principal tectonic surfaces of a nappe. Lack of sufficient outcrop in the Pelzer quadrangle makes it difficult to determine if rock units have been displaced. However, minor displacement can be seen in outcrop scale.

The above definition seems to exclude the thrust fault near the Saluda River as a major tectonic slide. There is considerable boudinage extension in the zone (Plate 24) but features such as the phyllonites and slickensides hint of a late Paleozoic (or later) deformation that did not leave a penetrative record. Thus, it is inferred that this thrust fault is not a slide separating two distinct Taconic thrust sheets. Therefore, this thrust fault is probably a subsidiary fault inside the Six Mile thrust sheet.

Wahlstrom (1955) states that a "phyllonite is a foliated or schistose rock which, in hand specimen resembles a phyllite, but owes its fine-grained origin to cataclastic grain size reduction of an originally coarser-grained rock." This cataclastic grain size reduction is inferred to have occurred under less than ductile conditions during possible thrusting.

Phyllonites, produced from quartz-mica schists, were evident all along the proposed thrust zone.

Plate 38 shows a small outcrop scale thrust. The transport direction of the hanging wall is to the northwest and the orientation of the thrust surface is N15E, 48 SE. This outcrop-scale thrust fault probably occurred under less than ductile conditions indicated by the discrete plane of crush microbreccia on the fault surface (Alleghenian or later). Several more of these outcrop-scale thrust faults were seen with a similar fault plane orientation.

The best direct evidence for faulting can be seen in Plate 39. This exposure at the junction of the Saluda River and South Carolina route 20 can be seen only at low water and shows two fault blocks separated by approximately 30 cm to 40 cm of weathered fault material. Because of weathering, the material between the foot wall and hanging wall could not be identified. The fault passes through medium-grained granitic gneiss and does not juxtapose different lithologies.

The thrust fault may be visible on the aeromagnetics map (Figure 12). Similar colors on each side of the thrust fault indicate rocks of similar magnetic character.

Plate 38. Photograph of an outcrop-scale thrust fault. The photograph is taken looking in the direction N6E. The transport direction of the hanging wall is northwest. Thrust fault is crush microbreccia (located between arrows).



Plate 39. Photograph of the thrust fault at the junction of the Saluda River and South Carolina route 20. The hanging wall and footwall are separated by 30 - 40 cm of fault zone material that was too weathered to identify.



METAMORPHISM

The metamorphic history of the Pelzer quadrangle can be inferred from a careful inspection of the rocks. The minerals and their morphologies contain evidence for the sequence of deformation, temperature of deformation, and depth of burial during deformation.

TIMING OF METAMORPHISM AND DEFORMATION

The timing of metamorphism and deformation in the Inner Piedmont has long been controversial. This disagreement implies the complex nature of resolving an inadequately known set of tectonic events in an area of generally poor outcrop and relief.

The main disagreement about Inner Piedmont tectonism is whether or not the orogenies act as “pulses” or as one long event. Tull (1979) states that contrary to popular belief, the deformation of the Inner Piedmont may not have been separate pulses of deformation that occurred for short geologic time intervals. He believes, like Griffin (1969b) and Higgins and others (1989), that the different orogenies represent unique types of deformation under a given set of deep crustal conditions that imparted the metamorphism and deformation recorded in the rocks.

Most workers agree that the Inner Piedmont is either a fault-bounded stack of crystalline nappes (Griffin, 1969a, 1969b, 1971a, 1971b, 1974b, 1978; Tobisch and Glover, 1971) or thrust sheets (Nelson and others, 1987; Higgins and others, 1989). Seismic profiles suggest that the thrust sheets/nappes are allochthonous (Cook and others,

1979; Harris and others, 1981; Coruh and others, 1987). However, the timing of the pre-Alleghenian events is still controversial (Higgins and others, 1989).

Odom and Russell (1975), using Rb-Sr dates on undeformed plutonic rocks of the Inner Piedmont, assign the initial prograde metamorphism an age of 450 Ma. Similarly, Horton and McConnell (1991) believe that the major episode of isoclinal flow folding in the Inner Piedmont occurred approximately 450 Ma. Butler (1972) estimated the age of metamorphism in the Inner Piedmont to be greater than 410 Ma to 430 Ma.

Sinha and Glover (1978) derived an approximate age of 460 Ma for the middle Paleozoic event, using U-Pb dates on zircons from the mylonitized Henderson Gneiss. They interpret this date to be associated with the first tectonic event in the Taconic.

Devonian tectonism in the southern Appalachians is still uncertain. However, Horton and McConnell (1991), after studying age dates on plutons from the Inner Piedmont, believe that there may have been a regional tectonothermal event during the Devonian.

Late Paleozoic deformation is constrained by the emplacement of Permian and Pennsylvanian granites including the Cold Point and Elberton (Higgins and others, 1989). The late Paleozoic deformation is reported to have occurred between 370-330 Ma (Horton and McConnell, 1991).

The weakly foliated Cherryville granite (on the North Carolina-South Carolina border) is post-metamorphic and has a whole-rock Rb-Sr age of 351 ± 10 Ma (Horton and

McConnell, 1991). The post-metamorphic Elberton batholith in northeast Georgia has a U-Pb concordia upper-intercept age of 320 ± 20 (Horton and McConnell, 1991).

METAMORPHIC GRADE

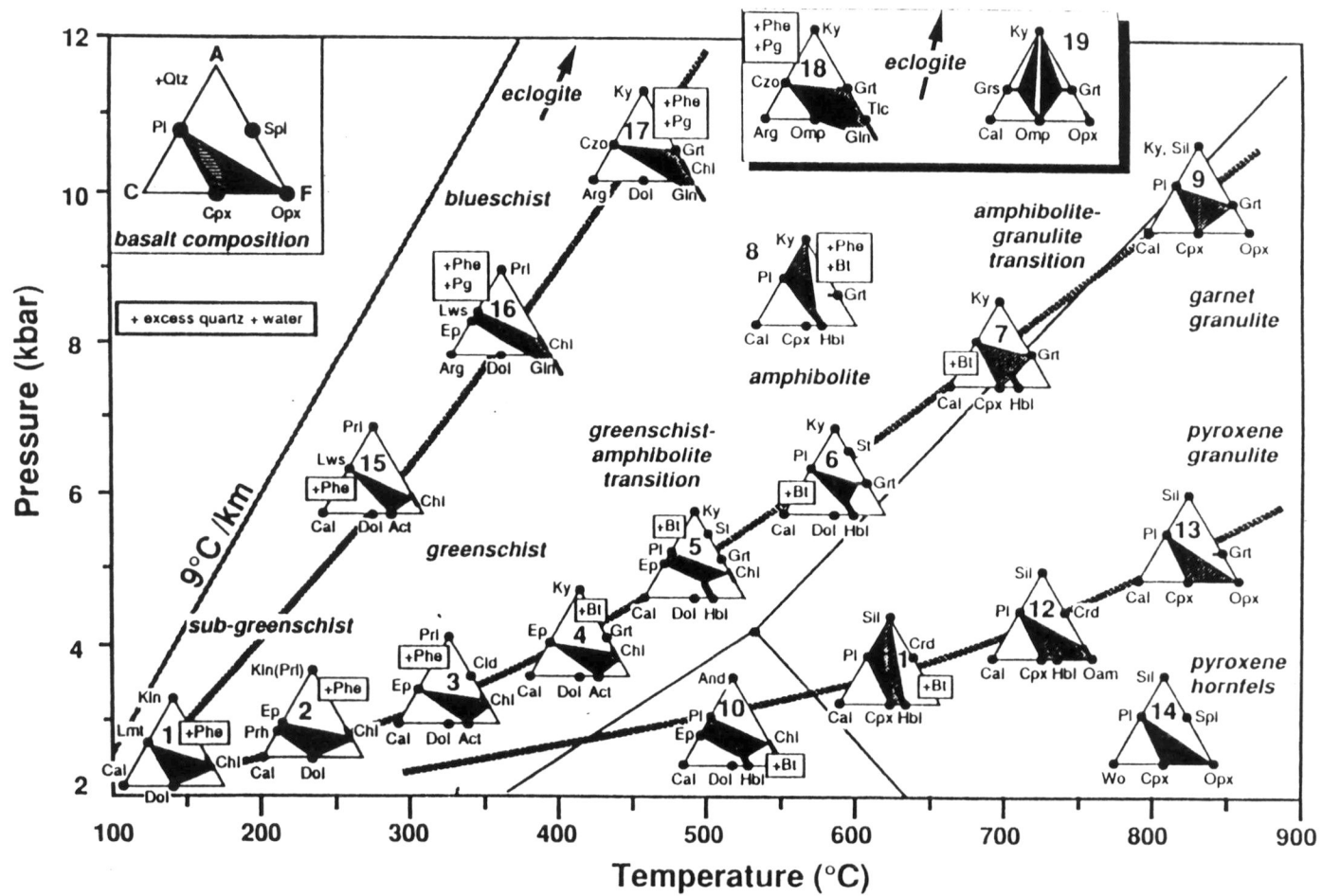
Several workers including Griffin (1974b) have described the metamorphic grade of the Six Mile nappe near the Pelzer quadrangle as upper amphibolite facies - sillimanite-muscovite zone.

Sillimanite is present in the granitic gneisses, biotite gneisses, and quartz-mica schists and is prevalent throughout the quadrangle. Microcline and sillimanite were not found in the same thin section, indicating that the second sillimanite isograd had not been crossed.

Two methods were used to determine peak metamorphic temperatures; "clinopyroxene in" in amphibolites/hornblende-plagioclase gneisses and the occurrence together of sillimanite in the wall rocks associated with granitic veins, seams and pods.

Clinopyroxene in amphibolites/hornblende-plagioclase gneisses can suggest temperatures at peak metamorphic temperatures. Figure 13 shows ACF diagrams representing the evolution of mineral assemblages through prograde metamorphism of mafic rocks (Bucher and Frey, 1994). The appearance of clinopyroxene (cpx) in assemblage seven marks the metamorphic peak temperatures for one amphibolite assemblage; garnet, hornblende, plagioclase, biotite, excess quartz, and water must also be available. It is important to note that the Al_2SiO_5 form in this diagram is kyanite.

Figure 13. Diagram showing prograde metamorphism in mafic rocks using ACF diagrams. ACF diagrams 7 and 9 abbreviations: Pl - plagioclase, Ky - kyanite, GRT - garnet, Bt - biotite, Cpx - clinopyroxene, Hbl - hornblende, Cal - calcite, Sil - sillimanite, Opx - orthopyroxene. Modified from Bucher and Frey (1994).



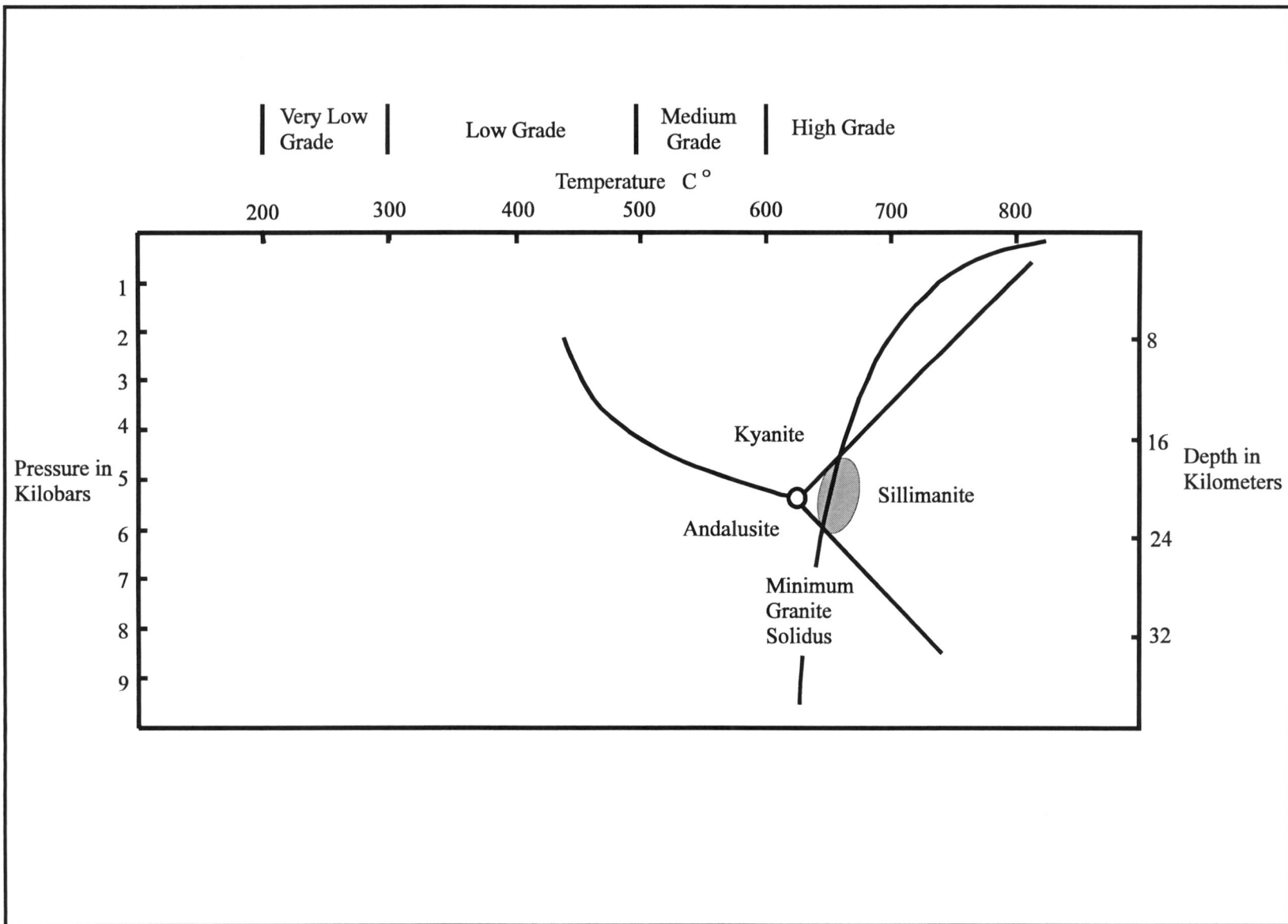
However, with a slight drop in pressure, sillimanite would be stable. Therefore, pressure during deformation may be a slight overestimate. Also, the temperature is a conservative estimate because it is difficult to tell how close to the “hornblende out” garnet-granulite triangle (assemblage nine) the assemblage may have been. Exsolution lamellae in the clinopyroxenes suggest that the temperature and pressure were well above clinopyroxene formation for a significant amount of time allowing the lamellae to form as the rock cooled.

The temperature and pressure predicted by this diagram are 680-700 C° and 8 kilobars.

Another temperature and pressure indicator is the granitic veins, seams and pods in quartz-mica schists. Bucher and Frey (1994) claim that, at about 650-700°C, partial melting begins to be important in rocks containing quartzofeldspathic components under water-saturated conditions. Also, a melt produced from quartz-mica schists is close to the eutectic composition of the H₂O-saturated granite system (Bucher and Frey, 1994). They say that small amounts of melt may not migrate far, but will form small pools that crystallize to create leucocratic quartzofeldspathic bands, pods, lenses and patches. Boudinaged pods of these leucocratic quartzofeldspathic rocks were seen and most granitic layers were emplaced along the primary structural component (i.e. foliation / layering) (Plate 24).

The triple point for the Al₂SiO₅ minerals and the line of incipient melting is shown in Figure 14. Note that the Al₂SiO₅ triple point is different from the one in the

Figure 14. Diagram showing the intersection of the sillimanite temperature/pressure field with the minimum granite solidus. Grey shaded area represents the probable pressures and temperatures for granitic rock formation. Modified from Bucher and Frey (1994).



previous ACF diagram because a different data set was used to determine Al_2SiO_5 triple point. The intersection of the incipient melting curve of granite and the sillimanite-only field brackets the peak metamorphic temperature and pressure. Granitic veins, seams and pods were pervasive but not extensive in the field area suggesting that conditions were just above the minimum granite solidus. This analysis gives peak metamorphic temperatures of 650-680°C and pressures of 5.5 - 6.5 kilobars (Bucher and Frey, 1994). This pressure can be inferred as equivalent to a burial depth of 20 km (Bucher and Frey, 1994).

RETROGRESSION

Chlorite and biotite in the quartz-mica schists and gneisses suggest retrogression. The chlorite appears to be replacing the garnet and biotite in many of the samples and biotite commonly replaces garnet.

In thin section, the distribution and texture of muscovite and sillimanite hint at possible retrogression. Often the quartz-mica schists lack sillimanite, probably due to a retrogression of sillimanite to muscovite. This interpretation is supported by the two distinct grain sizes of muscovite. The smaller grains represent the retrogressive grains formed from the fine-grained sillimanite and the larger grains grew during prograde metamorphism.

Garnets in the quartz-mica schists (Plate 6) show evidence of replacement by biotite. Chlorite was also a common retrogressive product that often grew in the tails of garnet porphyroclasts.

Frequently, clinopyroxene in gabbro-norites are surrounded by amphibole (Plate 16). This texture suggests a reaction of pyroxene being influenced by the upper amphibolite metamorphism temperatures and pressures. Conversely, it may have formed as the pluton was emplaced and cooled after the metamorphic event.

METAMORPHIC TIMING

Rocks and minerals in thin section can indicate the series of events in metamorphism. Although the sequence of mineral growth can be determined, the absolute age can usually not be obtained.

In the quartz-mica schists, the coarse-grained, foliation-concordant muscovite and sillimanite probably grew during the first metamorphic event, the Taconic orogeny. The boudinage in the sillimanite indicates that deformation was still active during the period of recrystallization during the Taconic metamorphic peak (Hibbard, 1995). Hibbard (1995) also states that stretch after crystal growth does not prove crystal growth exactly during deformation; stretching during a later metamorphism is the alternate explanation. The semipolygonal arcs created by some sillimanite grains in the quartz-mica schists suggest crystallization during folding (Hibbard, 1995).

Subsequent deformations also left an overprint on the minerals. Cross micas in the quartz-mica schist indicate a post-Taconic metamorphic event. Either Acadian or Alleghenian, this metamorphism weakly affected the rocks, producing micas that cut across the main foliation but in no way obscure the earlier penetrative foliation developed during Taconic nappe emplacement (Plate 7). Post-tectonic crystals including micas, amphiboles, or other platy minerals often lie across the main rock fabric or cleavage (Compton, 1985).

Mineral grains in chevron folds, expressed in the quartz-mica schist thin sections (Plate 27), are polygonized. Since the chevron folds deform the main penetrative foliation, they probably came after the Taconic orogeny. However, the micas have recrystallized and are not bent. This suggests a subsequent thermal metamorphic event that caused bent, strained mineral grains to recrystallize. The chevron folds may have formed during the Acadian orogeny and were possibly recrystallized during the Alleghenian or a post folding tectonothermal Acadian event.

The Taconic metamorphic peak is responsible for extensive melting. These melts solidified creating granitic veins, seams and pods that are often boudinaged. This boudinage could represent limb attenuation during Taconic isoclinal folding and nappe emplacement. However, it could have happened in a subsequent deformation event. The same event that boudinaged the veins, seams and pods may also have boudinaged the sillimanite crystals.

THE SHEAR ZONE

The GCSZ probably formed during the Alleghenian orogeny. Horton and Zullo (1991) state that strike-slip movement, dominantly right lateral, occurred along major faults from the Brevard zone southeast through the Inner Piedmont. The semi-ductile to ductile internal structure of the GCSZ suggests high temperatures and pressures. Separate ductile shearing events indicate that more than one shear event was accommodated during the collision. This secondary shear event is also dextral.

THE THRUST FAULT

The thrust faulting near the Saluda River seems to be less than ductile. The phyllonite in the fault zone suggests brittle cataclasis of mica and sillimanite grains. Also, the crush microbreccia and slickensided surfaces (Plate 38) indicate brittle fault conditions (Hibbard, 1995). This faulting probably occurred during the Alleghenian orogeny. Horton and McConnell (1991) state that the Alleghenian orogeny produced thrusting and strike-slip faulting.

The existence of a thrust sheet boundary between a Paris Mountain thrust sheet and a Six Mile thrust sheet (Nelson and other, 1987) is now in question (Figure 4). Aeromagnetic data suggest a fault, but does not indicate contrasting lithologies on each side although different rock types may have the same magnetic signatures. It is possible that a fault separating different thrust sheets may be east of the quadrangle, but no such fault lies in the quadrangle.

A better explanation is that this fault is probably a minor thrust splaying upward from the main thrust between the Six Mile and Walhalla nappes. This thrust probably did not have enough movement to juxtapose contrasting lithologic units.

WHOLE ROCK CHEMICAL ANALYSIS

Whole rock chemical analysis was performed on eleven samples and the results are given in the Appendix. The procedure produced all major oxides with 0.01% detection limits using Fusion-ICP-AES and 50 trace elements in parts per million using Fusion-ICP/MS.

TECHNIQUE

The ICP-AES technique relies on placing the sample material into a solution either single acid, mixed acid or fusion techniques using fluxes. The sample is then put into a radio frequency excited plasma at 8000 K. Each element in the solution produces a characteristic spectrum and the intensity of the spectral lines is directly proportional to the quantity of the element present. The sensitivities of this technique are better than X-ray fluorescence. The ICP-MS technique combines the radio frequency excited plasma from above with a quadropole mass spectrometer to measure mass rather than emission lines (Actlabs, 1997).

Five amphibolite/hornblende-plagioclase gneisses, a gabbro-norite, two quartz-mica schists, two fine-grained granitic gneisses, and a mylonite were chosen as samples.

MAJOR OXIDE ANALYSIS

The major oxide analysis provides an accurate description of the samples chosen (Appendix). The gabbro-norite and amphibolites/hornblende-plagioclase gneiss samples

show very low SiO_2 and typically have substantial amounts of Al_2O_3 , Fe_2O_3 , MgO and CaO . The quartz-mica schists typically have low SiO_2 content but contain a lot of Al_2O_3 , Fe_2O_3 , and K_2O . The granitic gneisses and mylonites have high SiO_2 , moderate Al_2O_3 , and minor amounts K_2O , Na_2O , and Fe_2O_3 .

The major oxide analysis reinforces the mineralogy described during petrographic analysis. The gabbro-norites and amphibolites/hornblende-plagioclase gneisses have typical basaltic signatures and contain a lot of plagioclase (Ca source), hornblende (Fe, Mg source), biotite (Fe source), and some clinopyroxene (Ca, Mg, Fe source). These four minerals can establish the high oxide percents described above. The low SiO_2 in the mafic samples is directly related to the low quartz content.

The quartz-mica schist's anomalously low SiO_2 is caused by the lack of quartz, not within the quartz-mica schist units, but as an artifact of sampling a mica rich layer within the schist. The high Fe_2O_3 is related directly to biotite content and the high K_2O is directly related to muscovite and biotite content. The Al_2O_3 comes from both sheet silicates.

Finally, the high SiO_2 content of the granitic gneisses and mylonite is directly related to quartz content and the abundance of felsic minerals. The minor amounts of the other oxides come from biotite, microcline and muscovite.

PROTOLITH

The rocks of the Pelzer quadrangle are a highly deformed and metamorphosed suite of sedimentary and igneous rocks whose original character has been changed dramatically. However, some interpretations about the original nature of the rocks can be made.

Most the rocks of the Pelzer quadrangle hint at a sedimentary/marine or igneous origin. As previously stated, Higgins and others (1989) said the rocks of the Inner Piedmont started as sediment prisms some 700 million years ago.

The interlayered quartz-mica schist and granitic gneisses suggest of interbedded siltstone/sandstone and mud. Although the granitic gneisses could be sills of igneous origin, the chemical analysis show that the gneisses contain elements such as chromium. Differentiation during the melting process would remove such elements from granitic magmas. Thus, it seems unlikely the granitic gneisses are of igneous origin. Griffin (1974b) states that southeast of the migmatitic front (which is bounded to the northwest by the Brevard fault) the quartzofeldspathic metasedimentary and (or) metavolcaniclastic and (or) metavolcanic stratigraphic units become granitoid gneisses.

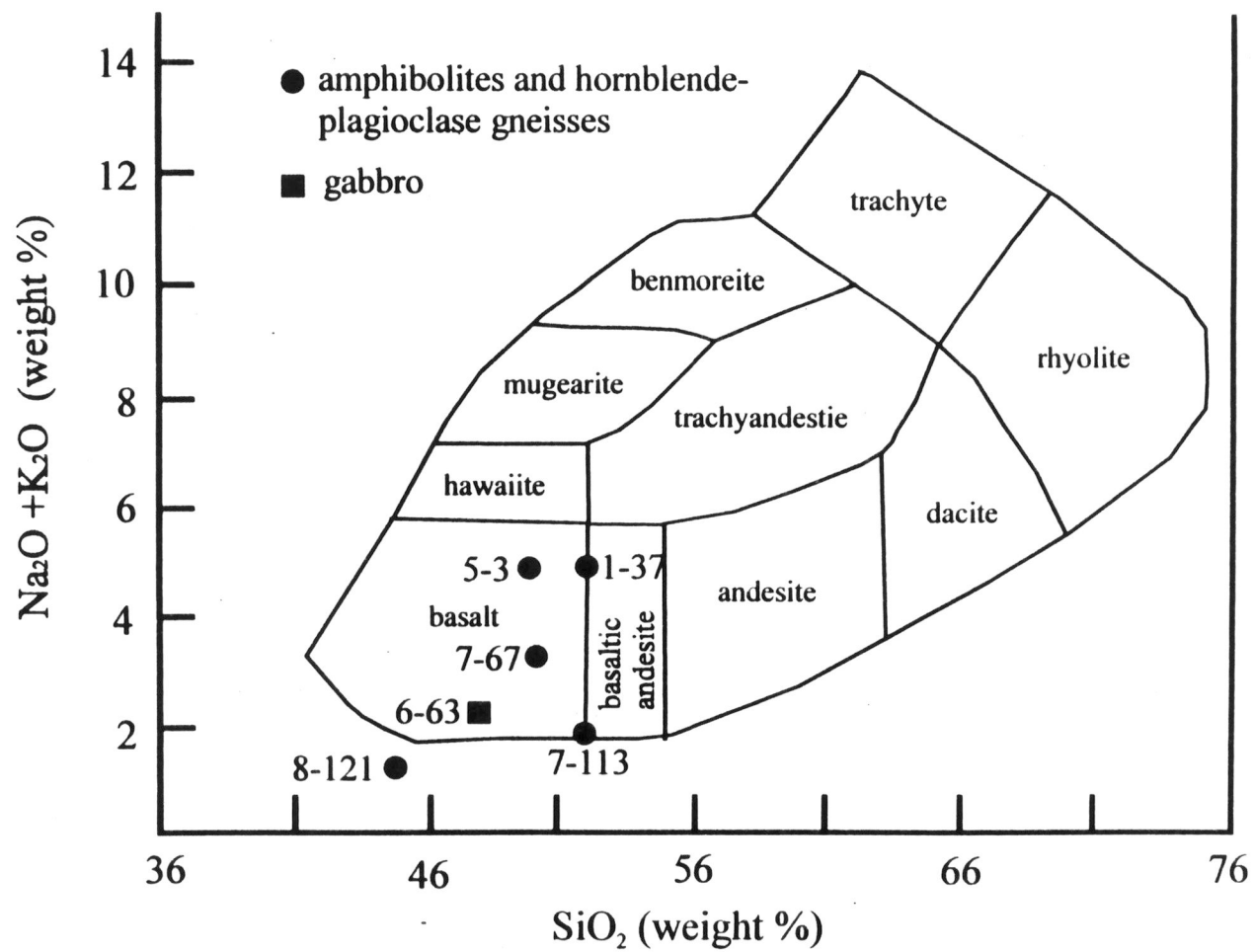
The quartz-mica schists are typical metapelites as described by Bucher and Frey (1994) and they state that the presence of sillimanite strengthens the argument for metapelitic origins. The zircon grains within the granitic gneisses also suggest a sedimentary origin. It is possible to have premagmatic zircons in a metagranite, but rounding of the zircon grains supports the sedimentary origin of the rock as well as the

zircons. Because of the almost indestructible nature of zircon as a detrital grain, the zircons have retained their general euhedral shape. However, the sharp crystal terminations are gone and the grains are rounded (Plate 11). If this was a rock of igneous origin, the zircons would probably be distinctly euhedral.

The interlayered nature of the above units also suggests ancient sedimentary strata. The interlayering of protolith muds and siltstones could produce such a metamorphic strata and may have originated in a turbidite environment.

The amphibolites probably have an igneous origin. The amphibolites and hornblende-plagioclase gneisses are probably basalts and/or ash falls/basaltic flows, respectively. The amphibolites may be pieces of oceanic crust that became caught up in the metapelites during the Taconic crystalline thrust sheet emplacement. Figure 15 shows a classification system that defines igneous rock types based on oxide weight percents. Assuming a closed system, the three amphibolites and hornblende-plagioclase gneisses plot well within the basalt region on the diagram confirming their protolith as mafic. It is difficult to determine whether the origin is oceanic or island arc volcanics. The interlayered nature of the hornblende-plagioclase gneisses and the biotite gneiss suggest that these rocks were somehow layered within the protolith. This interlayering probably resulted from intrusions of basaltic sills into sedimentary protolith. Alternatively, these layers could be volcanic ashfalls that were collecting in the back arc basin between the ancestral North American continent and a volcanic island arc (the slate belt?).

Figure 15. Diagram showing the delineation of mafic rock types using oxide weight percent from chemical analyses. Modified from Bohrson and Reid (1995).



The gabbro-norites appear to be small plutonic bodies of unknown origin.

Chemical analyses give a typical basaltic signature in Figure 15.

SUMMARY OF TECTONIC HISTORY

The rocks of the Pelzer quadrangle began as a sedimentary sequence of terrigenously derived sediments approximately 700 Ma either from the ancestral North American continent and/or from the micro-continent that was separated from North America during initial rifting that formed the Iapetus Ocean. Occasionally within that sedimentary sequence, a layer of volcanic (basaltic in composition) material was introduced from possible ashfall/concordant intrusions of sources unknown. Six hundred million years ago the tectonics of closing the Iapetus Ocean basin began, ultimately creating the supercontinent of Pangea. Whether or not the orogenies in between were “pulses” of deformation or a continuous deformation with different expressions on the rocks is still up to debate.

The Taconic orogeny transported the sedimentary rocks, along with chunks of the oceanic crust (amphibolites?), towards the hinterland of the ancestral North American continent. This deformation raised the temperatures (upper amphibolite facies - sillimanite zone) of the newly metamorphosed rocks up to approximately 650° C and the pressures to 5-8 kilobars. This created sillimanite in the metapelites, clinopyroxene in the amphibolites, and granitic veins, seams and pods everywhere. The rocks were buried by approximately 20 km of other material.

The rocks were emplaced as nappes that occasionally detached from one another along thrust faults. As the rocks were deformed in these nappe structures, they were folded into isoclinal forms that are typically reclined to recumbent. These isoclinal folds

are F1 and the associated fold axial planar schistosity is S1. Fold limbs were boudinaged during the emplacement of the nappes. The open synform and antiform folds may be an artifact of cooling temperatures and layer buckling due to continued compression.

The Acadian orogeny is not well expressed in the Pelzer quadrangle, however, the orogeny is best expressed as a tectonothermal event in the Inner Piedmont. These high temperatures may be responsible for cross-micas in some thin section samples.

During the Alleghenian metamorphic peak, stresses were created that could not be accommodated by forcing the thrust sheets toward the hinterland. These dextral transpressive stresses were accommodated by the shear zones trending north-south throughout the field area.

Finally, as the temperature dropped, the Alleghenian orogeny thrust the Pelzer area (along with the Inner Piedmont) toward the hinterland, ultimately producing the Blue Ridge province. The stresses of this emplacement may have caused reactivation of the Six Mile nappe producing the thrust fault east of the Saluda River. The chevron folds may have been created at this time.

SUMMARY OF CONCLUSIONS

Analysis of the rocks of the Pelzer quadrangle support five major conclusions:

1. The rocks of the Pelzer quadrangle are predominately sedimentary in origin excluding the minor occurrences of amphibolites, plagioclase-hornblende gneisses, plutonic gabbro-norites, and other mafic rocks of the mafic complex (Plate 1).
2. The peak metamorphic grade in the quadrangle is upper amphibolite facies (sillimanite-muscovite zone). Temperatures peaked at approximately 650-700°C and maximum pressures ranged from 5 to 8 kilobars. Estimated depth of burial is 20 km. This peak probably occurred during late Taconic or early Acadian.
3. Three, possibly four, orogenies affected the field area imparting three fold styles: isoclinal, open synform and antiform, and chevron. The entire field area was emplaced as a nappe.
4. The north-south trending shear in isolated areas throughout the quadrangle and in the Grove Creek Shear Zone were locations of stress relief for dextral motion during Alleghenian transpressive collision of Laurentia and Gondwanaland.
5. The thrust faulting just east of the Saluda River was caused by reactivation of the Six Mile thrust sheet during the Alleghenian orogeny. The thrust fault does not separate two distinct thrust sheets suggesting that the Paris Mountain thrust sheet does not exist or the thrust boundary is farther to the east. The entire quadrangle is still located within Griffin's Six Mile nappe.

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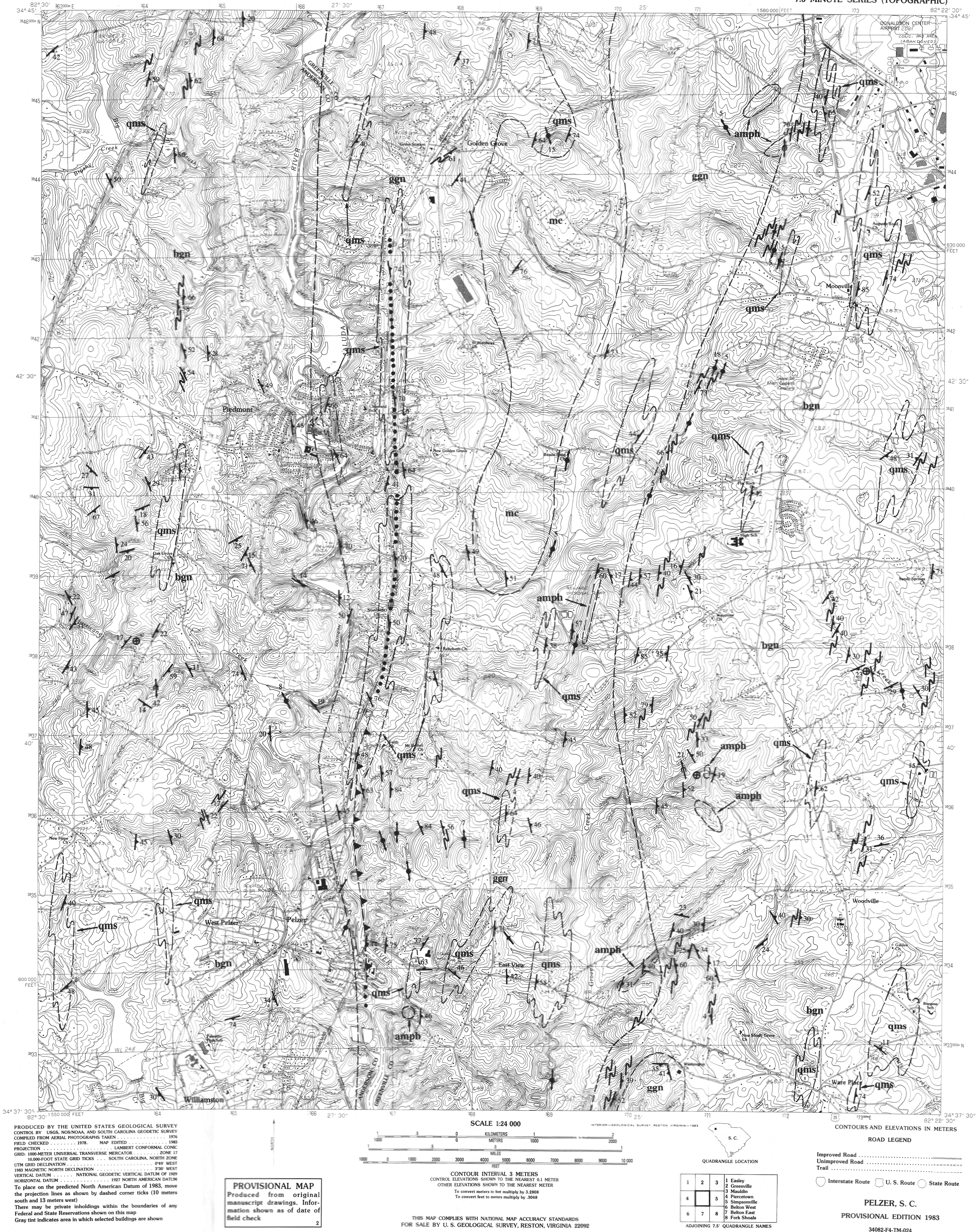
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APPENDIX
WHOLE ROCK CHEMICAL ANALYSIS DATA



Bedrock Geologic Map of the Pelzer 7.5 Minute Quadrangle,
Greenville and Anderson Counties, South Carolina

Funded and supported by the USGS EDMAP
Program and the South Carolina Geological
Survey.

Geology by: David R. Sieling (1997)
East Carolina University

This map and explanatory information is submitted for
publication with the understanding that the United States
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EXPLANATION

- Lithologic Units**
- bgn** medium- to very coarse-grained biotite gneiss
(+/- garnet and/or sillimanite); may be
homogeneous, layered and porphyroblastic;
interlayered with quartz mica schist (+/- garnet
and/or sillimanite), labeled where schist
concentration is high (**qms**); contains isolated pods
and layers of amphibolite and hornblende-plagioclase
gneiss, labeled where mappable (**amph**). Pegmatite veins and
bodies are common
- ggn** fine- to medium-grained granitic gneiss which contains
biotite in varying amounts (+/- garnet and/or sillimanite)
and can be porphyroblastic; interlayered with quartz mica
schist (+/- garnet and/or sillimanite), labeled where
schist concentration is high (**qms**); contains
isolated pods and layers of amphibolite and
hornblende-plagioclase gneiss, labeled where mappable (**amph**);
contains rare quartzite layers. Pegmatite veins and bodies are common
- mc** complex of mafic rocks including amphibolites, hornblende-
plagioclase gneisses, gabbros, diorites, and mafic hornfels

- Symbols**
- Lithologic contact - inferred
- 26 Strike and dip of foliation
- Vertical foliation
- Horizontal foliation
- 27 Bearing and plunge of lineation
- Horizontal or very low dip lineation
- 24 Minor fold axis orientation of anticline showing bearing and plunge
- 18 Minor fold axis orientation of syncline showing bearing and plunge
- Thrust Fault, dashed where approximate, dotted where uncertain (teeth on upper plate)
- Area of sheared rocks