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Petrography and Stratigraphy of the Carolina Slate Belt Union County, North Carolina

BY

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Abstract

Four formations are recognized in the Union County portion of the Carolina Slate Belt. The Uwharrie Formation represents a period of extensive volcanism with the formation of crystal lithic and devitrified tuffs. The Tillery Formation consists of thin bedded, laminated argillite with some interbedded nonlaminated argillite and sandstone. Thick bedded, tuffaceous argillite characterizes the McManus Formation which also contains an appreciable amount of crystal tuff and very fine-grained sandstone. The youngest unit is the Yadkin Graywacke which consists of thick-bedded graywacke and laminated argillite. Quartz and igneous intrusions are found in all of the units. Age of the rocks studied is Early Paleozoic, probably Cambrian and Ordovician.

Major structures of the region are the Troy Anticlinorium and the New London Synclinorium. Projection of the Gold Hill Fault into Union County was made on the basis of geomorphic, geophysical and field evidence. A buried syncline is present beneath the Wadesboro Triassic Basin. The name Peachland Syncline is proposed for the structure. Two principal joint sets were observed one of which is dominant in the adjacent Triassic basin. Two periods of deformation have been inferred.

The quartz-albite-muscovite-chlorite subfacies of the greenschist facies is present. A slight but progressive increase in degree of metamorphism exists to the west.

Petrography and Stratigraphy of the Carolina Slate Belt, Union County, North Carolina

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INTRODUCTION

Purpose and method of investigation

The Carolina Slate Belt is unusual in providing intriguing problems to workers of igneous, sedimentary, and metamorphic terrains. The rocks in the Union County portion of the Slate Belt are particularly challenging and regionally important because sedimentary characteristics are usually well preserved in spite of the low rank metamorphism. The purpose of this investigation is the detailed lithologic and stratigraphic study necessary to reconstruct the geologic history of the region.

Approximately 500 square kilometers were mapped. More than 300 thin sections and corresponding hand specimens were studied. Special attention was paid to original sedimentary and secondary metamorphic textures, mineral assemblages and microstructures. Fifty selected samples were X-rayed with a Phillips X-ray diffraction unit equipped with a scintillation counter. A procedure modified after Tatlock (1966) was employed in order to obtain semiquantitative modal analyses of the rocks (Randazzo, 1969a). X-radiography techniques were attempted in order to determine ghost ghost microstructures. This approach, however, proved unfruitful.

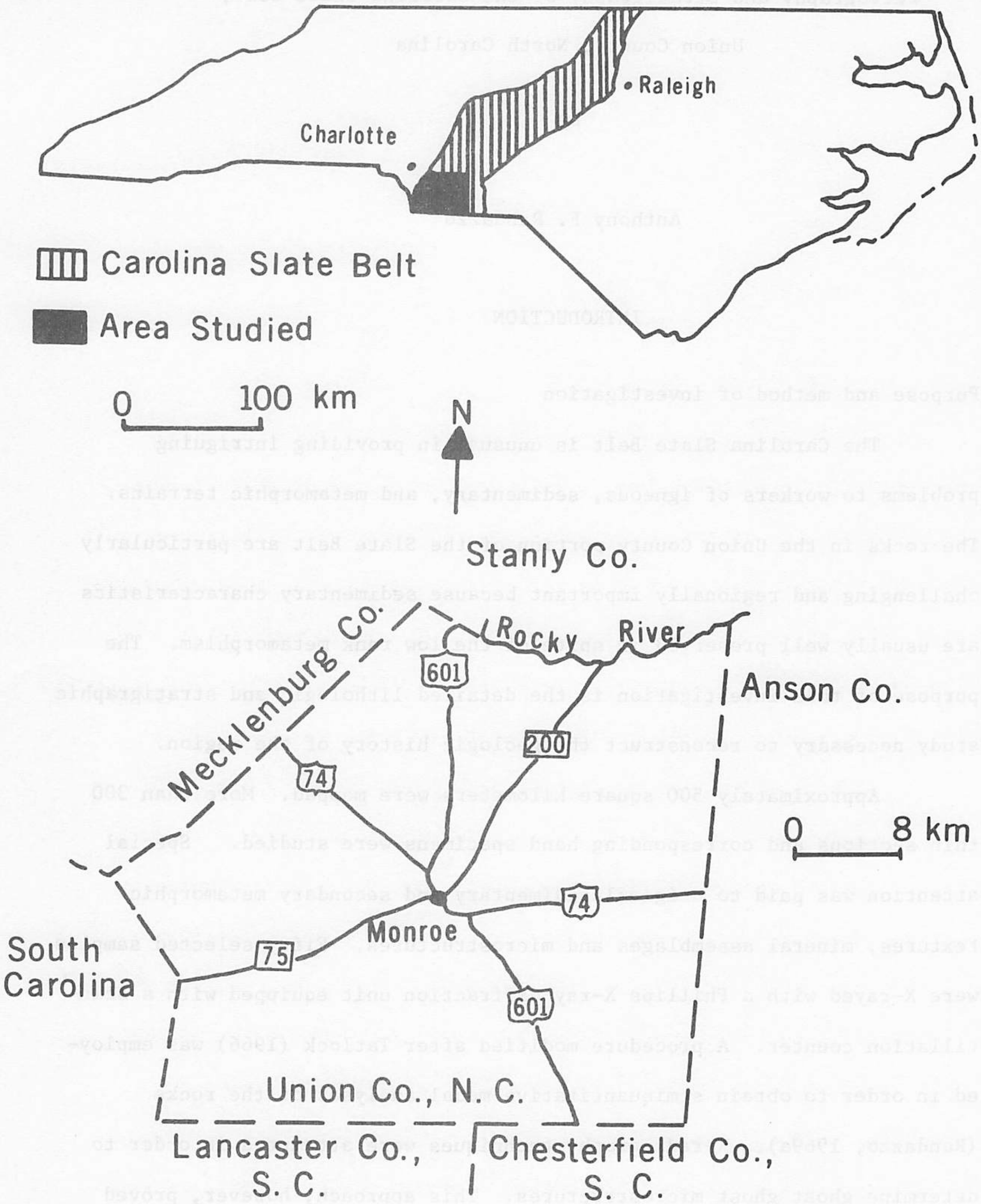


Figure 1. Index map of the Carolina Slate Belt in North Carolina and Union County

Regional geology

The Carolina Slate Belt extends across Virginia, North Carolina, South Carolina, and Georgia in a northeast-southwest direction. This belt of low rank metamorphic volcanic and sedimentary rocks is situated in the east-central portion of the Piedmont of North Carolina (Fig. 1). Coastal Plain sediments overlap the Slate Belt from the east while the Charlotte Belt, consisting of higher rank metamorphic and igneous rocks, borders it on the west. The Deep River and Wadesboro Triassic Basins surficially bifurcate the Slate Belt in North Carolina where its outcrop width is greatest. Granitic bodies have intruded the Carolina Slate Belt in a number of places. In Union County, the Carolina Slate Belt is bordered on the east by the Wadesboro Triassic Basin and on the west by the Charlotte Belt.

Acknowledgments

The writer extends thanks to Walter H. Wheeler for initial guidance in defining the problem; and to Daniel A. Textoris for his advice and assistance in carrying out the field, laboratory and writing phases of this report. Additional counseling was given by members of the Department of Geology of the University of North Carolina at Chapel Hill, where the investigation was carried out.

Funds for field work, petrographic thin sections, and equipment were provided by the National Science Foundation, the Society of the Sigma Xi, Division of Mineral Resources of the North Carolina Depart-

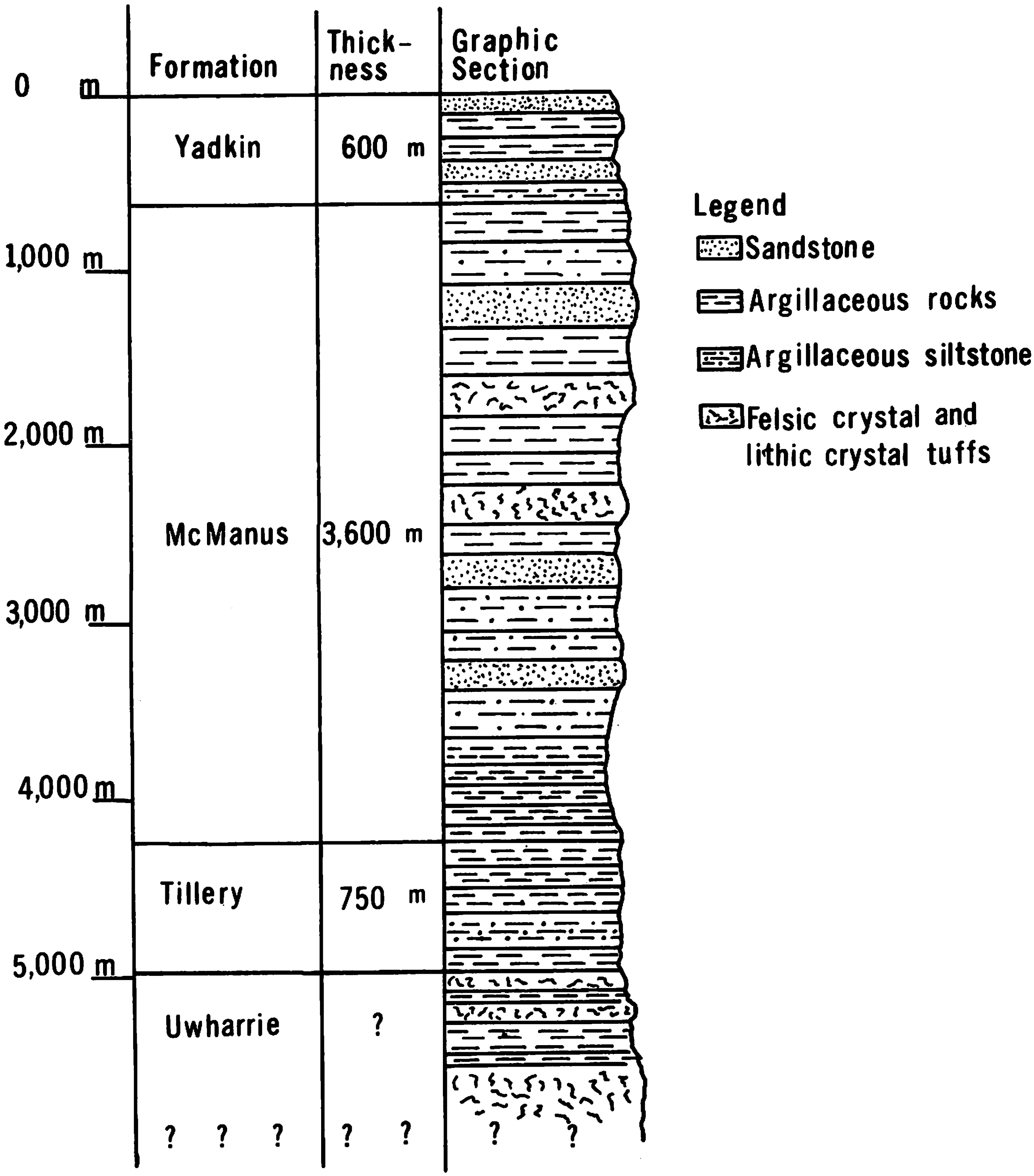


Figure 2. Generalized stratigraphic section of the Carolina Slate Belt in Union County.

ment of Conservation and Development, and the Smith Fund of the University of North Carolina.

PETROGRAPHY AND STRATIGRAPHY

Conley and Bain (1965) proposed formation names for units of the Carolina Slate Belt but were unable to make time-rock designations. The author was able to recognize several of these formations in Union County. Four distinct sequences of rocks are present in the area of this report (Fig. 2). Thickness estimations were made for several of these sequences based on structural and topographic relationships. Lateral relationships were difficult to infer because of the common interbedding and similarity of rock types. Repetition of beds is inadvertently included in the thickness estimations because of local folding and faulting and lateral facies changes.

All of the rocks in Union County except those of Triassic or younger age are slightly metamorphosed; therefore, the prefix "meta" has been deleted from the complete rock names used in this report. Bedding thickness terminology is from Ingram (1954).

Petrographic descriptions presented in the past for the Carolina Slate Belt show a need for consistency in terminology. Fisher (1961, 1966) established a system of nomenclature which is logical and precise. His system has been adopted in this report.

The distinction made by Fisher (1966, p. 288) between pyroclastic and epiclastic is important for interpretations. These terms refer to processes of fragmentation but not necessarily different processes of deposition. Grain size limits for the pyroclastic terms are from Heinrick (1965, p. 93) and Fisher (1961, p. 1410). Epiclastic terminology is from Flawn (1953, p. 564) and Folk (1965, p. 116, 130).

Uwharrie Formation

The Uwharrie Formation is the oldest formation in the Slate Belt and was formerly referred to as "The Lower Volcanic Unit" (Stromquist and Conley, 1959, p. 4). This formation occurs in the south-central and southwestern portions of the area (Pl. 1).

The Uwharrie Formation is exposed in the partially eroded Troy Anticlinorium and New London Synclinorium. The base of the formation is not known. The upper contact is gradational.

Rarity of fresh exposures makes the Uwharrie Formation the most difficult to define adequately. The rocks are extremely weathered and soil color changes were often employed in order to differentiate between the Uwharrie and Tillery Formation. Soil colors of the Uwharrie vary from white and creamy yellow to deep red. Interbedding and interfingering of the various rock types are very common which makes recognition of marker beds impossible. In few instances could beds confidently be traced more than a few hundred meters.

Felsic tuffs. Felsic crystal and lithic crystal tuffs are the dominant rock types in the Uwharrie Formation. The color of these rocks varies from bluish-gray to green when fresh, but colors upon weathering are brown, reddish-orange and white.

Metamorphism has not appreciably effected the testure of the coarser portion of these rocks. Large crystals and rock fragments up to 2 mm are incorporated in a microcystalline groundmass. Only one specimen contained pyroclastic fragments greater than 2 mm and was identified as a crystal lithic lapillistone.

Quartz and albite are the principal crystals. They are usually subhedral although both euhedral and anhedral crystals are present. Lithic fragments of the lithic crystal tuffs consist of quartzite, vein quartz, felsite, and particles of indeterminate origin. Lithic fragment ghosts were observed in several slides.

The groundmass of these tuffs consists of fine ash-size quartz, albite, muscovite, sericite, and epidote with microscopically unidentifiable birefringent material (identified by X-ray diffraction to be chlorite, microcline, epidote, actinolite, kaolinite, and 14 A chlorite-like intergrade material). A white opaque mineral believed to be leucoxene is fairly abundant.

Quartz is the predominant mineral. No paramorphs of alpha quartz after beta quartz were observed. Embayment and recrystallization are common. Much of the quartz displays undulatory extinction.

Albite is the most prevalent plagioclase but some oligoclase and andesine crystals are present. Anorthite percentage determinations were made by two procedures: the Michel-Levy Technique as described in Kerr (1959, p. 257-260); and X-ray diffraction methods and the curves of Smith and Yoder (1956). Euhedral and subhedral

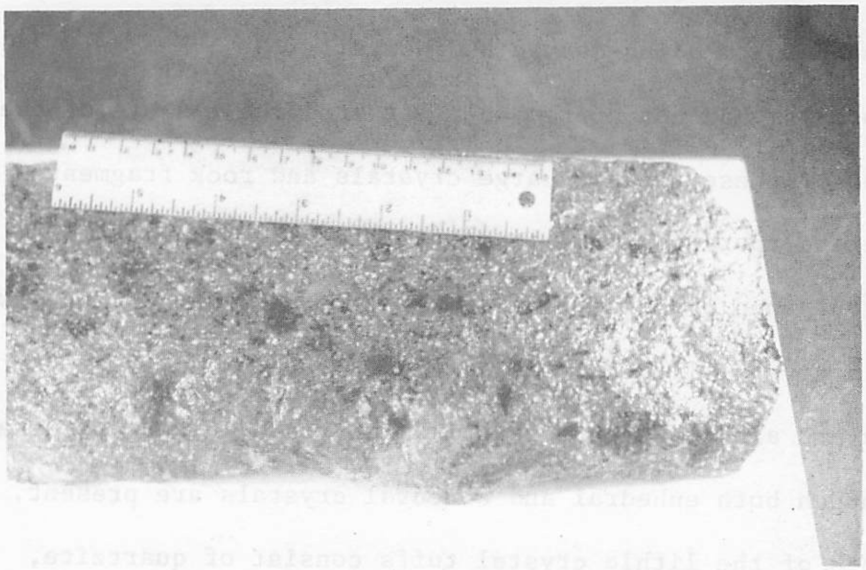


Figure 1. Photograph of crystal lithic tuff displaying dark areas which may represent pumice fragments that have devitrified without collapse.

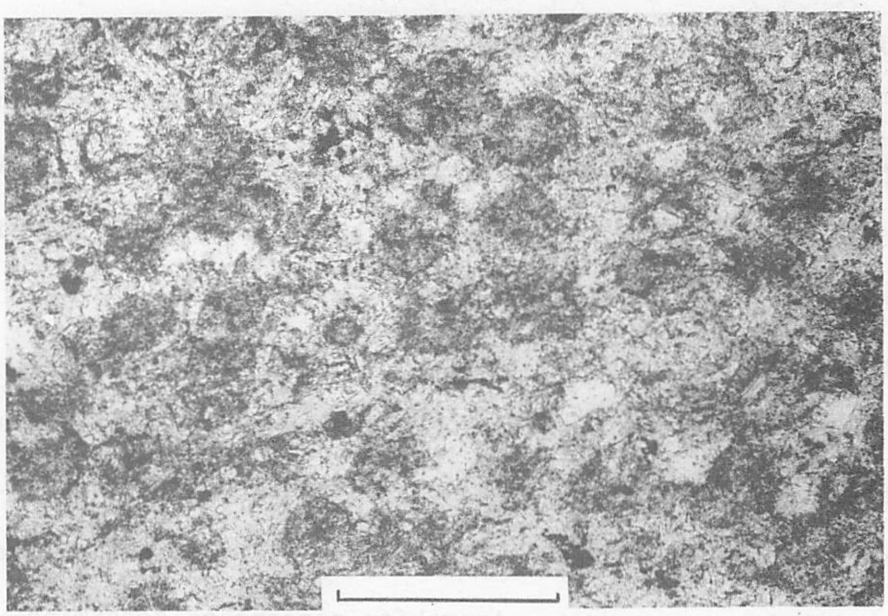


Figure 2. Photomicrograph of silicified accretionary tuff. Bar scale is 1 mm long.

LITHOLOGIC FEATURES OF THE UWHARRIE FORMATION crystals predominate but display no zoning. Albite shows polysynthetic and Carlsbad twinning. Various stages of corrosion of larger crystals was observed. A few albite crystals have been completely replaced by clay minerals resulting in ghost crystals.

Rarity of microcline in these rocks was verified by X-ray diffraction. Muscovite, chlorite, and epidote crystals can be readily identified in thin section . Epidote commonly occurs as inclusions in plagioclase. Biotite, zircon, and garnet are rare.

Quartz veinlets ranging from 0.1 mm to 1 mm generally transect these tuffs. Quartz, chlorite, and epidote are common void filling materials. Conclusive evidence of devitrification is rare. One specimen contained distinct dark areas which may represent pumice fragments that devitrified without collapse, and in which vapor-phase minerals have formed (Pl. 2, fig. 1). Ross and Smith (1960, p. 27) reported similar findings on a large scale in Yellowstone National Park, Wyoming. Small, radial spherulitic growth in the groundmass of other specimens may also represent devitrification. Enlows (1955) reported such features in the tuffs of Chiricahua National Monument, Arizona.

Felsite. The felsites of the Uwharrie Formation are both porphyritic and aphanitic textured. They are dark bluish-gray in fresh exposures, and weather reddish-brown and white.

Rare quartz spherulites and flow banding were observed in two porphyritic specimens. Evidence of deformation associated with flowage is the orientation of platy minerals around broken and bent crystals.

The aphanitic felsites are very finely crystalline. Only two occurrences were noted, and thin section studies revealed little about the mineralogy. X-ray diffraction analyses showed quartz and albite to be the principal minerals present. Minor constituents include chlorite, muscovite, and epidote. The absence or low percentage of alkali feldspars in the felsite porphyries and felsites indicates these rocks are dacites and rhyodacites.

Impure chert. These rocks contain an abundance of quartz but plagioclase, sericite, and kaolinite are finely disseminated throughout. Textures are extremely fine-grained and homogeneous. Some have the texture and fracture of unglazed porcelain. Bedding is poorly expressed. One chert displayed a number of small elliptical and circular bodies of silica having slightly concentric structures. It may represent a subaerially deposited accretionary tuff that has been completely silicified (Pl. 2, fig. 2).

The close association of impure chert with volcanic rocks suggests a volcanic source of silica. The texture of these rocks intimates inorganic precipitation of silica with penecontemporaneous incorporation of fine ash.

Volcanic-sedimentary rocks. Thin-bedded laminated and nonlaminated argillite and sandstone are present in minor proportions in the Uwharrie Formation. The character of the argillites and sandstones in the Uwharrie Formation is identical to those found in great abundance in the overlying units; therefore, their descriptions have been deleted from this section of the report.

Tillery Formation

Rocks of the Tillery Formation were previously known as the "Varved Argillite Unit" (Stromquist and Conley, 1959, p. 4), the "Argillite Unit of the Volcanic-Sedimentary Sequence" (Conley, 1962, p. 5), and the "Laminated Argillite Unit" (Floyd, 1965, p. 16). This formation is exposed as a continuous belt wrapping around the New London Synclinorium and Troy Anticlinorium. It is also exposed in many creek beds along the axis of the Troy Anticlinorium (Pl. 1). Maximum thickness estimated in Union County is 750 meters.

Interbedded laminated and nonlaminated argillite are a common occurrence in the Tillery Formation as well as in the overlying McManus Formation. The field criteria used in distinguishing between the two units were thickness of beds and the percentage of beds exhibiting laminations. The Tillery Formation is generally thinner bedded (10 cm or less) and more than 40 percent of the beds are laminated. Similar criteria were employed by Conley (1962, p. 5).

Rock cleavage is well developed and has been recognized as bedding plane and axial plane in a number of exposures. This formation appears to be more metamorphosed in the western part of the county. The rocks here have developed a phyllitic sheen and rock cleavage formation is extreme.

Laminated argillite. Laminated argillite is the most prevalent rock type in the Tillery Formation. Color varies from bluish-gray when fresh to brown and reddish-orange when weathered. This unit is thin bedded and bedding plane cleavage is well developed.

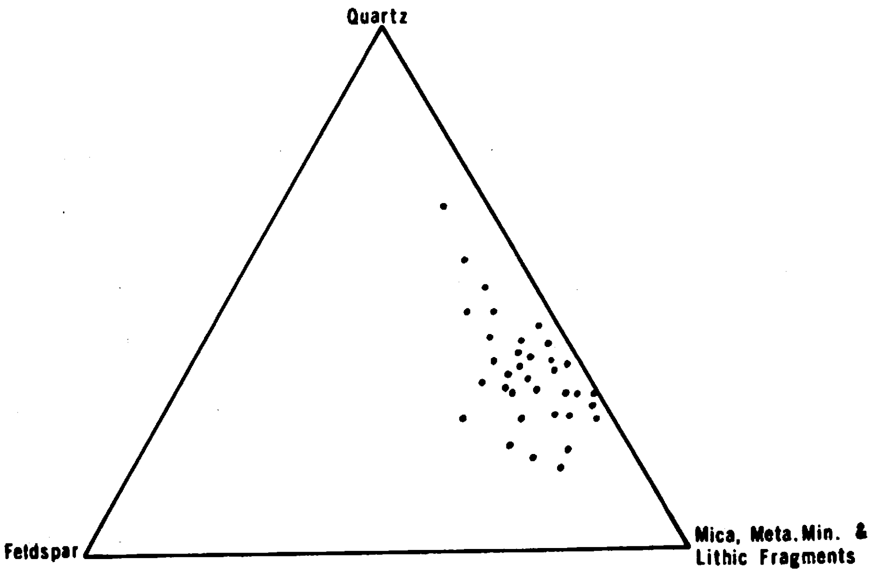


Figure 3. Compositional diagram of argillites of the Tillery Formation (based on visual estimates from thin sections)

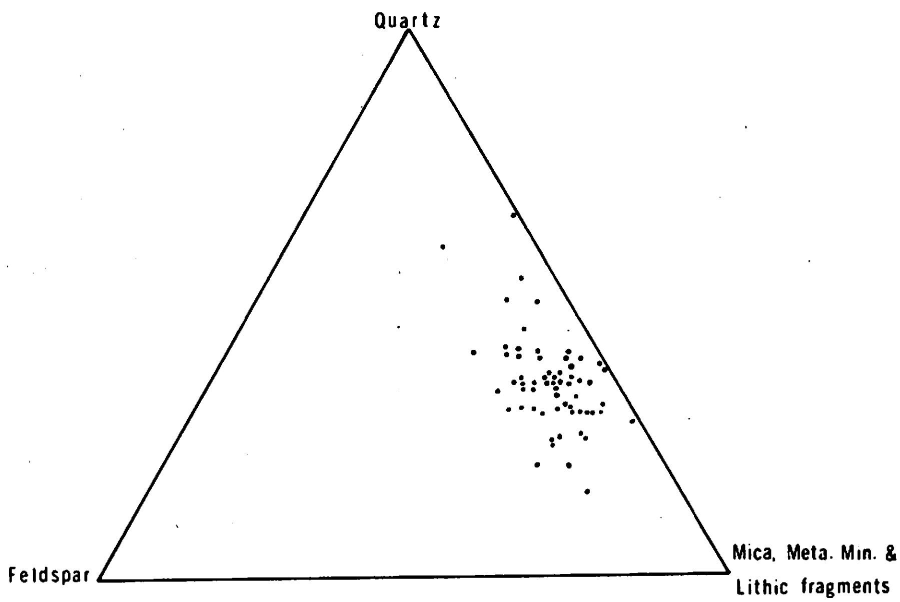


Figure 4. Compositional diagram of argillites of the McManus Formation (based on visual estimates from thin sections)

Graded bedding is the major characteristic of the formation. Lighter colored silt layers grade upward to darker colored clay layers. Less commonly, sand-size particles will grade to silt and clay size particles. The contact between layers is somewhat abrupt. Subangular quartz grains are the chief constituent of the coarser layers and minor amounts of feldspar are usually present. The finer grained layers generally consist of muscovite, sericite, chlorite, illite, kaolinite, and less frequently epidote. Many of the silt-sized particles display extreme corrosion and masking. Recrystallization is evidenced by larger and fresher appearing chlorite and epidote crystals. Chlorite is also a common void filling material. The individual laminae comprising the graded beds are usually less than 5 mm thick, yet extend continuously for considerable relative distances (up to 200 meters). These laminae are repetitive vertically.

Crystal molds, probably representing previously existing evaporite crystals, are a striking feature of the laminated argillite (Randazzo, 1969b). Slump structures, cross-bedding and faulting are fairly common on a microscopic scale. Much of the deformation appears to have been penecontemporaneous with deposition.

Only gross visual estimates of mineral percentages were made because of the small particle size of the argillites. Percentages of 35 samples have been plotted on a triangular compositional diagram (Fig. 3). Grain size distribution studies within the Tillery Formation were somewhat inconclusive. No apparent trends were recognized horizontally. Locally, vertical grain size trends exist but do not display a regional pattern. The only apparent vertical trend was an increase in bedding thickness and less graded bedding as the Tillery Formation passes into the McManus Formation.

Other rock types. Nonlaminated argillites are also present in the Tillery Formation but are far less abundant. They occur interbedded with laminated argillites and with sandstones of this unit. Lithologic character is identical to the laminated argillite except for the absence of graded bedding.

Laminated slate, extremely compact and fine-grained, begins to appear in the western part of Union County. It possesses moderately developed slaty cleavage and platy minerals are somewhat oriented.

Sandstones present in the Tillery Formation may be categorized as feldspathic graywacke and feldspathic subgraywacke according to Folk's (1965) classification. They are very-fine-grained sandstones and uncommon in this unit. Quartz is the dominant mineral but appreciable amounts of feldspar, chlorite, sericite, epidote, and clay minerals occur. The sand-size particles range from angular to subrounded. These rocks are matrix supported and lithologically similar to the sandstones of the Yadkin Graywacke.

Cherts and crystal tuffs identical to those described in the Uwharrie Formation occur in rare amounts in the Tiller Formation. A small metagabbro body is present at the approximate contact between the Tillery and Uwharrie Formations. This body is lithologically similar to the metagabbro bodies of the Charlotte Belt described by Hermes (1966) and represents an eastern extension.

McManus Formation

The contact between the Tillery and McManus Formation is gradational, based on criteria previously mentioned. The McManus Formation has been called the "Monroe Slate" (Nitze and Hanna, 1896, p. 36), and the "Tuffaceous Argillite Unit" (Stromquist and Conley, 1959, p. 5). It is the most widespread formation in Union County. It has retained almost all of its sedimentary character and is the least metamorphosed formation in the area. Maximum thickness is estimated at 3,600 meters.

Nonlaminated argillite, predominantly medium bedded, is the principal rock type. Laminated argillite, sandstone, crystal and lithic crystal tuffs, felsites, and diabase and quartz dikes are also present. Interbedded laminated and nonlaminated argillite and sandstone are common with the number of laminated argillite beds far less than in the Tillery Formation. Rare relic limestone beds are also present in the McManus Formation.

Rock cleavage is well developed in the argillites. Axial plane cleavage accompanies the small, symmetrical, open folds which are more prevalent than in any of the other units. Most of the exposures of thin-bedded argillite have a splintery fragmentary appearance accentuated by weathering. This "splinter weathering" is very common and is characteristic of thin argillite beds present in all formation in the region.

Tuffaceous argillite. The argillites comprising the McManus Formation are tuffaceous. They are very-fine grained, thick bedded and fairly homogeneous, and display dark, thin tabular areas which may represent altered biotite. The color of these rocks varies from bluish-gray to reddish-brown depending upon the stage of weathering.

Megascopically, the complete mineralogy was indeterminable because of the fine-grained nature of the rock. Occasionally, slightly larger grains of quartz and feldspar could be recognized. Small pyrite cubes were present in only the freshest exposures, which were principally in quarries.

Conley (1962, p. 6) reported the presence of thin beds and lenticular masses of impure calcite in the Albemarle region. He theorized that they " . . . probably represented thin primary limestone beds." The only carbonate encountered in Union County occurred in two large quarries. No actual beds were observed. The lenticular masses were occasionally continuous and many appeared to belong to the same zone, oriented paralled to bedding. They possess a brown weathering surface but are bluish-gray in fresh exposures. Many were completely dissolved leaving lense-shaped cavities filled with silt and clay. It is probably that these carbonate bodies adumbrate former primary limestone beds in Stanly County. No radial crystallization, transection of bedding planes, or other evidence suggestive of concretionary origin are present.

Microscopically, the tuffaceous argillite consists of clay, silt, and occasionally, very fine sand-size particles. This rock type is generally microcrystalline but approaches cryptocrystallinity.

Subangular quartz and plagioclase feldspars can usually be identified in a somewhat altered groundmass of sericite, chlorite, and clay material. Limonite is present in weathered specimens. The larger particles are corroded. Relic crystal outlines and minute lithic fragments also occur. The rock is matrix supported and well-sorted. Larger and fresher appearing quartz, chlorite and epidote indicate occurrence of crystallization. Quartz and chlorite are common void fillings.

Conley (1962, p. 6) described the occurrence of dark, tabular bodies in the argillites of Stanly County. Similar wispy features are present in Union County. Their composition consists of extremely fine-grained amorphous, ferruginous and low birefringent material. They sometimes possess an orientation of long dimension parallel to bedding. Conley suggested that these bodies might represent devitrified shards. Their shapes, however, do not resemble typical shards. Biotite is associated with many tuffaceous rocks (Larsen and others, 1937; Deer and others, 1966). Thin, oriented biotite flakes are recognizable in the "Tioga Bentonite" of West Virginia (D.A. Textoris, personal communication, 1968). Weathering of these flakes has released iron which has resulted in their staining. A comparison of photomicrographs (Pl. 3) of the weathered biotite falkes of the Tioga and the questionable wispy bodies of the McManus reveals a remarkable similarity. Based upon characteristic size, shape, and orientation, it is more likely that these tabular bodies are replaced biotite flakes.

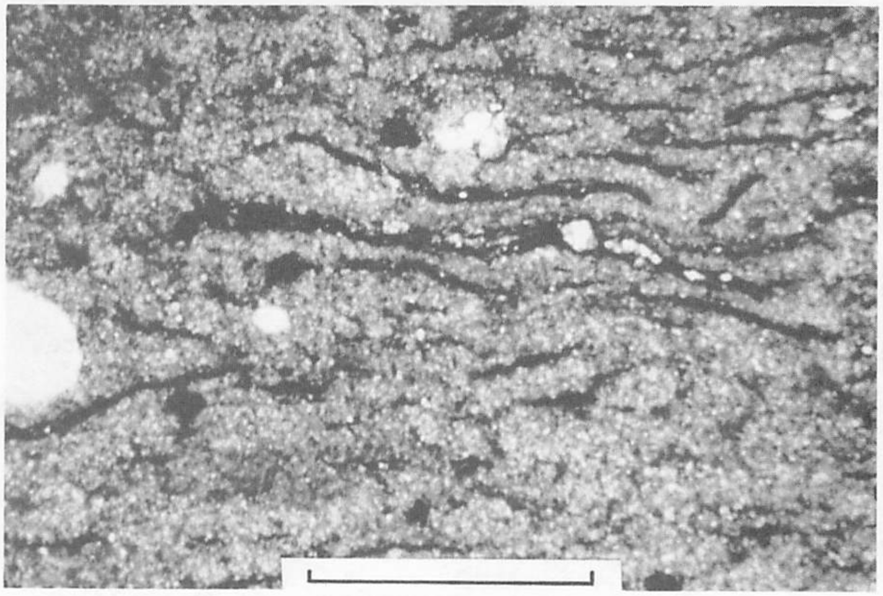


Figure 1. Photomicrograph of dark tabular bodies believed to be replaced biotite, McManus Formation. Bar scale is 1 mm long.

Figure 2. Photomicrograph of altered biotite flakes in Tioga Bentonite. Bar scale is 1 mm long.

COMPARISON PHOTOMICROGRAPHS OF ROCKS OF THE MCMANUS FORMATION AND TIOGA BENTONITE

Graded bedding in the McManus Formation is identical in character to that of the Tillery Formation although not as common. Slump structures, cross-bedding and faulting also are not as prevalent. Only a few specimens displayed evaporite crystal molds.

Visual estimates of mineral percentages were attempted for the tuffaceous argillite. The percentages of 47 samples have been plotted on a triangular compositional diagram (Fig. 4). This diagram is very similar to that of the Tillery laminated argillite (Fig. 3). It indicates no change in the composition of the source material during two somewhat different episodes of deposition.

Grain size distributions within the McManus Formation are variable, and no apparent trends were recognized horizontally. Vertically, the argillites show local cyclical trends from coarser to finer grained rocks. These local trends could not be projected onto a regional basis because of sparse occurrence and lack of continuity. The regional trend observed was a gradual increase in the number of sandstone beds as the McManus Formation grades into the Yadkin Graywacke.

Other rock types. The laminated argillite characteristic of the Tillery Formation is interbedded with the tuffaceous argillite. Its petrologic properties have already been described.

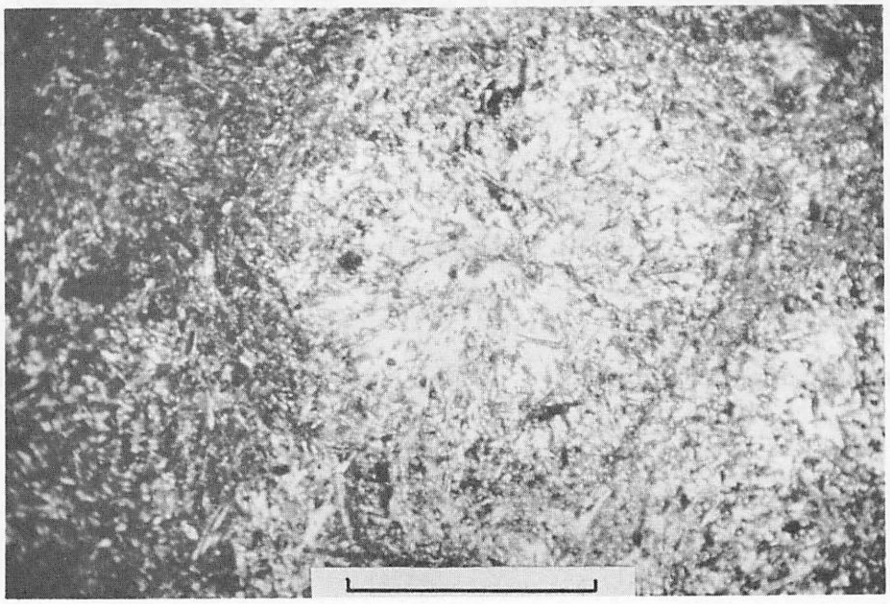
Sandstones comprise the third most abundant rock type in the McManus Formation. They consist predominantly of very fine and fine size sand and when plotted on Folk's (1965) compositional diagram (Fig. 5), they can be categorized as feldspathic subgraywacke, feldspathic graywacke, and graywacke. The latter rock group, however, is rare. These sandstones are lithologically similar to those comprising the overlying Yadkin Graywacke and, therefore, will be discussed under that heading.

Felsites, felsic tuffs, and cherts similar to those of the Uwharrie Formation are present in the McManus. These rock types are not nearly as abundant as those of the Uwharrie but they are more numerous than in the Tillery and Yadkin.

One outcrop in Union County consisted of lapillistone interbedded with a coarse-grained, devitrified lithic crystal tuff. No other outcrop encountered displayed such a coarse-grained nature, suggesting that this may represent the near-source for the volcanic sequence found. The lapillistone is more highly weathered than the accompanying tuff. The relief of the lapillistone is accentuated on weathered surfaces. Some lapilli weather leaving small spheriodal voids.

The lapilli consist of irregular spheroids and ellipsoids with a mean diameter of 2.3 mm. These lapilli are in contact with one another and some appear to have been deformed by compaction.

Each lapillus has a radial crystalline inner zone encompassed by a finer grained outer zone (Pl. 4), and appears to be a spherulite. The inner zone consists of fibrous quartz and plagioclase radiating from a common center. Occasionally, a large clear, anhedral quartz grain will occur in the inner zone, and may represent a void filling. The inner zone comprises some 90 percent of the lapillus. The outer zone is composed of very fine-grained chlorite, sericite, and epidote



Bar scale is 1 mm long. Photomicrograph taken under crossed nicols.

PHOTOMICROGRAPH OF SPHERULITIC LAPILLISTONE IN THE MCMANUS FORMATION concentrically arranged about the inner zone. Larger subhedral epidote, biotite, and chlorite partially obscure the inner area of the lapillus. These lapilli-size spherulites may be further evidence of devitrification.

This lapillistone is similar megascopically to those reported in Stanly County by Sundelius (1963, p. 42). Microscopically, they are quite different. The Stanly County lapillistones display a concentric structure characteristic of accretionary bodies. The concentric nature of the outer zone of the Union County lapillistone does suggest the former existence of a complete concentric structure. Recrystallization at a later time would have produced the radial structure. Accretionary lapilli suggest subaerial deposition from a nearby source (Moore and Peck, 1962, p. 191).

Yadkin Graywacke

The Yadkin Graywacke was named for exposures along the Yadkin River in northern Stanly County. Stromquist and Conley (1959, p. 5) first recognized this unit and referred to it as the "Graywacke Unit." Conley and Bain (1965) reported the presence of this formation in the New London Synclinorium of Union County. The author, however, was unable to delineate this unit in the synclinorium. Although graywacke is present in this region, it is not the dominant lithology. Floyd (1965) did not recognize such a unit in his reconnaissance study of Union County. Floyd (personal communication, 1967) stated that the presence of this unit was questionable and its inclusion in the map accompanying Conley and Bain's report was based on superficial reconnaissance of the region.

The author recognized the Yadkin Graywacke in the extreme eastern portion of Union County (Pl. 1). Here the Yadkin Graywacke occupies a synclinal structure which underlies the Wadesboro Triassic Basin. Reconnaissance in Anson County revealed that this formation is continuous along the western and eastern limbs of the syncline. Sandstone gradually thins out along both limbs, becoming finer grained to the southeast. Observations of adjacent areas in South Carolina indicate the presence of the synclinal structure but not the sandstone.

Sandstone comprises 20 to 30 percent of the formation. It is thick and medium bedded and has a massive blocky appearance characteristic of the formation in other areas of the Slate Belt. Laminations are common both in the sandstone and accompanying argillites. Thickness of the laminated argillite beds varies from thick to thin.

The contact between the Yadkin and McManus units is gradational and can be seen best along U.S. 74 from Marshville to Peachland (Anson County). Field criteria used in distinguishing between the two formations were thicker beds and the prevalence of sandstone and laminated argillite in the Yadkin unit. Yadkin exposures are also fresher in appearance. The rocks are blue and blue-green, and weather green and brown. Estimated thickness of this unit in the area studied is 600 meters.

<u>Sandstones</u>. Three basic sandstone types are present in the Yadkin Formation. In order of decreasing abundance these are feldspathic subgraywacke, graywacke, and feldspathic graywacke. They are interbedded with laminated and nonlaminated argillites. Only a few

exposures were found in the limited extent of this formation in Union County.

Quartz is the principal coarser grained mineral but considerable amounts of plagioclase, rock fragments, chlorite, sericite, epidote and clay minerals may also be present (Fig. 6). Corrosion is common particularly in the feldspars. These sandstones are generally matrix-supported although some local zones are grain-supported. Angular to subrounded grains, poorly sorted, characterize these rocks.

The grain size of the sandstones ranges from very fine to medium sand, with the finer fractions more common. Compared with the graywacke of the type area in Stanly County, these rocks appear to be the finer grained equivalent. Regional grain size distributions within the study area did not reveal any apparent sedimentological trends. Vertical repetition of finer and coarser particle deposition was encountered locally.

Graded bedding is more common in the Yadkin than in the underlying McManus. Very fine sand layers grade into silt and clay layers. Boundaries between layers are abrupt. No cross-bedding, slump structures, or other deformational features were observed in the sandstones of this formation; however, only a small portion of this unit was studied.

Other rock types. Laminated and nonlaminated argillites are the other rock types in the Yadkin. Laminated argillite is abundant but differs from that of the Tillery Formation in being much thicker bedded. Reconnaissance of Anson County revealed a great abundance of thick bedded laminated argillite which reflects the major sedimento-

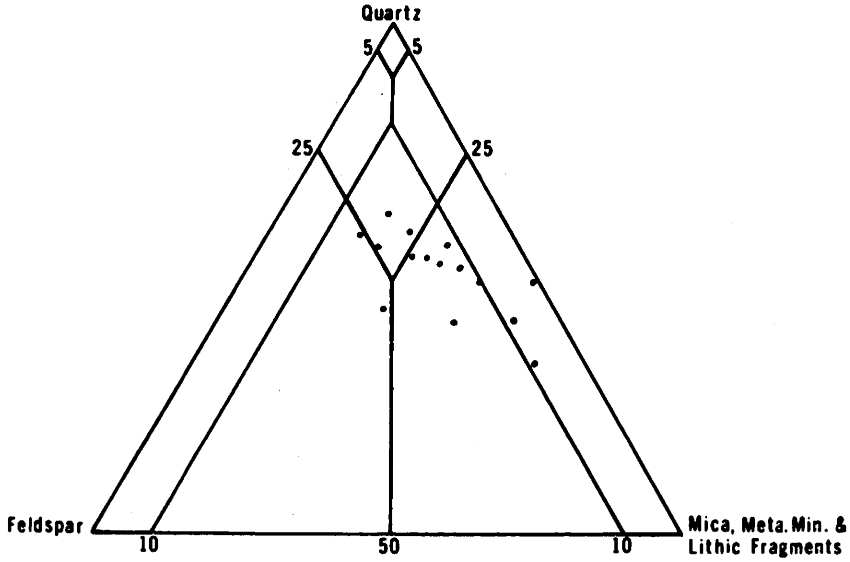


Figure 5. Diagram of sandstones of the McManus Formation (based on visual estimates from thin sections). Sandstone classification from Folk (1965)

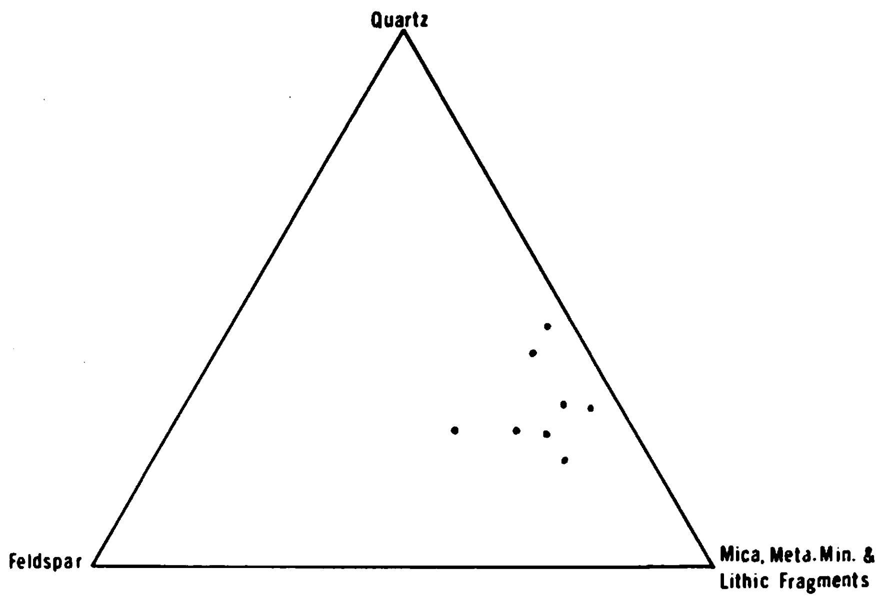


Figure 6. Compositional diagram of sandstones of the Yadkin Graywacke (based on visual estimates from thin sections)

logical trend of the Yadkin unit. There is a progressive regional decrease in grain size toward the southeast. The non-laminated argillites are identical to those of the McManus Formation.

Quartz and Igneous Intrusions

Quartz veins are present in all of the formations but more were observed in the Uwharrie Formation. Large muscovite flakes are commonly seen along the contacts, possibly indicating recrystallization of country material during time of intrusion. Quartz is usually milky in appearance. Occasionally, clear and cloudy quartz prisms with single terminating pyramids are found along fracture planes.

Igneous intrusions also occur in all of the units. They are comprised of diabase and metagabbro. The diabase is far more common and occurs as dikes. It possesses an ophitic or subophitic texture characteristic of Triassic dolerites. Most of the dikes have textures similar to the Type I diabase of Hermes (1964). General mineralogy is plagioclase, clinopyroxene, and chlorite with biotite and quartz occurring as void fillings. Antigorite is very abundant in these rocks and probably represents the alteration product of some previously existing olivine.

Gabbroic intrusions are more highly altered and poor exposures prevent recognition of concordant or discordant nature. In hand specimens, the metagabbro appears to be highly weathered diabase. It has been identified as "greenstone" in Stanly County (Bowman, 1954, p. 29).

Texture of the metagabbro is generally xenoblastic, but abundant sericite and epidote obscure structure and mineralogy. Occasional crystals of biotite are present. Quartz grains found in the metagabbro have an anomolous appearance. They are well rounded to rounded and very clear, and may have been derived from the country rock and entrapped in the molten intrusion. There is also the possibility of their being amygdules.

From evidence in this area, there may have been two periods of intrusions (pre-Newark episode and post-Newark). The relationship between the tabular metagabbro bodies and isolated metagabbro previously mentioned (p. 12) is unclear. It may be that the tabular metagabbro has been locally metamorphosed in portions of the folded belt where pressures were higher. Such metamorphism would have had to change both mineralogy and texture.

Age

The age of all Piedmont rocks is still speculative. Early Paleozoic (Cambrian to Silurian) is indicated by documented fossils from Maryland (Jonas and Stose, 1936, p. 1669), Virginia (Stose and Stose, 1948, p. 404), and North Carolina (St. Jean, 1965, p. 307).

Within the Carolina Slate Belt, lead-alpha age determinations have dated rocks in Montgomery County as 440 ± 60 and 470 ± 60 million years (White and others, 1963, p. 107). Rubidium-strontium age determinations have dated rhyolite from the Uwharrie Formation near Albemarle, North Carolina as 535 ± 50 million years (Hills and Butler, 1968, p. 45) . These absolute ages are Late Cambrian and Ordovician according to current time charts.

Metamorphism

Semi-quantitative X-ray modal analyses (Randazzo, 1969a) and petrographic studies indicate that the most abundant minerals present in the rocks of Union County are quartz, albite, muscovite, chlorite and epidote. This assemblage is typical of the quartz-albite-muscovite-chlorite subfacies of the greenschist facies. Pressure and temperature ranges characteristic of this subfacies are 3,000 to 8,000 bars and 300° to 500° C (Turner and Verhoogen, 1960, p. 534). These low pressure and temperature conditions resulted in the low rank regional metamorphism distinctive of this portion of the Carolina Slate Belt.

X-Radiography

An X-radiography procedure modified after Hamblin (1962) was used for 12 samples to determine internal structures. Samples were selected on the basis of apparent homogeneity. Several laminated rocks were included as a control. These samples included laminated and homogeneous argillite of the Tillery and McManus formations, chert and sandstone of the McManus Formation, and crystal tuff of the Uwharrie Formation.

The radiographs were taken with a Picker medical X-ray unit supplied with Kodak Industrial Type A film. Focus-film distances were kept constant at one meter. Rock slices approximately 3 mm thick were exposed for one second at a constant milliamperage of 100. Kilovoltage was varied from 50 to 70 in order to obtain maximum contrast and sharpest detail.

Results obtained verified the homogeneous character of the non-laminated argillites, sandstone and crystal tuff. Those structures megascopically visible were also seen in the radiographs. The significance of homogeneous argillite is discussed in a later section of this report.

STRUCTURE

The Troy Anticlinorium and the New London Synclinorium are the dominant structures in the area. The Gold Hill Fault and the synclinal structure underlying the Wadesboro Triassic Basin are other major structural elements in Union County. The fault and axial plane traces of the folds trend northeast-southwest. The folds are asymmetric and plunge northeast. Outcrop patterns display the asymmetry and plunge of these folds (Pl. 1).

Bowman (1954) recognized 11 structural axes in southern Stanly County. Of these, five could theoretically be projected into the area of this report. Although several local axes did align with those proposed by Bowman, they lacked continuity. Also, several were found which were not accounted for by Bowman. It appears that only the New London and Troy fold systems are of regional dimensions.

Troy Anticlinorium

The Troy Anticlinorium represents a series of local anticlines and synclines which regionally form a large anticline. This anticlinorium can be traced through several counties and was named after Troy, North Carolina, through which the axial trace extends.

The local folds are open and predominantly asymmetric. Axial plane cleavage is best developed where only argillites are involved in the folding. Minor thrust and normal faults are present in the McManus and Tillery formations. The lack of bedding in rocks of the Uwharrie Formation and the small areal extent of the Yadkin Graywacke account for the lack of observed minor folds and faults in these two units. The regional dip of the east limb of the Troy Anticlinorium is 29° SE. and the western limb dips 37° NW.

New London Synclinorium

The New London Synclinorium is a broad, general synclinal structure comprised of several smaller folds. This synclinorium was named after New London, North Carolina, through which the axial trace passes. Known extent is much less than the Troy Anticlinorium. Local folds and faults are of the same character as those within the Troy fold belt. The New London Synclinorium appears to be more asymmetric than the Troy Anticlinorium. Near the axis of folding, the eastern limb dips 29° NW. and the western limb dips 21° SE.

Peachland Syncline

Beneath the Wadesboro Triassic Basin and bordering it on the east, south, and west is a synclinal structure, the complementary fold of the Troy Anticlinorium. The Slate Belt rocks bordering the basin on the west were postulated by Swe (1963, p. 16) as being " . . . . a limb of a possibly northeast-trending anticline." Randazzo (1965, p. 12) hypothesized that if Swe's postulation was correct, the ". . . argillites along the eastern border are a complementary limb of a fold." More detailed work has revealed that these bordering rocks comprise the limbs of a syncline, probably plunging to the northeast. The author proposes the name Peachland Syncline after the town of Peachland which lies on the western limb of this structure. The northern termination of this structure is unknown and its southern extent was only followed a short distance into South Carolina.

Although correlation is presumptuous in the light of present knowledge, this syncline is roughly aligned with the Virgilina Synclinorium of Virginia and North Carolina (Laney, 1917). More extensive investigations of the structures and lithologies underlying the Triassic basins of North Carolina would be necessary to demonstrate this correlation.

Gold Hill Fault

Laney (1910, p. 68) proposed that a thrust fault trending N. 15° E. separated the Carolina Slate Belt from the Charlotte Belt in Rowan and Cabarrus counties. His evidence was based on lithologic changes, minor fault trends, jointing and slickensides, stream patterns, and extensive mineralization along the proposed line of contact.

The Gold Hill Fault was projected into Union County on the North Carolina State Geologic Map (Stuckey, 1958). Guidroz (1964) conducted a gravity survey from Charlotte to Monroe and reported a large negative anomaly proximal to the mapped fault in Union County. Floyd (1965) mapped its position farther to the east but indicated its questionable location.

The farthest western extent of the area covered in this report coincides with the position of the fault proposed by Floyd. Rocks along this western margin are more highly metamorphosed as shown by occurrence of slate and phyllite. Local fault planes, many quartz veins, and minor but persistant joints strike approximately parallel to the proposed major fault trend. In this area, streams flowing into the Rocky River (Goose Creek, and the North and South Forks of Crooked Creek) show changes in direction from east-southeast to east-northeast (Fig. 7). The points of deflection of these streams can be aligned parallel to Floyd's proposed position of the Gold Hill Fault. The East Fork of Twelve Mile Creek which drains to the southwest is parallel to the fault trace. Mineralization is concentrated in the western part of Union County as shown by the number of gold mines (Fig. 7).

This evidence suggests continuation of the Gold Hill Fault into Union County. Scarceness of meaningful outcrops in the region prevent anymore than an approximation of the actual position of the fault. This region represents an intriguing series of problems concerning the exact relationships of the drainage patterns, zones of mineralization, and position and nature of the Gold Hill Fault.

Structural Trends

The Troy Anticlinorium axial plane has an average strike of

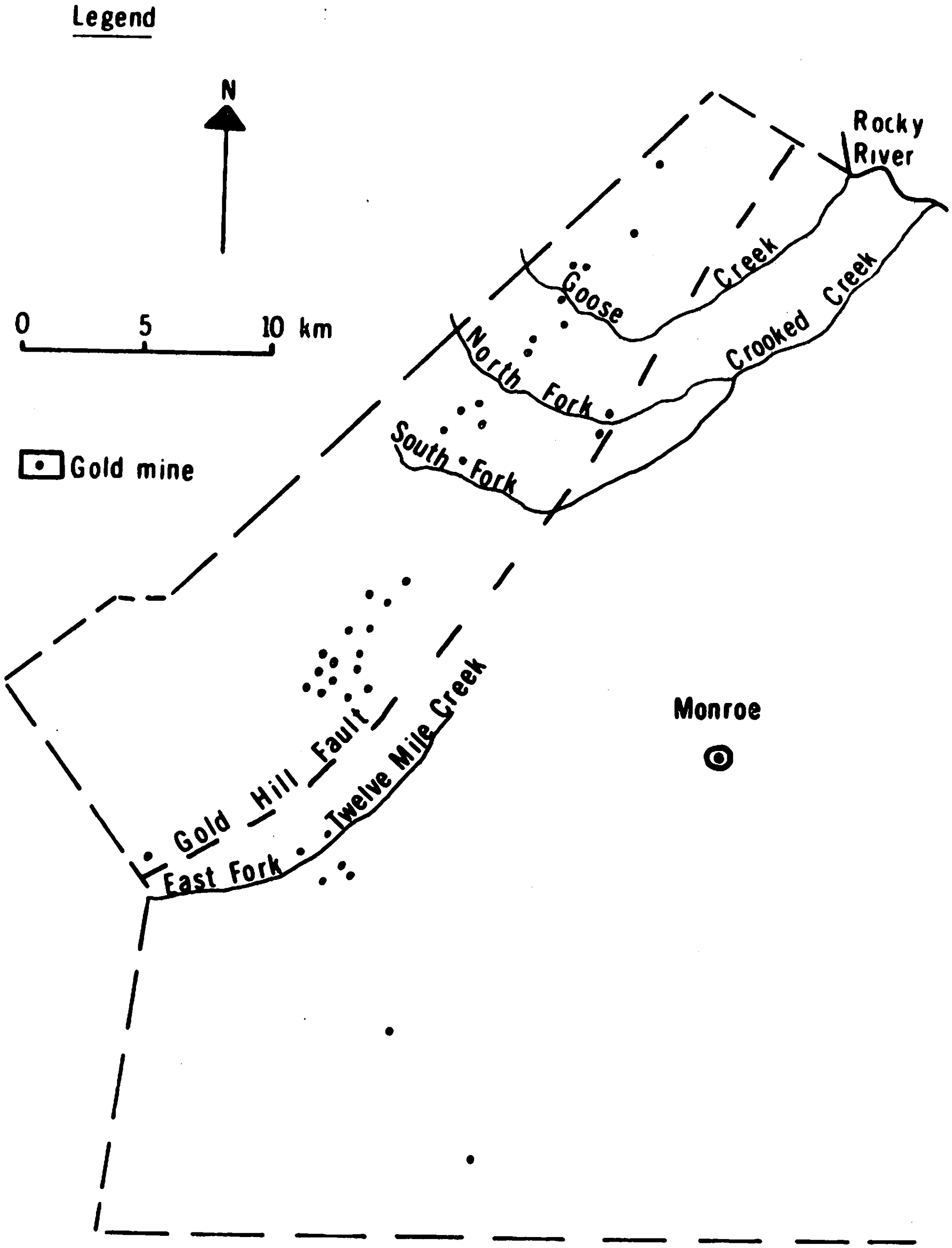


Figure 7. Map showing relationship of the position of the Gold Hill Fault to the drainage system and goldmine locations in western Union County (gold mine localities from Pardee and Park, 1948, Pl. 22)

N. 48° E. and dips to the northwest at a high angle. The axial plane of the New London Synclinorium has an average strike of N. 25° E. and dips to the southeast at a high angle. Average strike of the axial planes of small local folds is N. 25° E.

Axial plane cleavage strikes N. 54° E. and dips 67° NW. in the Troy fold system, and 77° SE. in the New London system. The 6° discrepency in strike direction between cleavage and axial plane trace can be attributed in part to instrumental and human error, the number of readings taken, local structural variations, and the dominance of the Troy Anticlinorium axial plane cleavage.

Local fault planes and quartz veins and diabase dikes have two principal directions of strike. The faults strike N. 54° E. and N. 48° W. and the dikes trend N. 42° E. and N. 33° W. The number of possible faults not observed, and dikes observed but whose trends were not discernable, make these figures somewhat unreliable as regional averages.

Regional joining is developed in several directions. All joint directions recognized at each outcrop were recorded. The most prominent set strikes N. 56° E. with high angle dips to the northwest and southeast. Another set strikes N. 36° W. and a third has an average strike of N. 17° W. These latter two sets dip northeast and southwest at high angles. Joint directions were plotted on a Schmidt equal-area net of 10 cm radius. The poles (perpendicular to the plane of each joint) were plotted using the lower hemisphere (Fig. 8).

Joint trend data from the author's earlier work in the Wades-

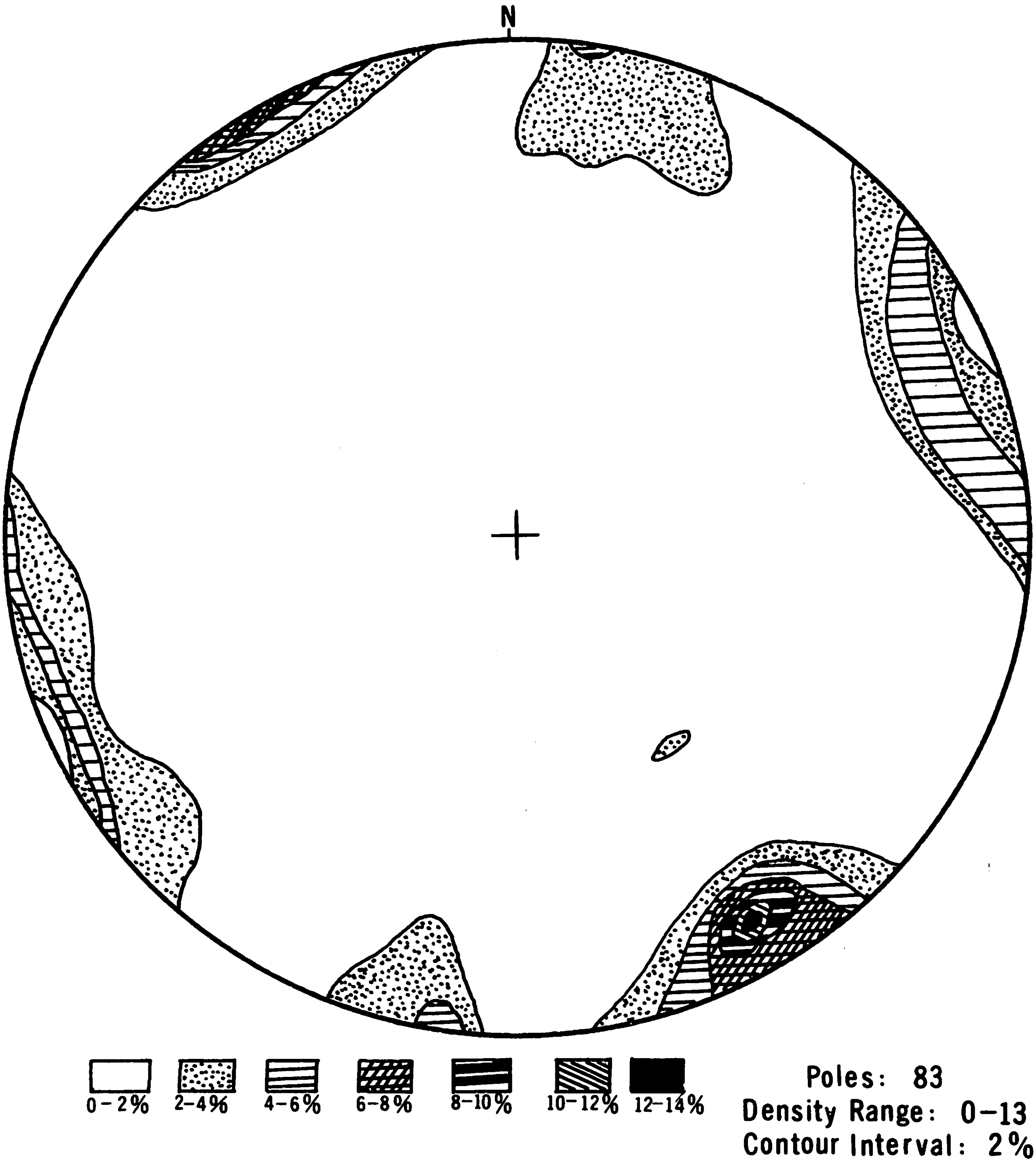


Figure 8. Stereonet plot of the joint directions in the Slate Belt of Union County.

boro Triassic Basin were also plotted on a Schmidt net (Fig. 9) and compared with that accumulated in the present study. These data were collected in the same way as those from the Slate Belt. The maximum high of the Triassic data (N. 16° W., 78° SW.) is coincident with the second highest maximum of the Slate Belt (N. 17° W., 80° SW.). This joint set may be the result of penecontemporaneous or post-Newark deformation while the maximum Slate Belt high (N. 55° E.) may have resulted from pre-Newark deformation. Smith (1951) found a similar relationship in his fracture analysis of portions of the Slate Belt north of this area.

GEOLOGIC HISTORY

The four formations occurring in Union County indicate several periods of volcanism and sedimentation climaxed by regional folding and metamorphism. The Uwharrie Formation represents the oldest volcanic episode Absence of volcanic breccia and rarity of lapillistones suggest a distant source area, probably to the north where the Uwharrie Formation does contain these coarse pyroclastic rocks. It is probable that some of the tuffs of this unit were deposited beneath water because of close association with well-bedded argillites. Ragland and Butler (1967) suggest marine deposition for other units of the Carolina Slate Belt based on the similar bulk composition of felsic tuffs to quartz keratophyres. The latter indicate marine deposition because of high sodium content.

Toward the end of Uwharrie deposition, epiclastic sedimentation was dominant. This is indicated by the greater prevalence of sedimentary rocks in the upper portion of the Uwharrie Formation and the gradational nature of its contact with the Tillery Formation. Renewed volcanic activity during Tillery sedimentation was very limited. Deposition of

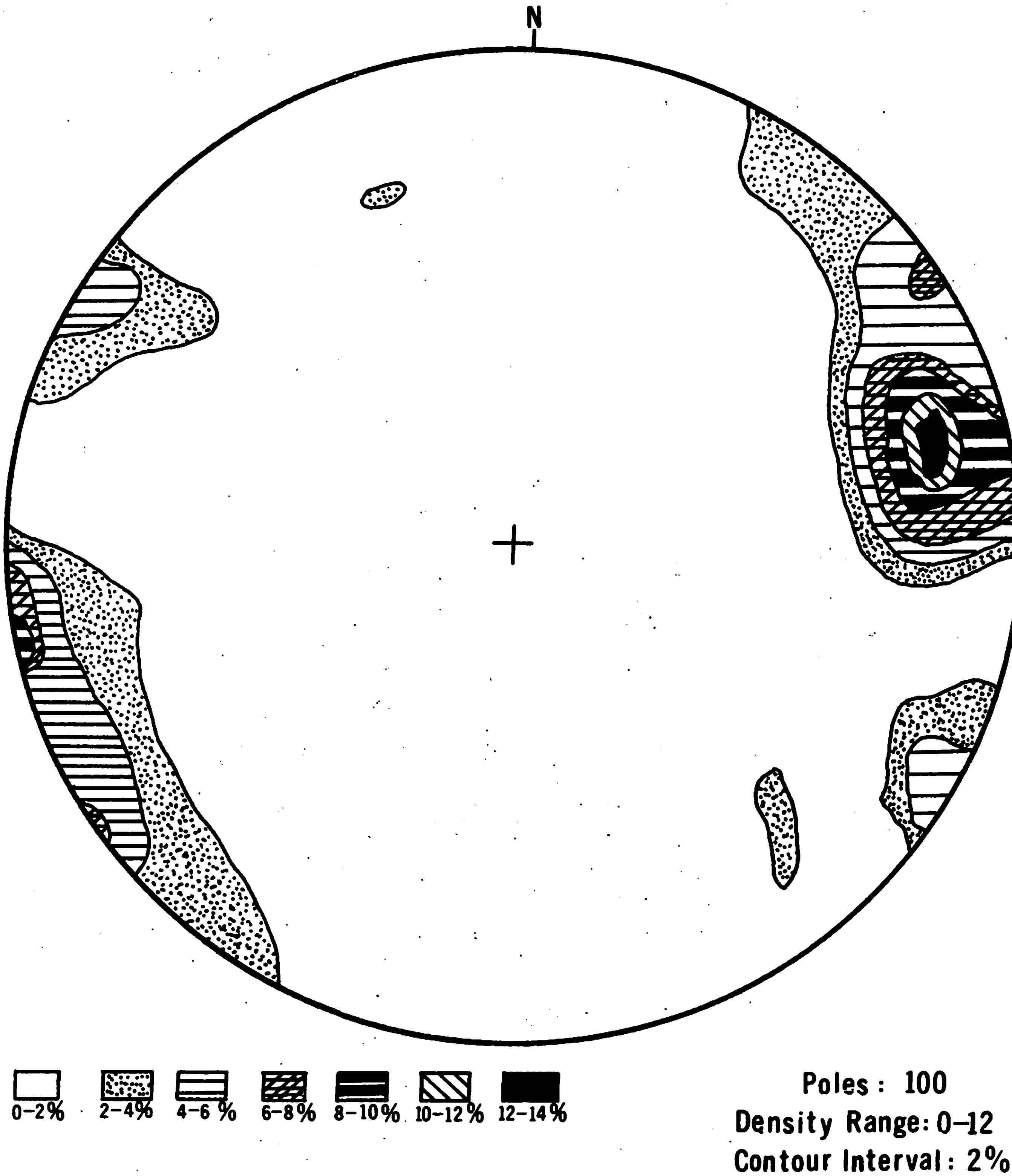


Figure 9. Stereonet plot of the joint directions in the Wadesboro Triassic Basin.

silt and clay size particles was characterized by minute but repetitive waxing and waning of currents. This resulted in graded laminae which typify the Tillery unit. For such a sequence to develop, a relatively low energy environment had to exist. The source area for the rocks of the Tillery Formation could not be determined because of the ambiguity of the grain size analyses of vertical sections and rare sedimentary structures which would indicate paleoslope directions. Conley (1962, p. 12) suggested the Lower Volcanic Sequence (Uwharrie Formation) as a possible source based on the presence of thin basal conglomerate derived from this sequence. The very similar mineralogical makeup of the Uwharrie and Tillery units does denote this possibility. Similarity of rock types, however, could suggest intraformational breakup.

The gradual increase in bedding thickness and decrease in graded bedding mark the beginning of a new chapter of deposition and the McManus Formation. Volcanism became more prevalent and argillites developed a more tuffaceous character. These argillites were probably derived from volcanic ash and fine-grained fragments of pre-existing material. The large amount of argillite and thick bedding has been attributed to aerial transportation and deposition in quiet water (Conley, 1962, p. 12). Angular shape of the particles and close association with crystal and lithic crystal tuffs suggest that during volcanic eruptions, fine ash was expelled into the atmosphere where it was sorted. Deposition in quiet water is indicated by the preservation of thin biotite sheets. In a higher energy environment, these sheets would not have withstood reworking. Homogeneity of these argillites also indicates a lack of current action. The source of the argillites and assorted tuffs of the McManus Formation appears to be to the north. The volcanic rocks are coarsest and most abundant in the northern part of Union County. Grain size distributions of the argillites do not reveal a particular source direction.

Presence of very fine-grained sandstone interbedded with argillite in the Yadkin indicates renewal of epiclastic sedimentation. The tuffaceous character of the argillite is somewhat diminished and graded bedding is again prevalent. The nature of the graded beds suggests both delicate and rhythmic fluctuations and abrupt changes in the energy of the depositing current. These more abrupt changes may indicate deposition by turbidity currents. The energy associated with these currents was probably low because coarse sand and pebble-size particles and sole markings are absent. The coarse-grained character of the Yadkin Graywacke to the north (Stanly County) indicates a regional facies change. The source area for rocks of this formation was probably to the north.

Rocks comprising the four stratigraphic units must have been almost completely derived from the great amount of volcanic material produced. Conditions under which the sediments were accumulated appear to be closely associated with initial fragmentation. The abundance of silt and clay-size particles in thin graded beds and in thicker homogeneous ones suggests as a site of deposition a low energy marine or lacustrine environment. The presence of accretionary lapillistones, probably subaerially deposited, and the crystal molds of previously existing evaporite crystals implies a site of deposition which was periodically uncovered by water. The character of the various rock types and great thickness are typical of eugeosynclinal sedimentation (Krumbein and Sloss, 1963, p. 427-428). The geographic position of the area has been considered the site of the Appalachian Eugeosyncline (Kay, 1951; King, 1959). If the source for these sediments and volcanic rocks was to the north, the area of accumulation would then be several kilometers offshore, in relatively shallow water. It is more likely that a marine environment was present because the lithofacies implies eugeosynclinal sedimentation (Aubouin, 1965, p. 132). Also indicative is the fossil of a marine organism found near the area (St. Jean, 1965). Little can be said about the climate of the region during sedimentation. If the crystal molds found in the Tillery and McManus formations are those of evaporites, then some degree of exposure must have existed periodically. These periods must have been minor, however, because of the relatively greater thickness of "normal" water-laid deposits.

Another period of volcanic activity was recorded in areas adjacent to Union County. Either this episode was not intense enough to effect a large area or evidence of its existence in Union County has been removed by erosion.

The region underwent a period of intense folding after Yadkin sedimentation. Jointing, faulting, and metamorphism developed. Regional metamorphism of the Slate Belt is related to the dynamic processes of regional folding. The very low-rank metamorphism within Union County may be indicative of broad open folding rather than the tight or closed folding that occurred in other portions of the Slate Belt. Penecontemporaneous with or after the regional deformation, quartz veins were emplaced chiefly along joints. Presence of free silica permitted a certain amount of silicification within the rocks. Gold and other metals were also emplaced at this time as well as igneous intrusions.

The exact time of development of the Gold Hill Fault is not known. It may have formed during or shortly after Slate Belt folding occurred or it may be related to disturbances which resulted in the border faults of the Deep River-Wadesboro Triassic Basin during the Late Triassic. This disturbance produced another joint set in the adjacent Slate Belt, and diabase intrusions formed along this new joint direction. During the Triassic disturbance, rocks of the McManus and Yadkin units were one of the two principal sources for the Newark rocks (Randazzo, 1965, p. 42). Since the Triassic, the region has undergone extensive erosion, with only remnants of an extensive fold system remaining.

Recent Analog

A geologic analog of the Carolina Slate Belt may be the Andaman Sea of southeast Asia. Bemmelen (1949, 1954) described the geologic setting and tectonic framework of the regions, and a similarity to the Slate Belt exists. Major fold axes and fault traces are present along with clastic and volcanic sedimentation. Originally the Andaman sea was much shallower, but faulting has resulted in its deepening.

Weeks and others (1967) have added geophysical and oceanograph data which divide the Andaman Sea into several geosynclinal zones. These zones consist of a foredeep, outer island arc, interdeep, inner volcanic arc and backdeep. The backdeep and inner volcanic arc best fit the setting envisioned by this author for the Union County area.

Among the older rocks found in the vicinity of these zones of the Andaman Sea are sandstones, shales, cherts, siliceous limestones, and volcanic ash beds. The more recent accumulations are silt-size sediments derived from the mainland and islands. It is unfortunate that little descriptive work has been performed on the rocks and sediments of that region. A more definite comparison can be made when this is accomplished.

SUMMARY AND CONCLUSIONS

Conclusions reached in this investigation are based on a synthesis of the fragmentary rock record and its conformity with the regional patterns of the Carolina Slate Belt.

Conclusions concerning the Union County portion of the Carolina Slate Belt are:

1) The four stratigraphic units present are the Uwharrie Formation, Tillery Formation, McManus Formation, and Yadkin Graywacke. They represent interrelated episodes of volcanic and epiclastic sedimentation.
2) The rock types of these formations are tuffaceous argillites, laminated argillites, felsic crystal and crystal lithic tuffs, felsite porphyries, and impure cherts.
3) Quartz veins and Newark or post-Newark diabase dikes are common in all formations. A pre-Newark period of intrusion may also have occurred because of the presence of highly altered metagabbro bodies.
4) Most of the coarse-grained tuffs were probably deposited beneath water but some may have been deposited subaerially.
5) The source for volcanic rocks appears to be from the approximate north.
6) A fine-grained lithofacies of the Yadkin Graywacke exists in Union County and reflects a northern source.
7) The rock assemblages represent eugeosynclinal facies, part of the former Appalachian Geosyncline.

8) A recent analog of the area may be the island arc system in the Andaman Sea in southeast Asia.

9) Crystal molds in rocks of the Tillery and McManus Formations, most likely of an evaporite origin, indicate deposition in an area only periodically covered with water.

10) The New London Synclinorium and Troy Anticlinorium are the major deformational structures. Minor folding is very common within these fold systems.

11) A partially buried syncline exists beneath the Wadesboro Triassic Basin. The name Peachland Syncline has been proposed for this structure.

12) Regional folding may be related to initial border faulting of the Triassic basin and the Gold Hill fault.

13) The prominent joint set is coincident with that found in the Wadesboro Triassic Basin. This indicates a younger period of deformation.

14) Metamorphic rank of the region is the quartz-albite-muscovite-chlorite subfacies of the greenschist facies.

15) A slight but recognizable increase in degree of metamorphism exists to the west.

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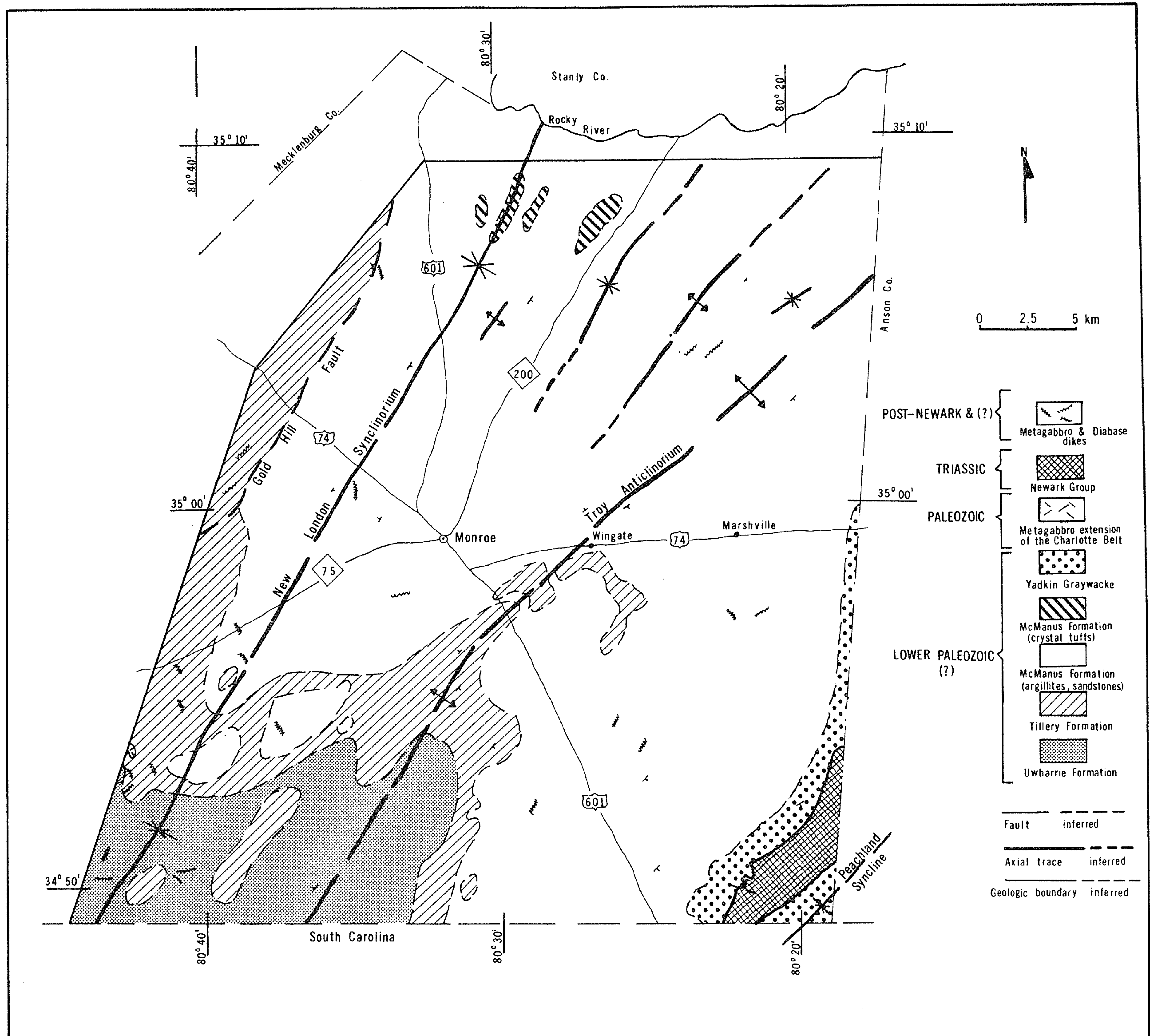

GEOLOGIC MAP OF THE CAROLINA SLATE BELT, UNION COUNTY, NORTH CAROLINA

RANDAZZO, PLATE 1