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GEOLOGY AND MINERAL RESOURCES OF ORANGE COUNTY, NORTH CAROLINA

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by

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This report is preliminary and has not been edited or reviewed for conformity with North Carolina Geological Survey standards and nomenclature.

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ABSTRACT

Orange County is located in the northern Piedmont of North Carolina and covers an area of 398 square miles. The county contains a variety of rocks which collectively can be divided into three distinct types. These are metavolcanic-metasedimentary rocks of Ordovician (?) age, igneous intrusive rocks of Devonian (?) or later Paleozoic age and sedimentary rocks of Triassic age.

Stratigraphically and lithologically the metavolcanic rocks in Orange County, North Carolina, have been divided into four units. Units I through IV are metavolcanic rocks consisting of flows, pyroclastics and epiclastics which are products of both subaerial and subaqueous deposition. This metavolcanic sequence locally grades from Unit I, composed of amygdaloidal basalt flows, some of which exhibit pillow structure, and interlayered basaltic lithic tuffs and crystal lithic tuffs to the andesitic to dacitic pyroclastic rocks with minor basalt flows of Unit II. Unit III, which overlies Unit II, is predominantly composed of dacitic to rhyolitic lithic tuffs, crystal lithic tuffs and scattered spherulitic flows and flow tuffs which are rhyolitic in composition. The epiclastics of Unit IV overlie Unit III and consist of conglomerates with intercalated graywackes, overlain by graywackes with laminated argillite interbeds which are in turn overlain by laminated argillites. These metavolcanic rocks have been thightly folded into a series of northeast trending asymmetrical anticlines and synclines and are considered of Ordovician (?) age.

Intrusive into the metavolcanic rocks are the igneous plutonic rocks. These intrusive plutons and plutonic complexes of Devonian (?) or later Paleozoic age range in composition from granites, quartz monzonites, granodiorites, quartz diorites, diorites and gabbros to ultramafics. These intrusive rocks were apparently injected along zones of weaknesses such as shear fault and fracture zones in the older metavolcanic rocks.

Fine-grained aplite and highly-weathered lamprophyre dikes and stringers, primarily found in the vicinity of the igneous intrusive rocks, cut one another as well as all other pre-Triassic rocks in the county. These dikes and stringers were apparently a later phase of the Paleozoic igneous intrusive activity in the area.

The extreme southeastern corner of Orange County contains sedimentary rocks of Triassic age which occupy a downfaulted area known as the Durham basin. These rocks are considered to be Late Triassic age and are assigned to the Newark group. The Triassic sedimentary rocks are fine-grained clastics and interbedded conglomerates which were apparently derived from the older metavolcanic and intrusive igneous rocks that occur west of the Durham basin.

Intrusive into the Triassic sedimentary rocks and the pre-Triassic rocks are discordant diabase dikes of a basaltic composition that are of Late Triassic or Early Jurassic age and are considered the youngest rocks in the county.

Numerous abandoned mines and prospect sites exist in Orange County that have in the past been worked for gold, copper and iron. At present, pyrophyllite, crushed aggregate, building stone and gravel are being commercially mined in the county.

INTRODUCTION

Location and description of area

Orange County is located in the northern Piedmont of North Carolina (see figure 1) between 35 degrees 51 minutes and 36 degrees 15 minutes north latitude, and 78 degrees 57 minutes and 79 degrees 16 minutes west longitude. The county is approximately rectangular in shape with an average width of 14 miles and a length of 28 miles from north to south. It encompasses an area of 398 square miles or approximately 254,720 acres and ranks 65th in size among the 100 counties in the State. On the north it is bounded by Caswell and Person counties; on the east by Durham County; on the south by Chatham County and on the west by Alamance County.

Purpose and scope of investigation

The Division of Mineral Resources of the North Carolina Department of Conservation and Development at the request of the Research Triangle Regional Planning Commission initiated in the summer of 1962, a detailed geologic mapping project and mineral investigation of Orange County, North Carolina. The objectives of the project were threefold: (1) map the geology of the area in detail and determine the local stratigraphic sequence; (2) interpret the structure of the sequence and (3) investigate known mines, quarries and mineral prospects in the area and through detailed mapping, locate and evaluate new areas of possible mineral potential, their relationship with the surrounding country rock and their probable mode of emplacement.

Four U.S. Geological Survey topographic quadrangle sheets were available as base maps. These maps are the Chapel Hill 7½-minute quadrangle, the Durham North 15-minute quadrangle, the Durham South 15-minute quadrangle and the Farrington 7½-minute quadrangle. Of the aforementioned maps, only the Chapel Hill 7½-minute quadrangle located in the southeastern section of the county was of significant aid in mapping. The Durham North and Durham South 15-minute quadrangles cover the eastern edge of Orange County and the Farrington 7½-minute quadrangle covers only the extreme southeastern edge of the county. Consequently, eleven 7½-minute planimetric maps acquired from the Research Triangle Regional Planning Commission were traced and were used as base maps to plot the geology. The contacts in turn, were transferred to the permanent base map on a scale of one inch to one mile.

A soils map of Orange County published in 1918 by the U.S. Department of Agriculture, Bureau of Soils, in addition to helping with the identification of soils, was particularly useful in locating now unmarked or abandoned roads and trails which provided access to many isolated areas.

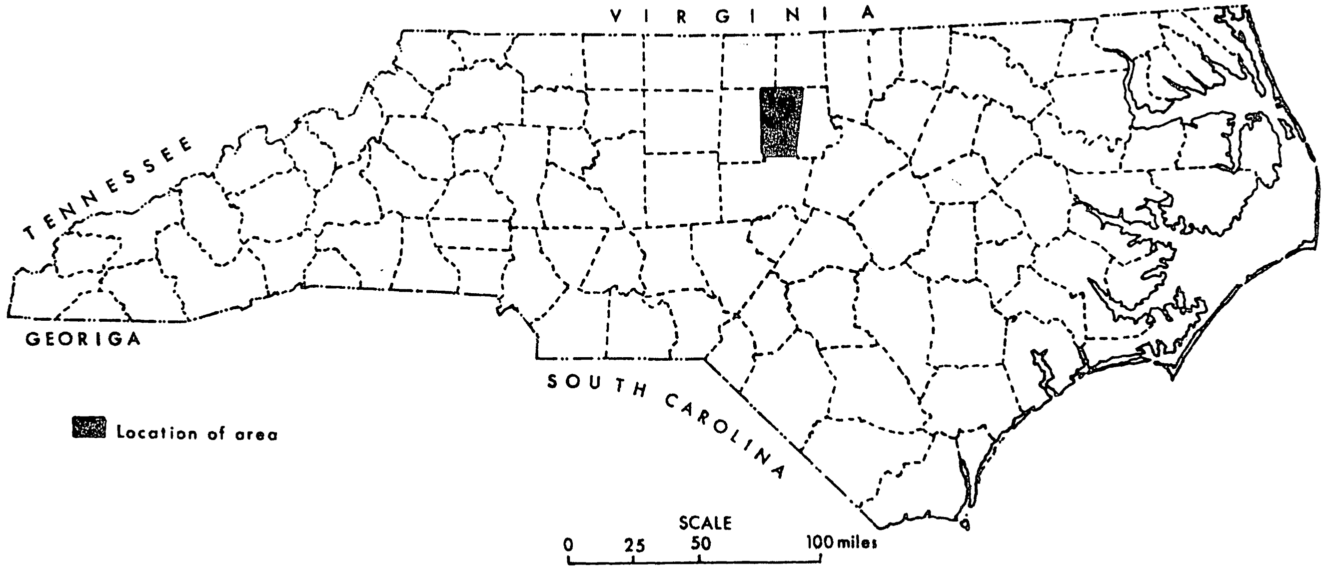

Figure 1. Index map showing location of Orange County, N.C.

Orange County area

The general stratigraphic succession in Orange County in ascending order is as follows: Unit I is predominantly amygdaloidal basalt lava flows exhibiting local pillow structures with intercalated basalt porphyries and lithic and crystal tuffs of a basaltic composition. Unit II is predominantly andesitic to dacitic lithic and crystal tuffs interbedded with intermediate tuff breccias and phyllites. Occasional amygdaloidal basalt lava flows, some of which exhibit pillow structures are intercalated with the tuffs. Interbedded andesitic to dacitic tuffs occur in the upper part of the unit. Unit III is composed predominantly of felsic tuffs, lithic and crystal lithic tuffs, some volcanic breccias and occasional spherulitic rhyolite flows, rhyolite porphyries and flow tuffs. Dacitic tuffs occur interbedded within the unit. Unit IV is predominantly epiclastic argillites and laminated argillites, graywackes with intercalated argillites and conglomerates containing graywacke interbeds. Intrusive into the metavolcanic-metasedimentary rocks are younger Paleozoic igneous plutonic complexes which are predominantly diorites and quartz diorites. Also present are granites, granodiorites, monzonites, quartz monzonites, gabbros and ultramafics. Undifferentiated interbedded arkoses, sandstones, siltstones, shales, conglomerates and graywackes of Triassic age, occupy a down-faulted basin in the extreme southeastern corner of the county. These sedimentary rocks are cut by diabase dikes of a basaltic composition that are of Late Triassic (?) or Early Jurassic (?) age.

Unit I

Unit I, the basal unit, is composed predominantly of fine grained, massive dark grayish green amygdaloidal basalt lava flows with some intercalated basalt porphyries, dark gray basaltic tuffs, basaltic lithic tuffs and basaltic crystal lithic tuffs (see plates 1 and 2).

The basalt flow rocks are located in the central part of the county. Three flows are located just east and south of the town of Efland, four flows crop out just south and east of Hillsborough, and another occurs just west of New Hope Church. These lenticular bodies of metabasalt follow the regional trend of the volcanic rocks and strike between N. 25° and 35° E. and have nearly vertical dips. The flows range from 0.5 mile to over 6 miles in length and from 0.1 mile to one mile in width.

In outcrop, the basalts are massive, have a hackly fracture and exhibit no apparent layering or cleavage. Weathering of the basalts produces a medium grayish green sharkskin surface which tends to emphasize the flow lines and the knobby weather resistant quartz-epidote-chlorite amygdules. The white and green colored amygdules are spherical to oval in shape and the area around them is distinctly greener than the bulk of the matrix as a result of a concentration of epidote in the vicinity of the amygdules. Sizes of the amygdules are varied, but the majority range in size from a fraction of an inch to more than one inch in diameter (see plate 2, nos. 1, 2 and 3). These amygdules were apparently formed by secondary mineral deposition in vesicles in the basalt flows.

Pillow structures present at several locations in the amygdaloidal basalt flow rocks indicate at least part are of subaqueous accumulation. Crude pillow structures are located just northwest of New Hope Church and west of Highway N.C. 86 and also on the southeast bank of the Eno River just south of Highway U.S. 70, and in outcrops exposed in the flood plane of the Eno River north of Highway U.S. 70. Well-formed pillows are located approximately one mile east of the intersection of Highway N.C. 86 and Secondary Road 1718 and crop out along the east bank of New Hope Creek.

Most of the pillowed outcrops show deformation of the pillows and at these locations, only a few of the pillows exhibit V-shaped bottoms. The shapes of the majority of the pillows in the outcrops exhibiting deformation are mostly loaflike or irregularly subelliptical to amoeboid (see plate 2, no. 5). With few exceptions, the pillows are wider than they are high and vary in length from 1 to 3 feet, with 2 foot lengths the most common. The measured thicknesses of the individual pillows range from 12 to 18 inches.

Many of the pillows observed contained flow structure and quartz-epidote amygdules which, because of weathering, contribute a knobby uneven texture to the pillowed surface. Both amygdules and flow lines are present in the matrix surrounding the rims of the pillows and the flow lines can be easily traced as they wrap around the periphery of the pillows. The tops and bottoms of some pillows are discernible and weathering in concentric rim fractures along their contacts has tended to emphasize the size and shape of the pillows (see plate 2, nos. 4 and 6).

Jointing is present in the pillowed outcrops and tends to parallel the exterior rims of the pillows. However, jointing also bisects the pillows in numerous outcrops and in a few locations three dimensional views of the pillows are exposed.

Usually the basalts have a greater resistance to weathering than the adjacent rocks, thus they frequently form ridges. Cascades and small waterfalls often occur where the basalts are crossed by streams.

Thin section analysis has shown the major minerals of the basalts are epidote, chlorite, albite, quartz, actinolite, sericite, opaques and calcite. Butler (1963) states that the most common mineral assemblages are:

epidote-chlorite-quartz-plagioclase-(sericite)
epidote-chlorite-quartz-actinolite-(sericite)
epidote-chlorite-quartz-actinolite-plagioclase-(sericite)
epidote-chlorite-quartz-plagioclase-calcite
epidote-chlorite-quartz-(sericite)

Chemical analyses of five randomly selected specimens collected from the metabasalt flows show an average SiO_2 content of 51.5 percent, an average Na_2O content of 3.5 percent and an average K_2O content of 0.65 percent. A comparison of the chemical composition of some basalts is listed in table 1. A graphic plot of silica against the ratio of potassium oxide to total alkalies indicates that the Orange County basalt specimens fall within the chemical norm for the plotted average of spilites as defined by Nockolds (1954) (see figure 5). The presence of these spilitic pillowed amygaloidal basalt flow rocks offers added emphasis to the fact that the metavolcanic-metasedimentary rocks of Orange County, North Carolina, are of eugeosynclinal deposition. The basalt flow rocks are classified as being of the spilitic variety on the basis of the following data:

(1) A very low potassium oxide content which averages 0.65 percent and a relatively high sodium oxide content of 3.5 percent for the chemical analyses of the five basalt specimens.
(2) The presence of pillow structure in the basalt flow rocks indicates subaqueous deposition.
(3) In places, the basalt flow rocks are interlayered and overlain by basaltic tuffs which exhibit a pronounced graded bedding which is also indicative of subaqueous deposition.
(4) The basalt flow rocks exhibit flow structure and abundant amygdules which are indicators of a true extrusive rock.
(5) The complete chemical composition of the flows places them as true basalts; when their silica content is plotted against their ratio of potassium oxide to total alkalies, the basalts plot within the chemical norm for the plotted average of spilites as defined by Nockolds (1954).

The basaltic tuffs intercalated with the metabasalts are massive, fine grained, dark gray to dark grayish green on unweathered specimens. The crystal clasts which are white to light green in color contrast with the dense fine-grained matrix and the lithic clasts which are, for the most part, darker than the matrix give the tuff a speckled appearance. Upon weathering, these tuffs attain a reddish brown to dark brown color, but still retain visible relict crystal and lithic clasts.

Good exposures of the weathered intercalated basalt flow rocks and basaltic tuffs can be viewed in a roadcut on a gravel road located several hundred feet southwest of Highway U.S. 70 and approximately 0.5 mile southeast of the business and U.S. 70 bypass.

As exposed, the tuffs strike N. 48° E. and dip 68° to the northwest, are reddish brown to dark brown in color and appear in places to be approximately four to six feet thick. However, the thicknesses of the tuffs vary considerably along strike. Graded bedding is evident in several areas of the weathered tuffs along strike in the road cut, and a basal, highly weathered basalt exhibits what appears to be small pillows in an advanced stage of weathering. This sequence would suggest that at least part of this unit is of subaqueous deposition.

In thin section, the more massive basaltic tuffs exhibit lithic clasts that are in general predominantly angular to subangular, are randomly oriented

TABLE I. COMPARISON OF THE CHEMICAL COMPOSITION OF BASALTS

	Orange Co. Allen-Wilson, 1968			Orange Co. Butler 1964	Hawaii Murato Richter 1966	Albemarle Quadrangle Conley 1962	Nockolds "56 average Central Basalts"
Sample No.	**8**	**9**	**18**				
SiO_2	50.5	50.7	50.0	47.48	50.74	53.6	51.33
Al_2O_3	19.4	16.7	18.0	20.42	13.57	18.4	18.4
Fe_2O_3	4.3	3.1	7.3	6.41	1.36	*5.2	3.40
FeO	5.7	7.6	2.3	3.61	10.63	—	5.70
MgO	4.7	5.6	5.1	4.53	6.16	5.9	6.01
CaO	6.4	5.8	9.7	10.52	9.94	7.0	10.07
Na_2O	3.9	3.8	3.0	2.0	2.64	1.88	2.76
K_2O	0.27	0.88	0.70	2.30	0.67	0.25	0.82
H_2O-	0.12	0.07	0.11	0.03	0.00	—	—
H_2O+	3.4	3.9	2.3	1.65	0.09	—	0.45
TiO_2	1.0	1.2	0.90	0.52	3.35	*	1.10
P_2O_5	0.13	0.24	0.22	—	0.37	*	0.16
MnO	0.15	0.27	0.26	0.22	0.18	*	0.16
CO_2	0.05	0.05	0.05	0.11	0.01	—	—

*Includes, P_2O_5, MnO, TiO_2
**Total iron content reported at Fe_2O_3.
Note: See Table 5A for sample locations.

and exhibit no apparent layering or sorting. A few of the lithic clasts contain relict glass shards, which indicates clasts within clasts and that a prior tuff, at or near the source area or areas furnished some larger clasts for this later tuff. The clasts appear to have been derived from fine grained to cryptocrystalline rocks. The crystal clasts are predominantly euhedral crystals of plagioclase feldspar exhibiting albite twinning. Quartz appears to compose 25 to 30 percent of the groundmass. The major mineral constituents observed are plagioclase, quartz, chlorite and epidote with minor amounts of sericite, calcite and opaques.

Unit II

Unit II is composed of pyroclastic rocks of andesitic to dacitic composition (see plates 3 and 4). Basalt extrusives, some of which exhibit pillow structures are present within the unit and are intercalated with the pyroclastic rocks but are few in number. A tuff breccia, locally containing lahars, is interbedded with the intermediate pyroclastic rocks. The lahars contain unsorted, randomly oriented clasts varying in size from less than an inch to over three feet in length and these clasts vary in composition from basalt to rhyolite. This sequence suggests that the volcanic cycle was still in a highly explosive phase emanating andesitic to dacitic ejecta over a wide area and for extended periods of time. The occasional basalt flow rocks in Unit II suggests that the extrusive phase of vulcanism had subsided to a considerable extent as compared to the abundance of basalt extrusives described in Unit I. The presence of lahars further suggests that the center or centers of vulcanism were relatively near.

Unit II appears to overlie conformably Unit I throughout the county. The cross section A-A' (see map, plate 13) shows in places that Unit I is directly overlain by Unit III, which appears to represent areas of nondeposition of Unit II rather than erosional unconformities. However, this is not to say that during the deposition of Unit II, the normal erosion-deposition cycle was not in effect.

Phyllites of andesitic to dacitic composition occur within Unit II and excellent exposures of this rock type can be viewed in the Old Duke quarry, one mile southwest of Secondary Road 1161 and 0.1 mile east of the intersection of Highway U.S. 70 and Secondary Road 1161 and in the New Duke quarry located southeast of Secondary Road 1181 and west of the Eno River. The phyllite varies considerably in color but the rock is predominantly dark gray to dark bluish gray with a well developed slaty cleavage that is parallel to the bedding. The average strike and dip of the cleavage and bedding of the phyllites in the Old Duke quarry is N. 45° E., 71° NW.

Table 2. Chemical Analyses of Andesitic-Dacitic Rocks in Unit

Sample Number	No. 2	No. 10	No. 16	No. 20
SiO_2	62.8	62.1	58.2	65.7
Al_2O_3	16.5	14.7	22.6	15.2
Fe_2O_3	5.9	5.2	5.8	3.0
FeO	.50	3.0	1.4	3.1
MgO	1.8	1.9	1.0	1.7
CaO	4.1	3.4	.49	3.3
Na_2O	3.1	4.1	2.7	3.9
K_2O	2.0	2.3	2.3	1.1
H_2O-	.06	.06	.28	.07
H_2O+	1.3	1.5	3.5	1.5
TiO_2	.87	1.1	1.2	.84
P_2O_5	.22	.30	.22	.20
MnO	.20	.20	.14	.30
CO_2	.35	.05	.05	.05
Total	100	100	100	100

Note: See Table 5A for sample locations

The composition of the phyllites varies considerably across strike from southeast to northwest in the Old Duke quarry. The clastic texture of the phyllites decreases in size from southeast to northwest along the quarry face (see figure 2). The southeastern end is composed predominantly of lithic tuffs and breccias containing deformed elongated clasts that are parallel to the bedding and cleavage. The phyllites exhibit excellent normal graded bedding from fine to coarse from northwest to southeast. This suggests subaqueous deposition for these rocks and indicates that the rocks are progressively younger from southeast to northwest through the quarry. Excellent exposures of normal graded bedding is exposed in the northwestern end of the quarry face occurring in a highly weathered reddish-brown phyllite.

The phyllites in the New Duke quarry are identical in appearance and composition to the phyllites in the Old Duke quarry with one major exception, the graded bedding is reversed. Detailed study of the immediate vicinity established the presence of an overturned syncline (see plate 13, cross section A-A').

Butler (1964) states, "The Duke quarry phyllite was derived from argillite, tuff or tuffaceous sandstone, and volcanic breccia. Occurrence of laminated argillites suggests marine deposition."

Four randomly selected hand specimens from Unit II in Orange County have an average SiO_2 content of 62.2 percent which would collectively group the specimens in the andesitic-dacitic range. The SiO_2 range for the four specimens is from 58.2 percent to 65.7 percent which is an SiO_2 range of 7.5 percent. Complete chemical analyses for the four specimens are listed above in table 2.

Unit III

Unit III is composed of pyroclastic and flow rocks of dacitic to rhyolitic composition (see plates 5 and 6). Pyroclastic rocks are very abundant; whereas, flow rocks are rare. This suggests that the vulcanism for the length of time represented by the accumulation of the rocks of Unit III was primarily one of explosive ejecta rather than one of outpouring of lavas.

The felsic pyroclastics are predominantly lithic tuffs and crystal lithic tuffs. The tuffs are dense, medium to light gray to light green in color and have a subconchoidal to conchoidal fracture. A speckled appearance, evident in many of the specimens, is caused by an abundance of white to light gray feldspar crystal clasts that are lighter colored than the matrix, and lithic clasts that are darker colored than the matrix (see plate 6, no. 4). The lithic clasts are randomly oriented, angular to subrounded and vary from two to twenty millimeters in size. The clastic texture is obvious in hand specimens but is more pronounced on weathered outcrops. In such outcrops, the tuffs weather to a white or buff color, but the clasts in general are more resistant to weathering than the matrix, causing a knobby appearance on the weathered surface. Some of the tuffs exhibit a high degree of welding and have a significant ring when struck with the hammer. This suggests that some of the pyroclastics were above the welding temperature when emplaced and were able to retain this temperature until welding was accomplished.

Evidence of devitrification was observed in thin section analysis of specimen number 3 (table 3), a felsic vitric crystal lithic tuff. In this specimen, vitroclastic texture was observed in the lithic clasts occurring in the tuffaceous matrix. The outlines of compacted glass shards were observed in various degrees of preservation and appeared to be confined solely to the lithic clasts rather than occurring in the matrix. Butler (1963, p. 180) describes the presence of vitroclastic texture occurring in flinty aphanites collected from Orange County, North Carolina, and postulates that "most of the flinty aphanites may be vitric-crystal tuff in which the vitroclastic texture was destroyed by subsequent metamorphism."

Rhyolite flow rocks occur at several locations in Orange County associated with felsic vitric crystal and vitric lithic tuffs. One such flow occurs on a northeast-trending ridge located approximately one mile north of the Cross Roads Baptist Church just east of Secondary Road 1134. In outcrop, the rhyolite forms a prominent ridge that strikes N. 55° E. and exhibits a poorly developed cleavage that dips approximately vertical. The rhyolite appears to have been a highly vitric porphyritic flow and contains abundant spherulites. It is a dense, light to medium gray siliceous rock exhibiting flow banding which is highly prominent on weathered surfaces. This flow structure is quite apparent and is easily traceable as it wraps around the spherulites. The spherulites disclose on weathered surfaces, grayish white concentrically arranged aggregations of feldspar and quartz that radiate outward from a common center or nucleus. The nucleus is usually composed of quartz and secondary epidote or a primary feldspar crystal. The spherulites range in size from less than one-tenth of an inch to over four inches in diameter.

Table 3. Chemical Analyses of Dacitic-Rhyolitic Rocks in Unit III.

Sample Number	No. 3	No. 7	No. 14	No. 19
SiO_2	70.6	70.3	71.7	65.2
Al_2O_3	14.8	14.2	14.2	14.3
Fe_2O_3	1.7	1.7	1.3	2.5
FeO	1.1	.93	1.4	1.8
MgO	.58	1.4	.37	.97
CaO	.94	2.1	1.8	3.2
Na_2O	4.6	3.7	4.6	2.7
K_2O	3.9	2.5	3.1	4.1
H_2O-	.05	.08	.07	.05
H_2O+	.65	1.1	.73	1.4
TiO_2	.38	.40	.40	.63
P_2O_5	.00	.08	.06	.10
MnO	.20	.12	.18	.20
CO_2	$<.05$	1.2	$<.05$	2.8
Total	100	100	100	100

Note: See Table 5A for sample locations

Trains of small spherulites are evident under thin section examination and can be traced as they wrap around larger spherulitic structures in the cryptocrystalline groundmass. These facts, along with the absence of lithic clasts, indicate that the rhyolite flow rock was a molten lava rather than a mobile welded ash flow.

The presence of spherulitic structures in the rhyolite extrusive provides further evidence of widespread devitrification among the felsic volcanic rocks of Unit III. Ross and Smith (1961, p. 37) have described the formation of spherulites occurring in devitrified rhyolites and welded tuffs and state that the spherulitic structures developed in welded tuffs differ in no way from those occurring in many rhyolite flow rocks. They further state that the identity of such rocks may be determined from geologic relations, and inclusions of materials of clastic origin may indicate ash-flow origin. Because of the absence of inclusions of clastic materials and the existence of flow lines, it is believed that the rock containing the spherulites is a flow.

Four randomly selected hand specimens from Unit III in Orange County have an average SiO_2 content of 69.5 percent. The SiO_2 range for the four specimens is from 65.2 percent to 71.7 percent which is a SiO_2 differential of 6.5 percent. Complete chemical analyses of the four specimens are listed in table 3.

Unit IV

The metavolcaniclastic sedimentary rocks of Unit IV consist of argillites, graywackes with intercalated argillites, and conglomerates with graywacke interbeds (see plates 7 and 8). The sequence strikes N. 48° E. dips vertically and appears to overlie conformably the volcanic rocks in Unit III. These epiclastics (Fisher, 1961, pp. 1409-1443) are composed of detrital fragments of pre-existing volcanic rocks, both flows and pyroclastics, that have been subaqueously deposited through the process of weathering, erosion and transportation. The volcaniclastic sedimentary sequence of basal conglomerates contains well rounded tuff, rhyolite and quartz pebbles and cobbles with intercalated graywackes. This sequence is overlain by graywackes with argillite interbeds which is in turn overlain by argillites and laminated argillites. This suggests that positive source areas were present and that slow moving saturated currents deposited the sediments below wave base in the relatively quiet-water zone. The evidence of graded bedding in the volcaniclastic sedimentary rocks indicates sedimentation below wave base and the laminated argillites are indicative of quiet-water deposition. "Only in the absence of any bottom turbulence could such laminations remain undisturbed" (Pettijohn, 1957, p. 593). The presence of laminated argillites was also noted by Butler (1963, p. 181) in which he stated, "The argillite and slate originated by accumulation of clay and silt-sized particles. The presence of laminations suggests a lacustrine or marine environment. The laminations must have been formed by intermittent changes in depositional conditions such as seasonal variations, periodic currents, or regularly-spaced eruptions of volcanic ash."

Chemical analyses of three randomly selected hand specimens of epiclastics from Unit IV appear in Table 4, p. 25. Specimen number eleven is the analysis for an argillite which compares favorably to similar rock types listed in the literature (Pettijohn, 1957, p. 344). The graywacke, specimen number twelve, compares favorably to the chemical composition of the average of twenty three graywackes listed by Pettijohn (1957, p. 307, Table 52). The conglomerate is felsic in composition, 66.3 percent SiO_2, a fact which may be attributed to the abundance of cryptocrystalline pebble to cobble sized, well rounded, sub-spherical to spherical felsic volcanic particles.

On outcrop, the conglomerate is light to medium greenish gray in color and contains an abundance of sand to cobble size, well rounded, moderately spherical to spherical particles of both flow and pyroclastic material that is predominantly darker gray in color than the matrix, but is felsic in composition. This suggests that the sediments were derived from positive areas of pre-existing felsic volcanic rocks. The roundness and sphericity of the pebbles and cobbles within the conglomerate further shows that the particles were transported. Brown to buff to white, rounded, moderately spherical to spherical quartz particles are present, but numerically compose only a minor fraction of the rounded pebbles and cobbles. Intercalated within the conglomerate are graywacke interbeds that are strikingly similar to the matrix of the conglomerate. The graywackes are predominantly light to medium greenish gray and have a speckled appearance because of the abundance of darker gray lithic particles and white crystal particles disseminated throughout the matrix. Clarke (1957) mapped a sedimentary sequence south of the town of Chapel Hill, North Carolina, on Morgan Creek which he called a "wacke conglomerate." Clarke described the sequence as a narrow east-west band 1.7 miles long and 1200 feet wide that dips vertically and is conformable with the underlying "slate series." The rock type was described as "a poorly sorted aggregate of varied grain size. About 75 percent of its volume is pebbles." The matrix was described as a "fine-grained groundmass, highly chloritized and moderately epidotized." Eaton (1908) recognized the presence of a sedimentary sequence in Orange County. He stated the rocks "consist of a series of conglomerates, sandstones, and flint-like slates lying in places upon felsite." Eaton also pointed out that the slates are bedded alternately with sandstones and conglomerates and that conglomerates are composed of well-rounded pebbles of several kinds of volcanic rocks, but are by no means volcanic agglomerates. Eaton noted that "the slates are coincident in dip with the sandstones and conglomerates with which they are associated, and from all field evidence obtainable, seem to have been deposited as regular members of the sedimentary series." Eaton describes the "slates" as being laminated or stratified and postulates that they were derived from "felsites" or rhyolites and were deposited in deep water. The authors are of the opinion that the "slates" which Eaton describes are not slates but are rather laminated argillites that occur in the sedimentary sequence mapped as Unit IV in Orange County. The intercalated conglomerates are conformably overlain by graywackes with intercalated laminated argillites. The graywackes appear as previously described and consist of sub-rounded to rounded quartz grains and small sub-rounded to rounded particles of pre-existing cryptocrystalline metavolcanic rocks and some fragments of feldspar crystals. Thin section examination of the graywackes further revealed albite and carlsbad twinning in the feldspars. Opaques present within the thin section were identified as being predominantly magnetite. The graywacke exhibits a fine-grained groundmass composed primarily of chlorite and epidote.

The intercalated laminated argillites on fresh surfaces are light to medium gray fine-grained rocks that are composed predominantly of quartz, chlorite and sericite in their order of abundance. Weathering of the argillites produces a buff to yellowish-buff rind, that when rubbed between the fingers has a distinctive silty feel. These intercalated argillites locally grade upward in the sequence of a zone of laminated argillites with no apparent graywacke interbeds. The strike and dip of the argillites are coincident with the underlying conglomerates and graywackes which is N. 48° E. and dip vertically. The cleavage of the argillites is parallel to the bedding. Sections or slabs ¼-inch thick can easily be cleaved. The laminations within the argillites are probably a result of the topography, climate and aqueous depositional characteristics that existed during the formation of this volcaniclastic sedimentary sequence. It appears that the sedimentary sequences found within the county are only small remnants of a larger area of similar epiclastics that have been destroyed through subsequent metamorphism, folding, faulting, weathering and erosion.

Three randomly selected hand specimens of epiclastics from Unit IV in Orange County have an average SiO_2 content of 64.1 percent which would collectively group the specimens in the dacitic range. The SiO_2 range for the three specimens is from 61.5 percent SiO_2 to 66.3 percent SiO_2 which is an SiO_2 differential of 4.8 percent. Complete chemical analyses for the three specimens are listed below in table 4.

Table 4. Chemical Analyses of Epiclastics in Unit IV.

Sample Number	No. 11	No. 12	No. 13
SiO_2	61.5	64.5	66.3
Al_2O_3	19.1	15.8	15.2
Fe_2O_3	3.3	5.9	3.6
FeO	2.9	1.3	2.4
MgO	1.8	1.8	2.0
CaO	1.6	.91	1.5
Na_2O	1.7	2.4	2.8
K_2O	3.4	3.0	2.4
H_2O-	.54	.33	.11
H_2O+	2.5	2.8	2.5
TiO_2	.82	.85	.72
P_2O_5	.11	.06	.13
MnO	.18	.18	.27
CO_2	<.05	<.05	<.05
Total	99	100	100

Note : See Table 5A for sample locations.

ENVIRONMENT AND MODE OF DEPOSITION

General statement

The occurrence of volcanic-sedimentary rocks in a long narrow zone extending for a length of approximately four hundred miles from central Georgia to southeastern Virginia and a width that in some places exceeds one hundred and twenty miles, suggests deposition under eugeosynclinal conditions.

Stuckey (1965) states that there seems to be little doubt that the rocks of the Carolina Slate Belt were formed in a eugeosyncline containing island arcs. He postulates that the volcanic rocks in the geosyncline came largely from beneath the surface by volcanic eruptions. The nonvolcanic sediments or landwaste in the form of clay, silt, mud, sand and rounded quartz pebbles were derived from narrow belts of uplift that were present in or adjacent to the trough.

Orange County area

Features observed in the rocks of the volcanic-sedimentary units in Orange County, North Carolina, indicate both subaqueous and subaerial environments of deposition. It is reasonable to infer that during the lengthy formative period of the units, events of predominantly volcanic character occurred, although they undoubtedly included periods of erosion and sedimentation. The rock sequences show that there were periods of lava outflows with violent periods of explosive pyroclastic discharges. The unit sequence also suggests that the order of vulcanism was from an initial basic phase gradually changing to an acid phase prior to quiescence.

Pillow structures present at several locations along strike in the spilitic amygdaloidal basalt lava flow rocks indicate at least part of the basalts accumulated in water. The extent and lithologic uniformity of the basalts suggest relatively near-source areas capable of extruding large quantities of material over a wide area. Intercalated basaltic lithic and crystal tuffs associated with the basalt flow rocks is further evidence for explosive pyroclastic discharges from source areas relatively near and are also indicative of a pulsating volcanic cycle that produced both extensive massive basalt extrusive rocks and thick accumulations of mafic pyroclastic rocks.

The andesitic to dacitic lithic and crystal tuffs, tuff breccias and phyllites which conformably overlie the basalt flow rocks exhibit characteristics for further evidence of subaqueous and subaerial deposition in the area. The presence of a well developed graded bedding indicates a subaqueous origin for many of the tuffs. However, many of these interbedded lithic tuffs show some degree of welding and contain randomly oriented clasts which suggests a subaerial rather than a subaqueous deposition. The abundance of intermediate pyroclastics is also indicative of highly active vulcanism which continued over a long period of time to emplace volcanic materials of considerable thicknesses in the area.

The tuff breccias with associated tuffaceous interbeds contain assorted clasts ranging in size from ½ inch to more than two feet in diameter and appear to compose approximately 35 to 40 percent of the rock. The presence of larger clasts in certain areas of the unit, suggests that the source area or areas were relatively near. Parts of the unit contain lahars, accumulations of unsorted volcanic debris that result from water saturated volcanic material resting on the flanks of vents then moving downslope as slides or flows.

Phyllites associated with the intermediate tuffs and breccias exhibit features indicative of subaqueous deposition which have not been destroyed by folding and shearing. These phyllites which were derived primarly from pre-existing tuffs, lithic tuffs and breccias show a pronounced graded bedding throughout much of the sequence. In places the graded bedding is normal and in other areas the graded bedding is overturned.

The argillites, graywackes with intercalated argillites and the conglomerates with intercalated graywackes which occur in the volcaniclastic sedimentary unit represent a normal uninterrupted conformable sedimentary epiclastic sequence derived from pre-existing metavolcanic rocks.

CHEMICAL AND SPECTROGRAPHIC ANALYSES

General statement

Chemical and spectrographic analyses of twenty hand specimens were made from rocks of volcanic origin collected by the authors from Orange County during the latter part of 1966 (see tables 5, 5A and 6). The specimens were collected from each of the major stratigraphic units mapped in the volcanic-sedimentary sequence previously discussed. These specimens were selected and obtained from outcrops which showed no apparent weathering or pronounced hydrothermal alteration.

The analyzed rocks contain between 50.0 and 71.7 percent SiO_2 with an average SiO_2 content of 62.3 percent and an SiO_2 differential of 21.7 percent. Using a standard of 50 to 55 percent SiO_2 content for basaltic volcanic rocks, 56 to 66 percent SiO_2 content for volcanic rocks in the intermediate andesitic-dacitic range and above 66 percent SiO_2 content for felsic volcanic rocks, the analyses indicate that five specimens are in the basaltic range, six in the intermediate andesitic-dacitic range and eight in the felsic volcanic range (specimen no. 1 not included in above calculations).

Alkali-lime index

The alkali-lime index is a plot of total alkalies ($Na_2O + K_2O$) and lime (CaO) plotted against silica (SiO_2). The percentage of silica at which the alkalies (o) and lime (x) intersect is called the alkali-lime index. The alkali-lime index is subdivided into four divisions. Alkalic is less than 51 percent silica, alkali-calcic is from 51 to 56 percent silica, calc-alkalic is from 56 to 61 percent silica and calcic is greater than 61 percent silica.

Chemical analyses of twenty rocks of volcanic origin from Orange County including flows, pyroclastics and epiclastics were used to determine the alkali-lime index as shown in figure 3. The intersection of the alkali-lime plots gives an alkali-lime index of 59.9 percent which is in the calc-alkalic range and is consistant with the figure of 59 percent plotted by Butler (1964) of analyses of volcanic rocks from the Virgilina area, Albemarle area and from Orange County, North Carolina.

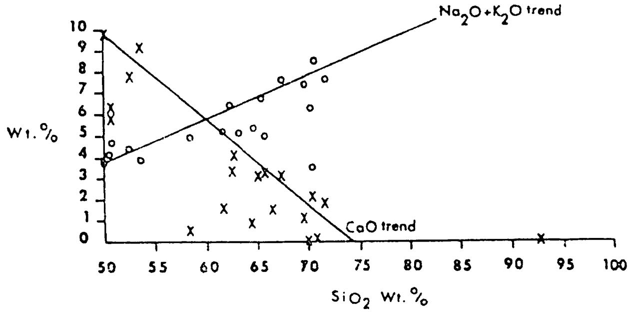

Figure 3. Plot of lime and total alkalies against silica.

Silica range

Figure 4 is a plot of the silica range and content of 19 rock specimens of volcanic origin collected from Orange County, North Carolina. Five specimens fall within the basaltic range of 50 to 55 percent silica, seven specimens fall within the intermediate range of 55 to 66 percent silica and seven specimens fall within the felsic range of 66 or greater percent silica. Each specimen appears on the plot (see figure 4) as a vertical line with the specimens' individual number appearing directly above the line. The height of the vertical lines indicates the percentage of silica for each specimen. The horizontal distance from the first to the last line in each group denotes the silica range. The horizontal distance also shows the relative position of each group within each of the three ranges. Specimens number 18, 8, 9, 6 and 4 plotted within the basaltic range and vary in content of 50.0 percent SiO_2 for specimen number 18 to 53.6 percent SiO_2 for specimen number 4. This is a silica range of 3.6 percent between the lowest and highest percent silica for the five specimens. Specimens number 16, 11, 10, 2, 12, 19 and 20 plotted within the intermediate range and vary in silica content from 58.2 percent SiO_2 for number 16 to 65.7 percent SiO_2 for number 20. This is a silica range of 7.5 percent for the seven specimens. The relative position of the silica range within the group indicates that the majority of the specimens fall within the dacitic range. Specimens number 13, 5, 17, 15, 7, 3 and 14 plotted in the felsic range and vary in silica content from 66.3 percent for specimen number 13 to 71.7 percent SiO_2 for specimen number 14. This is a silica range of 5.4 percent. The relative position of the silica range within the felsic unit indicates that the specimens are rhyodacitic to rhyolitic in composition.

Variations in silica and alkalies

Figure 5 is a diagram (modified after Butler, 1964) of a plot of silica against the ratio of potash to total alkalies. Coincidence to two points on the diagram does not necessarily denote that the two specimens are chemically identical, but in many instances they are chemically similar. The complete analyses must be compared before evaluation and conclusions can be made about their origin.

The basalts are chemically similar to the analyses of basalts published by (Clarke, 1959, p. 460), (Nockolds "56 average Central Basalts") and basalts from Hawaii (Murata and Richter, 1966). The basalts fall below the line connecting averages for the igneous rocks and are characterized by an average K_2O content of 0.65 percent and an average Na_2O content of 3.5 percent. The basalts fall within the plotted average for spilites. They are chemically different from the porphyritic phase of the greenstones of the Virgilina district but are similar in composition to the tuffaceous phase of the greenstones (Laney, 1917, pp. 33-34).

The composition of the argillite is similar to published analyses for this rock type (Pettijohn, 2nd edition, p. 344).

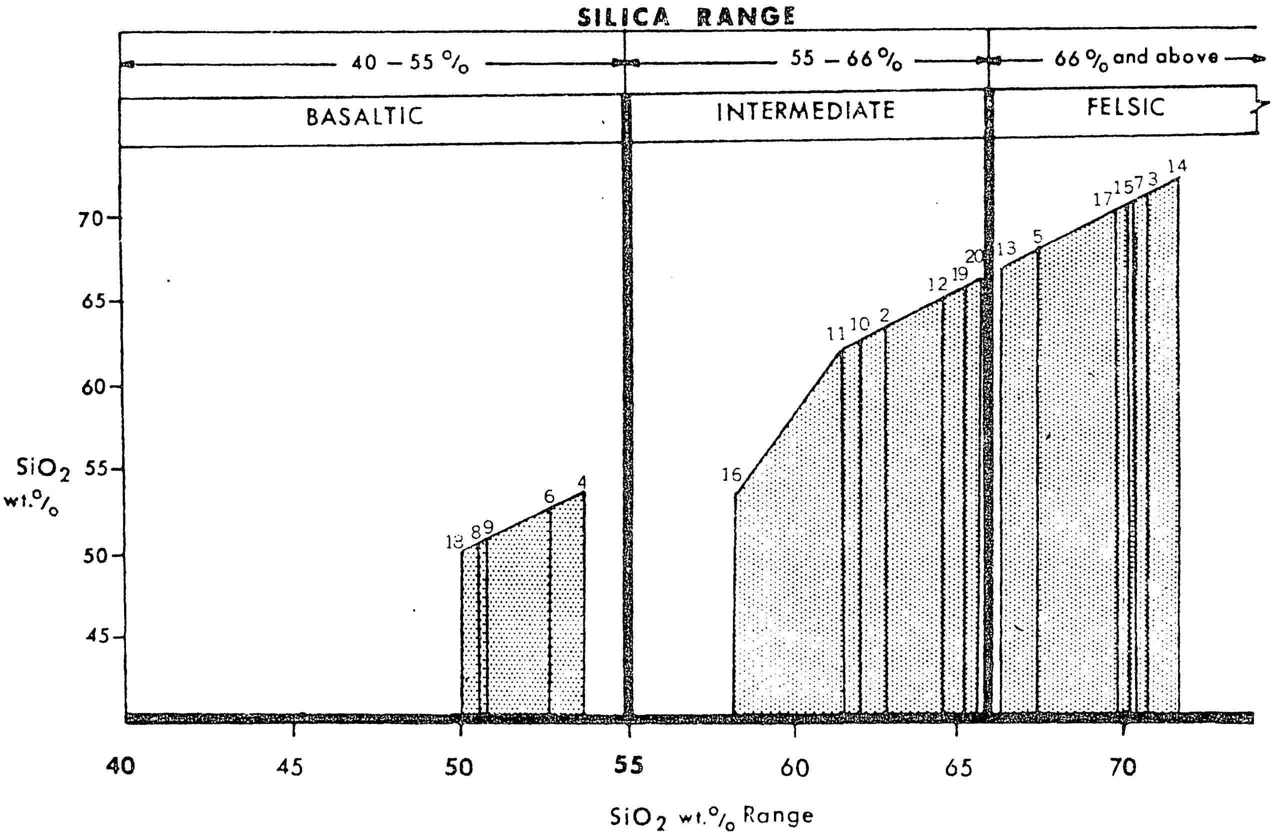

Figure 4. Plot of silica range and content, of 19 rock specimens of volcanic origin from Orange County, N.C.

TRIASSIC ROCKS

General statement

Sedimentary rocks of Triassic age occur in the extreme southeastern corner of Orange County. These rocks occupy a downfaulted area known as the Durham basin which is the northward extension of the great northeast trending, trough shaped downfaulted Deep River basin. The Triassic sedimentary rocks in the Deep River basin are considered of Upper Triassic age and are assigned to the Newark Group, a name given to them by W. C. Redfield because of their similarity to Triassic rocks in the vicinity of Newark, New Jersey. Emmons (1852) recognized certain differences in the rocks and subdivided them into three divisions without formal names. Later in 1856, Emmons subdivided the rocks now known as the Newark Group into four divisions: Lower sandstone, Coal slate and coal, Salines and Upper sandstones. Later, Russell (1892) applied the term Newark Group to the rocks of both the Dan River and Deep River basins of North Carolina with the idea that possibly future workers might subdivide the group into a number of formations. Campbell and Kimball (1923), stated that, "the Newark group in the Deep River basin consists of three generally recognizable parts, called formations." They named these formations the Pekin, Cumnock and Sanford. The Pekin Formation is the basal unit and is overlain conformably by the Cumnock Formation, a coal bearing sequence containing the Gulf coal bed and the Cumnock coal bed. These coal beds are approximately 250 and 200 feet respecrively above the base of the formation.

The Cumnock Formation is overlain conformably by the red to brown shales and sandstones of the Sanford Formation. Stuckey (1965) states, "As no key horizons exist along the margins of the basins, the Pekin and Sanford formations should be considered sedimentary facies rather than time-stratigraphic units." Reinemund (1955) states that the strata within the Sanford Formation are laterally gradational and lenticular in shape with few distinctive beds and no subdivisions that are consistently mappable. He considers the Sanford Formation between 2,000 and 3,000 feet thick at the south end of the Durham basin and states that more than three-fourths of the rocks within the formation are red, brown or purple fine grained clastic sediments.

The rocks of the Deep River basin also contain concordant and discordant diabase intrusives that are present in the form of dikes, sills and sill-like masses that are only partly controlled by bedding. Reinemund (1955) states that sills and sill-like masses are not present in the pre-Triassic rocks but are present in all the Triassic formations and they are thickest and most extensive in the Cumnock Formation. The diabase dikes are extensively distributed in the pre-Triassic rocks of the Piedmont plateau and in the pre-Cretaceous rocks beneath the Coastal Plain.

Orange County

Triassic sedimentary rocks occupy the extreme southeastern corner of Orange County and extend northeastward from the Orange-Chatham county line for approximately 8.5 miles and vary in width westward from the Durham-Orange county line from 0.25 mile to 2.25 miles. Efforts were made to map accurately the western border of the Triassic rocks; however, because of the limited extent of these sedimentary rocks in the county and the presence of few distinctive beds, no attempt was made to differentiate the Triassic rocks into formations.

The Triassic rocks in Orange County are considered to be of the Upper Triassic Newark Group and belong to the Sanford Formation. The rocks are fine grained clastic sediments and interbedded conglomerates that were apparently derived from the older metavolcanic and igneous intrusive rocks that occur west of the Durham basin. These clastic sediments contain a variety of rock fragments and range in color from light buff, buff, yellow, orange, brown, reddish brown, red, maroon and gray to purple. Rock types appear to vary laterally in lithology and in color throughout the area with buffs, reds and browns occurring most frequently. Sandstone, arkose, siltstone, shale and conglomerate are the predominant rock types and are interbedded. Crossbedding was observed in a buff to orange arkose in a 10 foot roadcut located on the north side of Ephesus Church Road, 0.2 mile east of Highway U.S. 15-501 bypass on the east side of Chapel Hill, North Carolina (see plate 10, nos. 1 and 2). In this roadcut, the crossbedded arkose overlies a reddish-brown siltstone which strikes to the northeast and dips at a low angle to the southeast.

Pronounced baked zones resulting from the intrusion of diabase dikes of Late Triassic (?) or Early Jurrasic age(?) are frequently found occurring in roadcuts throughout the area. These baked zones are prominent features that are easily recognized. One such baked zone occurs on the north side of Ephesus Church Road in a small roadcut 0.4 mile east of Highway U.S. 15-501 bypass on the east side of Chapel Hill. A reddish-brown siltstone has been intruded by a narrow diabase dike. The dike exhibits excellent spheroidal weathering and is grayish black on fresh surfaces weathering to a rusty brown color (see plate 10, no. 4). Extending inward from the reddish-brown siltstone towards the diabase, the siltstone assumes a dark maroon color that grades into a narrow charcoal colored baked zone that is approximately four feet wide on either side of the dike. At this site, the baked zones adjacent to the dike are no more indurated than the adjacent siltstone. However, in several locations within the county, it was observed that even though the diabase dikes themselves were weathered, the adjacent baked zones exhibit a high degree of induration which formed narrow weather-resistant ridges paralleling the dike. Reinemund (1955) states that baked zones usually extend less than 30 feet from the intrusives with some zones in claystones extending only 10 feet. The principal metamorphic effect in claystones is a blackening of the rock caused by the development of magnetite, while in general shales and siltstones become much harder as the result of the recrystallization of the quartz. Several large diabase dikes are located just east of Chapel Hill with a north to northeast trend (see geologic map, plate 13). These dikes are easily mapped because of the abundance of large residual boulders occurring on the surface which are a direct result of the spheroidal weathering that is characteristic of the diabase intrusives. The dikes have been traced overland for distances of 5 to 8 miles and appear to have been injected along fault zones that parallel the resequent faultline scarp that separates the metavolcanic and igneous intrusive rocks on the west from the Triassic rocks to the east. Numerous small diabase dikes were observed throughout the county, but were too small to show on the geologic map.

One area of significant interest in the Triassic rocks of the county is an arkose-capped hill with an elevation of approximately 450 feet above sea level. This area is the highest point in the county on which Triassic rocks occur. The hill affords a commanding view of the low lying, gently rolling topography of the Durham basin, that ranges in elevation to the south and southeast from 240 to 340 feet above sea level. This area is located 0.4 mile north of the intersection of Secondary Roads 1717 and 1305 (see plate 10, no. 3). The yellow to orange arkose contains an abundance of petrified wood fragments that range in size from several inches to fragments as large as two feet in diameter. This anomalously high area of Triassic rocks is apparently a result of faulting, and reflects Harrington's (1951) view on the structural picture along the western border of the Triassic basin which is, "The basin is not a simple graben structure with two similar sides. The movement along the west border was a slumping action with minor displacement on many faults and perhaps major displacement on a few."

The most recent estimate of the thickness of the Triassic rocks in the Durham basin has been given by Mann and Zablocki (1961). Based on a gravity study of the area and they state, "The residual curve across the Durham basin along the traverse from Hillsborough to Raleigh suggests that the basement rock in the northwestern half of the basin lies much closer to the surface than it does in the southeastern half of the basin." They further state, "The anomaly difference between bedrock and basin sediments is 4½ milligals. Therefore, the thickness of the sediments in the basin at its deepest point is estimated to be 3,100 feet," along the traverse from Hillsborough to Raleigh, North Carolina. They concluded from gravitational interpretation that the maximum thickness of the Triassic sediments in the Durham basin is 6.500 feet.