Bulletin 86

GEOLOGY AND MINERAL RESOURCES OF WAKE COUNTY

By
John M. Parker, III

Raleigh 1979

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Eldon P. Allen, Chief Geologist

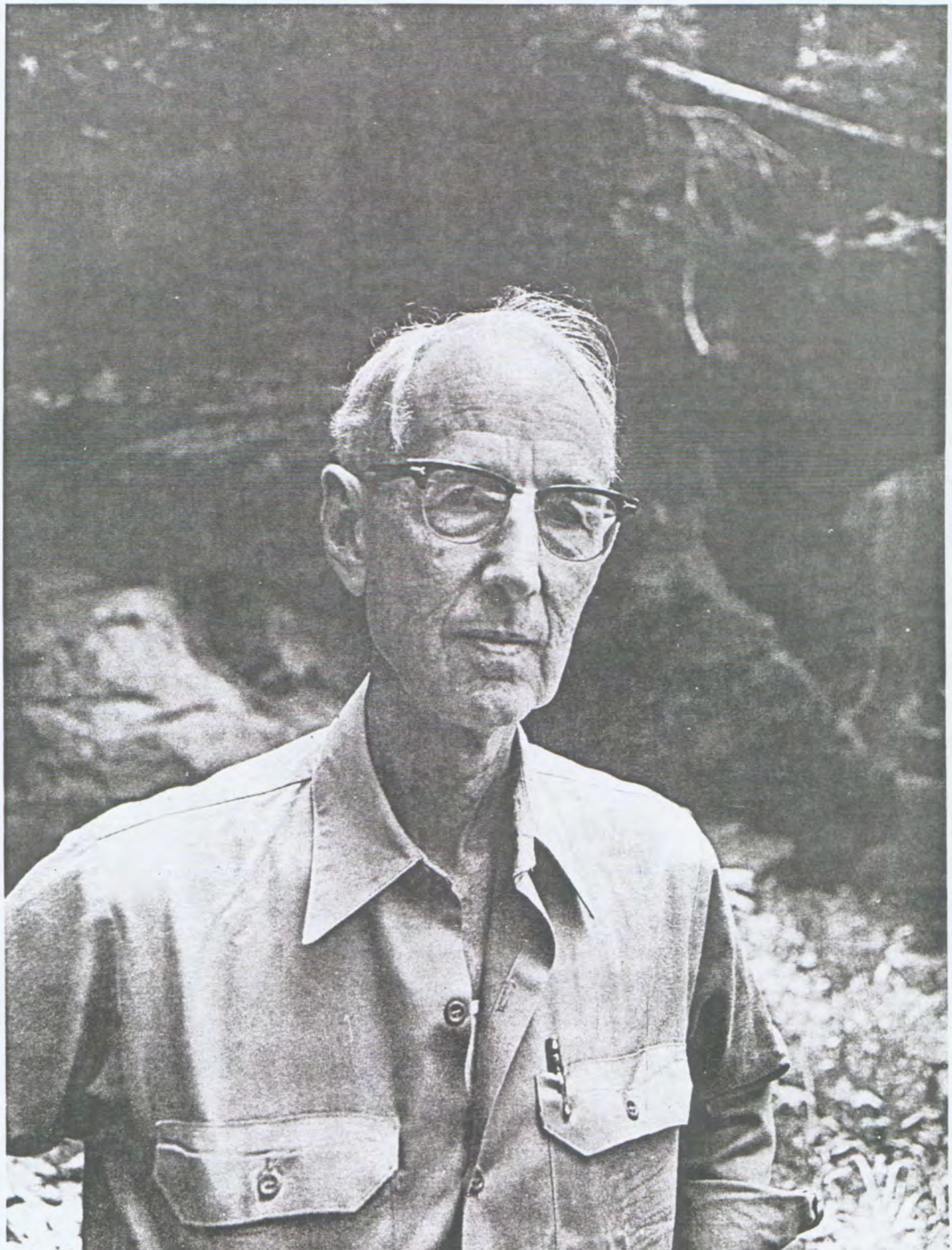
After receiving his doctorate degree from Cornell University in 1935, Dr. Parker joined the faculty of North Carolina State College (now North Carolina State University) as an instructor in geology in the Department of Geology, School of Science and Business. Except for four and one-half years during World War II while in the strategic minerals program of the U.S. Geological Survey, Dr. Parker has devoted his entire professional career to teaching and geological research in North Carolina. In 1972, he retired as Professor of Geology in the Department of Geosciences, North Carolina State University.

As a former student who greatly admires his teaching ability, high professional standards, and moral integrity, it gives me much pleasure to acknowledge this report as a very special tribute to an outstanding teacher, geologist, and citizen -- John Mason Parker, III.

Stephen G. Conrad, Director
Divison of Land Resources

and

State Geologist



ABSTRACT

Metamorphic, igneous, and sedimentary rocks underlying Wake County, North Carolina, range in age from Late Precambrian to Recent. Metasedimentary and metavolcanic rocks extend northeastward through the middle of the county and also underlie the southeastern and eastern edges. The sequence of Late Precambrian and Early Paleozoic age totals 20,000 to 25,000 feet in thickness and includes phyllite, various metavolcanic types, mica gneiss and schist with graphitic zones, quartzite, hornblende gneiss, and amphibolite. Quartz veins are ubiquitous. An unconformity may separate biotite gneiss and schist and overlying rocks of the Carolina slate belt type from felsic quartzo-feldspathic gneisses beneath them to the east. Regional deformation and dynamothermal metamorphism occurring in two stages of mid-Paleozoic age have tightly folded the metasedimentary and metavolcanic rocks and produced widespread bedding schistosity and several lineations; axial plain flow cleavage and strain-slip cleavage are uncommon. An asymmetrical anticline outlined by graphitic belts extends northward through west Raleigh. An isoclinal syncline is inferred to lie farther east. Ultramafic bodies, now largely altered, and a diorite-gabbro complex have intruded the northern and northwestern parts of the metamorphic belt; three small granitic bodies lie to the southwest. An adamellite batholith of probable mid-Paleozoic age occupies most of the eastern half of the county and extends into adjacent counties; it formed in two magmatic stages. Dikes and sills of granite, pegmatite, and aplite abound in a belt 2 to 4 miles wide west of the batholith and in a narrower zone on the east side. Barrovian-type metamorphic facies series, ranging from lower greenschist to middle almandine-amphibolite facies, is related to this batholith. Retrogressive mineral alterations are widespread in metamorphic and igneous rocks. Minor low-angle reverse faults and high-angle strike-slip faults are common, and joints of various sorts are numerous.

Triassic sedimentary rocks (Newark group) in the Durham basin underlie the western quarter of the county. They rest unconformably on metamorphic and igneous rocks peneplained during Late Paleozoic and earlier Triassic times. They are separated from the crystalline rocks to the east by the Jonesboro fault, a normal fault displaced down to the west some 10,000 feet. The sediments dip generally but variably eastward at about 10 degrees. They grade westward from coarse fanglomerate and red silty sandstone to mudstone with a little impure limestone and chert. Bedding is abruptly variable; channel scours and cross-bedding are common. The thickness along the east side is probably about 10,000 feet but decreases westward. Sediment was deposited under continental (alluvial plain) conditions in a half-graben bounded on the east by a steep scarp intermittently renewed by recurrent faulting. Fossils are comparatively rare but include remains of plants, fish, ostracods, and reptiles. Normal faults striking mostly north or west and having slips of only a few tens of feet displace the Newark rocks. Abrupt bends in the trace of the Jonesboro fault may also be due to post-depositional faulting.

Many diabase (dolerite) dikes cut through the metamorphic rocks, the adamellite batholith, and the Newark rocks. Most trend north-northwest but a few strike north and east. Thicknesses range from 200 feet to a few inches. The diabase consists chiefly of labradorite and pyroxene with variable amounts of olivine and opaque minerals. Most dikes are strongly magnetic. Contact metamorphism is noted only in Newark rocks. Effects include blackening of red beds by change of hematite to magnetite and recrystallization of a sandstone inclusion to sanidine-quartz hornfels. Date of intrusion was probably Jurassic.

Gravity values in Wake County are low in the eastern half (minimum of -35 milligals near Wendell) in the adamellite batholith. Values rise steadily westward across the metamorphic and Triassic rocks to a maximum (+15 milligals) at the western boundary. An aeromagnetic survey shows distinctive patterns for various rock types. The metamorphic rocks range abruptly from low to high values; some amphibolite is without local difference, but one body is exceedingly high. The ultramafic rocks are high, diabase dikes mostly high but some are indistinguishable, the diorite-gabbro complex low, adamellite low, and the Newark sediments are low. The Jonesboro fault generally coincides with an abrupt magnetic gradient (lower to the west) but locally is without expression.

Coastal Plain sediment covers wide areas in the east and southeast, lying unconformably on deeply eroded metamorphic, igneous, and Newark sedimentary rocks. Uplands farther west and north across the whole county have strips and patches of similar sediment, remnants of a once continuous sheet. Thicknesses range from about 80 feet to only a foot or so. The sediment varies from well sorted to unsorted. Most is unconsolidated, but some is well compacted. Some is cemented by limonite, and innumerable limonitic nodules commonly are present. These deposits locally include "Tuscaloosa" Formation (upper Cretaceous), Macks Formation (upper Miocene), and "Pinehurst" Formation (Pliocene ?); the formations have not been separately mapped. Fossiliferous Eocene rock consists of reworked cobbles and slabs in younger deposits. The scattered patches of upland sediment in central, western, and northern parts of the county occupy the locally highest topographic positions. They are detected chiefly by the presence of well rounded quartz pebbles in the soil. They have proved to be much more numerous and extensive than was previously known. Of fluvial origin, they seem to be a consequence of peneplain erosion and probably range in age from Cretaceous to Pliocene or even Pleistocene. Terrace deposits and floodplain alluvium occur along all the larger streams.

About half the county consists of flat uplands that are remnants of the Piedmont peneplain, thinly covered in most places with sediment. This surface rises from an altitude of 300 feet in the east to over 500 feet near the west side. The remainder of the area includes valley sides and bottoms of the incised

stream system. The divide between drainage into the Cape Fear River and the Neuse River extends generally northwest, lying successively across Coastal Plain sediments, along the Jonesboro fault, and then in the Triassic sediments. A group of isolated flat sediment-covered uplands above 500 feet in elevation extends northeastward from the divide in Triassic rocks diagonally across the metamorphic belt. Ridges between larger streams commonly descend in a series of broad sediment-covered steps, separated by steeper slopes. These terraces and those along valley sides are believed to be fluvial, related to valley deepening, rather than marine in origin. The central belt of metamorphic rocks is higher and has greater relief than areas to east or west. The granitic area has low elevation and relief. Broad "flat-rock" outcrops of granite probably are patches of exhumed unconformity. The Triassic basin is topographically lower than the adjacent metamorphic area and has much less relief. The Jonesboro fault is marked in a few places by a distinct fault-line scarp facing west and by abrupt narrowing of the valleys of east-flowing streams where they cross it.

Residual soils of many kinds have formed by weathering of the various types of bedrock. They grade downward through decomposed rock (saprolite) into solid bedrock, which lies commonly 10 to 60 feet below the surface. Rounded, exfoliated boulders abound in granite and diabase areas. Parent materials of the widespread soils in the upland areas are partly bedrock formations but also largely upland fluvial sediment. Engineering properties of soils and depths to bedrock vary drastically in short distances because of differences in rock composition and the presence of layering, foliation, cleavage, and fractures with various orientations. Landslides, limited to excavated slopes, are promoted by mica-rich foliated rocks and by black-coated, slickensided fractures.

The geologic history of the county begins in Late Precambrian time with gradual deposition in an ocean basin of thousands of feet of sediment and volcanic rocks. This sequence was intruded by mafic and felsic magma, closely folded, and metamorphosed during at least two Early to Middle Paleozoic tectonic episodes. During Late Paleozoic and Early Triassic times, recurrent uplifts resulted in erosion of some 70,000 feet of rock, thus developing a peneplain. Late in the Triassic period the region was block faulted and continental sediment was trapped in the Durham basin as adjacent higher areas were eroded. In the Jurassic period, the area was fractured and diabase dikes intruded. Erosion during Jurassic and Early Cretaceous times beveled a new peneplain across Triassic and all older rocks. During Late Cretaceous and Cenozoic times, the area was alternately flooded from the east by the ocean and then exposed as relative sea level rose and fell several times. Deposition of marine or near-shore continental sediments alternated with partial erosion of earlier deposits. Present topography gradually evolved by incision of the drainage system into the sediments and the underlying old rocks.

The chief mineral product has been, and continues to be, stone. Dimension stone from injected layered gneiss, lineated quartzitic gneiss, and granite has been produced at some 18 quarries, chiefly during the 19th Century. Crushed stone has been produced on large scale from granite, injected layered gneiss, and quartz-disk gneiss at 8 quarries. Sand and gravel have come from Coastal Plain sediment west of Fuquay-Varina and from streams east of Raleigh. Brick manufacture used alluvial clays along Walnut Creek in the 19th Century and Triassic shales in recent years. Graphite was mined intermittently for nearly a century before about 1906. Additional minor or potential mineral products include mica, feldspar, limestone, manganese, iron, titanium, soapstone, talc, and chrome.

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General Description of Wake County

Geologically, Wake County is of exceptional interest. Lying at the eastern edge of the Piedmont, it combines the complex geology of old, greatly deformed rocks that once were deep in the earth's crust with that of young Coastal Plain sediment lying on top much as it was left by rivers and the sea. The rocks, structures, and landforms span a history of some 600 million years. They attest to deposition of thousands of feet of sediment, to accumulation of lava from volcanoes, to intrusion of huge masses of molten magma on several occasions, to tight folding of the rocks under crustal compression, to later fracturing and vertical displacements under tensional extension of the crust related to opening of the Atlantic Ocean basin, to profoundly deep erosion exposing rocks formerly miles within the crust, to incursions by the sea, and finally to the still continuing shaping of the landscape by weathering and running water. Few areas the size of Wake County provide such a wide variety of geologic features and events.

Wake County is a little east of the center of North Carolina (fig. 1). It is about 36 miles wide east to west and 38 miles wide north to south; its area is 864 square miles. Raleigh, the state capital, is at its center. Several railroads and major highways cross the area, and secondary roads form a close network throughout the county. The southern part of the Research Triangle Park extends into western Wake County. William B. Umstead State Park lies near its western border.

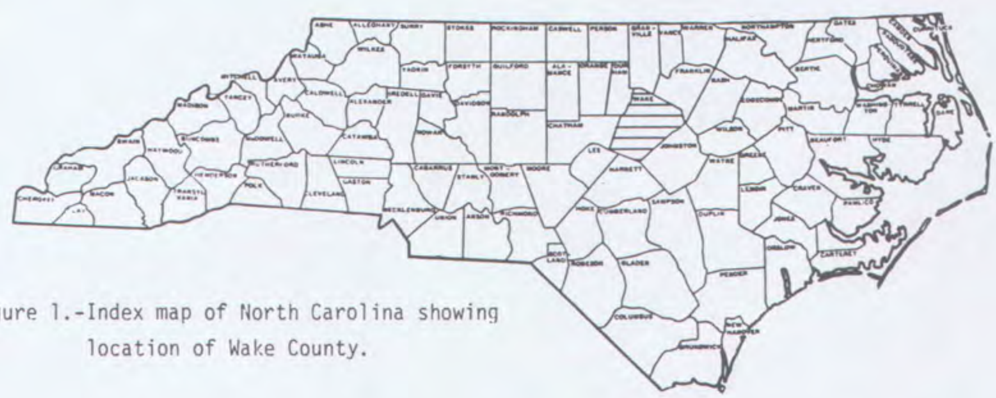


Figure 1.-Index map of North Carolina showing location of Wake County.

The climate is warm, moist, and temperate. The average daily temperature is 70 degrees Fahrenheit maximum and 51 degrees minimum, and the average total annual rainfall is 47 inches (Cawthorn, 1970, p. 114).

The land surface is about evenly divided between flat to gently rolling higher interstream areas and valleys cut 50 to 100 feet lower. The uplands stand about 300 feet above sea level in the eastern part of the county and more than 500 feet in the western part. Drainage is mostly southeastward by the Neuse River and its tributaries; a small area in the southwestern part of the county drains into the Cape Fear River. At least half the county is woodland, mainly along valley bottoms and sides, with cultivated ground generally occupying the flatter uplands.

Soils and weathered rock extend downward to depths of 10 to 60 feet in most places. Outcrops of hard bedrock are rare, and most are confined to stream beds and excavations.

Geologically, the county is made of three different groups of rocks of contrasting type, structure, and age (pl. 1). First, the eastern three quarters of the county is underlain by a complex group of old metamorphic rocks (mostly gneisses, schists, and phyllites) with mafic and granitic intrusions; these are of Late Precambrian or Paleozoic age. This portion is referred to as the "crystalline area", so called conventionally because most of the bed rock is so coarse grained as to consist obviously of crystalline mineral material. The various rocks in the crystalline area extend across the county in irregular, north-northeastward trending belts. Second, along the western edge of the county gently dipping, stratified sedimentary rocks of Triassic age underlie a strip as much as 8 miles wide; these are separated from the older rocks by a great fracture (the Jonesboro fault). Many diabase dikes fill fractures in the metamorphic and granitic rocks and in the Triassic sedimentary rocks. Third, Coastal Plain sediments of Cretaceous and Cenozoic age form one large patch and numerous smaller ones that partly cover the older rocks, chiefly in the southern and eastern parts of the county. The bedrock geology is described below according to these three successively younger sequences of materials.

The geologic setting of Wake County as it relates to adjacent parts of the state is shown by the Geologic Map of North Carolina (N. C. Div. Mineral Resources, 1958) with Explanatory Text (Stuckey and Conrad, 1958), and in articles by Conley and Bain (1965), and by Parker (1968).

Scope of the Report

The purpose of this report and the accompanying geologic map is to supply to the general public, as well as geologists, information on the geology of Wake County and to point out applications to practical human affairs. It is intended to be both a semi-popular and a scientific account. A wide range of readers is sought, including students and teachers, public officials, civil and mining engineers, geologists and interested citizens. Population growth makes it ever more needful that decisions on optimum use of land be based on adequate knowledge of the natural environment, of which geologic factors form so large a part. The information is presented, it is hoped, in a manner useful to any intelligent and serious reader even if not trained in geology. A minimum of technical terms is employed, most of which are readily found in a dictionary.

Scientific information on the county is provided to the extent consistent with the main purpose of the report, of the map scale, and of the limitations of the project. Answers to technical questions regarding the genesis and original character of many of the rocks and the processes of their deformation and metamorphism will require further detailed mapping at larger scale, as well as geochemical and petrofabric studies. The present map and text constitute a progress report on a little studied area; they are to be regarded as semidetailed and partly tentative. Many interesting problems remain to be investigated in more detail or by new means.

Present Study and Acknowledgements

The investigation on which this report is based was begun in 1936 and continued through the years as an intermittent, side-line project supplementing full-time teaching duties at North Carolina State University. It commenced as a joint venture with Dr. J. L. Stuckey to prepare a geologic map of Wake County for instructional use. The project was completely suspended during World War II. Little or no work was done during long periods because of other over-riding interests and engagements. A good deal of time between 1962 and 1967 was devoted to reconnaissance study of the easternmost Piedmont in North Carolina (Parker, 1968) in order to gain a better understanding of the regional geologic setting of Wake County. The work was concluded, following my retirement from teaching, during the period 1972-1976. Short preliminary reports on various aspects of the investigation have been given from time to time (Parker, 1937, 1949, 1953, 1965, 1966, 1971).

Dr. Stuckey shared the work during the period 1936-1940. His field work was done mostly during the summer of 1939 in the strip of metamorphic rocks adjacent to the Triassic sediments between Cary and the north end of the county. Following his appointment in 1940 as State Geologist, new duties prevented his further active participation, though he continued his interest. During the summer of 1966 following

his retirement, he spent several weeks on the microscopic petrography of Wake County rocks. He has discussed many phases of the geology of the county and its surroundings. I am greatly indebted to him for information, encouragement, and interest.

Many data embodied in the report have been acquired incidentally to instructional activities. Field trips and mapping projects with undergraduate students have furnished many details. Master's theses and other reports prepared by graduate students in geology at N. C. State University have provided much information that has been verified or revised. The location of such work is shown on Plate 1; material that is available for reference is listed in the bibliography. Of particular help in the mapping were theses by J. B. Dickey, C. R. Farquhar, C. W. Fortson, Jr., and D. B. Grannell. I take pleasure in acknowledging the permanent value of their hard work.

Base maps used for plotting the geologic observations include county road maps (scales one inch equals one mile and one inch equals two miles) from the North Carolina State Highway Commission and topographic maps from the United States Geological Survey. Topographic maps covering Wake County include all or parts of seven 15-minute quadrangles at scale of 1:62,500 and of thirteen 7 1/2-minute quadrangles at scale of 1:24,000 (pl. 1). A major handicap to geologic mapping in the county has been the lack of modern, large-scale (1:24,000) topographic maps, which became available for about two thirds of the area only in 1964 and 1972-73. Preliminary topographic maps of the four 7 1/2-minute sheets of the Fuquay quadrangle in the southwestern part of the county became available only in 1975. These maps will be useful to the user of the present geologic report.

Cost of transportation during Dr. Stuckey's active participation in 1936-1939 was partly reimbursed by small grants totalling about $150 from the Research Committee of N. C. State College. The U. S. Geological Survey underwrote costs of about a week's work in 1941, as an adjunct to another project. The Engineering Experiment Station of N. C. State College provided funds for 50 thin sections of rocks in 1945. The Geological Society of America granted $350.00 toward cost of travel and thin sections in 1958 (Project Grant No. 805-58). Throughout the years N. C. State University has provided office and laboratory facilities. The author is grateful for this assistance.

Assistance, information, and advice on various matters in the field, laboratory, and office not specifically cited in the text have been generously given by E. P. Allen, G. L. Bain, E. L. Berry, S. D. Broadhurst, P. A. Carpenter, V. V. Cavaroc, T. L. Kesler, W. H. Spence, B. W. Wells, R. M. Whisnant, and W. F. Wilson. Parts of the report and map have been critically reviewed by G. L. Bain, R. B. Daniels, E. E. Gamble, A. D. Howard, C. J. Leith, W. H. Spence, and J. L. Stuckey. E. R. Burt painstakingly reviewed the entire report from both the geological and editorial veiwpoints. Mrs. L. C. Bain typed the manuscript repeatedly and supplied many editorial improvements. Maps and other illustrations were redrafted by B. J. McKenzie and Anne Viront-Lazar. I greatly appreciate their meticulous work in preparing the bulletin for printing. Any errors, omissions, and misinterpretations, of course, are the author's responsibility.

The work was accepted and approved for publication as a state bulletin by State Geologist, Mr. S. G. Conrad, though the investigation had not been officially commissioned in advance.

The bulk of the work has been done by the author and without financial support. Its value to him in terms of recreation, satisfaction, and the pleasure of many personal associations has been incalculable. He is sincerely grateful for the many aids of all who have furthered the completion of this report. Crucial in this assistance has been the encouragement, forebearance, and editorial criticism of his wife, Mattie Erma Edwards Parker.

Previous Investigations

The earliest recorded reference to geological features in Wake County seems to be that of John Lawson in 1701 (Lefler, 1967, p. 64). Near the end of his journey through the wilderness of the Carolinas, he spent a night by a waterfall "where lay mighty Rocks. I take this to be the Falls of Neus-Creek. . ."

The first scientific observations that have been found by the present author are embodied in the famous geological map of the United States by William Maclure (1809, 1818). The region in which Wake County lies was shown as underlain by "Primitive Rocks" (including granite, gneiss, slate, and others) with overlying "Alluvial Rocks" (sandy sediments) beginning a short distance to the east. Though he showed "Secondary Rocks" (in part equivalent of Triassic sediments) in Virginia, Maclure evidently had not detected them in North Carolina, where a belt extends through western Wake County. In his text he mentioned beds of black lead (graphite) in North Carolina and other states but did not cite localities.

Denison Olmstead (1824, 1825, 1827) carried out in North Carolina the first geological investigation authorized and financed by any state in the United States. His geologic map of North Carolina (Olmsted, 1825) showed most of Wake County to be made up of Primitive Rocks, with the western edge having "Sandstone or Grit Formation." A north-trending belt designated "Plumbago of Wake" (i.e., graphite) was plotted just west of Raleigh. "Sandy low country" was shown a little east of Wake County. His first report (Olmsted, 1824) described at some length the graphite, fire-stone, serpentine and soapstone, sandstone, and limestone in the county. In his second report (Olmsted, 1827) he pointed out that the eastern half of the county is largely gneiss and granite, while slate rocks come in at the eastern edge. Thus, the rough outlines of Wake County geology were made known nearly a century and a half ago, much as we recognize them today.

Elisha Mitchell's textbook and map (1842) gave about the same information, except that coastal plain sediment was shown on the uplands in the eastern and southern parts of the county.

The work of Ebenezer Emmons, State Geologist 1852-1863, supplied greater detail on the boundaries of "The Raleigh belt of granite" (Emmons, 1856, p. 28-31) - in which he included gneisses, on the location of the slates (ibid., p. 58) that lie to the west, and on the bordering sandstones of the coal series (i.e., Triassic rocks) (ibid., p. 241) still farther west in the county. He described the occurrence and production of graphite (ibid., p. 221-227) at length and briefly mentioned various building stones and soapstone.

W. C. Kerr, State Geologist 1866-1885, prepared a geologic map of North Carolina (Kerr, 1875) on which Wake County was shown as underlain chiefly by Upper Laurentian rocks (granite, gneiss, and hornblendic rocks). These were bordered on the west by Huronian rocks (chloritic slates, conglomerates and others) and these in turn by Triassic sandstones and shales. Much of the eastern and southern parts were shown overlain by Quaternary sands and clays, with narrow strips of Upper Laurentian rocks along Middle and Black Creeks. A patch of Eocene shell rock was shown near Auburn. The boundary between Huronian and Triassic rocks was shown about 5 miles too far west in the Cary-Morrisville area, and the Quaternary sediment areas to the east and south were shown too large. The map otherwise was very good for the small scale. Mineral localities were listed by Genth and Kerr (1881) and by Genth (1891).

A revision of Kerr's map, made by J. A. Holmes in 1887, was included in a report on ores by Kerr and Hanna (1888). Holmes amended the belt of Huronian rocks in western Wake County. This revised map was used to illustrate subsequent reports on building stone and granite in the state (Lewis, 1893; Watson, 1904; Watson and Laney, 1906). The maps used to illustrate the report on building and ornamental stones of North Carolina (Watson and Laney, 1906, pls. III and IV) did not differentiate areas of gneiss and granite in Wake County, though the belt was labelled "Granite, diorite, and other rocks largely igneous" (ibid., pl. III) and "Granite and Gneiss" (ibid., pl. IV). Descriptions in the text, however, make it clear that rocks in and near Raleigh are gneisses while those in the Wyatt-Rolesville area are granite.

Clark and others (1912) in their classic study of the Coastal Plain in North Carolina showed the approximate western limits of the sediments in eastern and southern Wake County. They mapped and described small patches of Eocene rocks between Garner and Raleigh and near Auburn. Their description of the Lafayette Formation (Pliocene) clearly applies to Wake County though this county was not mentioned specifically.

A geologic map of the state at scale of 1:500,000 was compiled by W. F. Prouty and J. H. Pratt in 1922 (Pratt, 1923, p. 20; Drane, 1925, p. 43 and 46), but for lack of funds it was never printed. This map has disappeared so that whatever contribution it might have made to understanding of Wake County geology is lost.

The eastern boundary fault of the Triassic sedimentary rocks was mapped in some detail by Prouty (1931, fig. 2). His small scale map of the Durham basin was the first to show some of the zig-zag irregularities of the Jonesboro fault. Several localities in Wake County were described in detail.

The first published map showing the granite in eastern Wake County separately from the gneisses appears to be that of Anna Jonas (1932, fig. 1). This small map of the crystalline rocks of the southeastern United States shows a belt of granite enclosed within oligoclase-biotite schist of high metamorphic rank underlying much of Wake County. These are shown bordered on the west by Triassic rocks and on the east and south by Coastal Plain sediments. The granite body was shown extending from Virginia as far southward as Harnett County where it was covered by younger sediments.

The 1932 Geologic Map of the United States (Stose and Ljungstedt, 1932), published by the U. S. Geological Survey, followed generally the Jonas map in the Wake County area. Carboniferous (?) unmetamorphosed granite extended from Virginia through the eastern half of Wake County and as far south as Smithfield and Lillington, where it was covered by Cretaceous deposits. The granite was bordered on the east by Algonkian (?) metavolcanic rocks, which were also shown in western Wake County just east of the Triassic rocks. The belt of rocks west of the granite, extending through Raleigh, was designated Wissahickon schist with igneous injection of Algonkian (?) age. Overlapping Coastal Plain sediments in the Wake County area were omitted.

In 1937 the North Carolina Department of Conservation and Development issued a geologic map of the state compiled by the Minerals Resources and Engineering Divisions under the direction of H. J. Bryson, State Geologist. This map is based chiefly on the 1932 Geologic Map of the United States (Stose and Ljungstedt, 1932). It seems likely that information from the Prouty and Pratt manuscript map was incorporated. The map was never printed but was reproduced in blueprint for limited circulation. The geology of Wake County is shown about as given on the 1932 U. S. Geological Survey map. The boundary between "Carboniferous granite and Algonkian (?) metavolcanic rocks" on the east side was placed too far eastward, outside Wake County. Extensive overlap of the "Pliocene Lafayette (?)" sediments was shown in southern and eastern parts of the county. A small patch of "Miocene Trent Formation" was placed near Garner.

The granite in eastern Wake County was later discovered to end just south of the county line, in northwestern Johnston County, rather than its southern portion merely being buried under Coastal Plain sediment. This fact seems to have been recorded first by S. D. Broadhurst (1952, p. 6) in a small-scale generalized geologic map of the state.

The 1958 Geologic Map of North Carolina (North Carolina Division of Mineral Resources, 1958) was the first map to show the major features of Wake County geology in their true relations, even though at small scale and with approximate boundaries. The eight map units employed were mica gneiss, hornblende gneiss, felsic volcanics, dunite, granite, Newark Group (Triassic), "Tuscaloosa" Formation (Cretaceous), and Castle Hayne Limestone (Eocene).

A reconnaissance study of the geology of Wake County and of four other counties to the north was made by V. J. May (1968) as part of an investigation of groundwater resources. The chief mapping changes made in Wake County were a subdivision of the felsic volcanic unit into phyllites and a metavolcanic sequence, as well as some minor revisions of contact locations. Map units included mica gneiss, hornblende gneiss, metavolcanic sequence, phyllite, soapstone, granodiorite, granite, Newark Group (Triassic), "Tuscaloosa" Formation (Cretaceous), and Castle Hayne Limestone (Eocene).

The soil survey of Wake County (Cawthorn, 1970), issued by the Soil Conservation Service, has provided important geologic guidance. Because the various soil series depend to a considerable degree on the parent material, among other factors, these soil maps have supplied clues to the nature and extent of underlying rocks and sediments where direct observation was impossible.

A preliminary version of the Wake County geologic map (pl. 1 of this report), at smaller scale, was included in the Geologic Map of Region J, North Carolina (Wilson and Carpenter, 1975).

Aeromagnetic maps covering Wake County and adjacent areas, prepared by the U. S. Geological Survey in cooperation with the N. C. Department of Natural and Economic Resources and the Wake County Board of Commissioners, became available on open file in June 1974. These proved invaluable in tracing and interpreting poorly exposed geologic features.

Other investigations bearing on certain local aspects of the county's geology will be cited at appropriate points in this report.

METAMORPHIC AND IGNEOUS ROCKS OF THE CRYSTALLINE AREA

General Description

Much of Wake County is underlain by a wide variety of metamorphic rocks that are interlayered with one another in northward-trending belts (pl. 1). The finer grained, lower rank types lie for the most part along the eastern, southern, and western sides, with coarser grained, higher rank rocks near a large central granitic mass that extends from Raleigh eastward to Zebulon and continues northward into Franklin and southward into Johnston counties. Within the metamorphic rocks in the northern part of the county are many small, altered ultramafic bodies. Other intrusions were emplaced in the western and southern parts of the crystalline area. The metamorphosed rocks seem originally to have been a great thickness of sedimentary and volcanic rocks of early Paleozoic and perhaps late Precambrian age that were deformed, metamorphosed, and intruded by magma at one or more times in middle and perhaps late Paleozoic time.

In the area west of Raleigh, the metamorphic rocks dip generally westward. The rocks succeed one another in nearly conformable sequence, and no indication of a major fold axis has been detected here. This homocline, then, seems to display a thick sequence that is younger to the west. In western Raleigh, however, along the line of House Creek, strong evidence indicates an anticline, referred to as the Raleigh anticline (Parker, 1968, p. 127 and fig. 1); this is discussed later. The fold axis passes along the belt of felsic gneisses. From this axial line eastward to the Rolesville batholith, the same metamorphic rocks must be repeated by isoclinal folding. They are considerably different, however, owing to greater deformation, higher temperature of metamorphism, and to injection by granitic material.

The approximate thickness of the exposed metamorphic rocks may be computed from width of their outcrop and average dip. The westward dips on the west limb of the Raleigh anticline range mainly between 50 and 70 degrees. This would give a total thickness between about 20,000 and 25,000 feet. This estimate assumes no significant repetition of beds by folding or complications from strike faults. The thickness of nearly vertical rocks east of the axis is greater by some 8,000 to 13,000 feet. This is accounted for in part by the great amount of injected granitic material, but also reflects repetition of strata by isoclinal folding.

Four parallel belts (pl. 1) in the metamorphic sequence in and west of Raleigh are distinguished by their differing aggregate characteristics. Some lithologic types, such as mica schist and hornblende gneiss, occur in more than one belt. The rocks are described below by belts, from west to east. The intrusive igneous rocks are described in order of presumed age, the older ones first.

Metavolcanic and Metasedimentary Rocks of the Cary Sequence

The westernmost belt of metamorphic rocks in Wake County comprises a series of metavolcanic and metasedimentary rocks that is informally referred to here as the Cary sequence. These rocks underlie a belt 1 to 2 miles wide just east of the Jonesboro fault; the belt extends through Holly Springs, Cary, Umstead Park and into northern Wake County in the vicinity where N. C. Highway 50 crosses the Neuse River (pl. 1). This sequence is best exposed along SR 1747 in northern Cary and along Crabtree Creek in southwestern Umstead Park. These rocks may also be seen along U. S. Highway 70 just southeast of the Jonesboro fault and in the Burt area in southwest Wake County. Though it is clear that both volcanic and sedimentary rocks are represented in this sequence, many individual specimens remain of dubious parentage.

Metamorphosed volcanic rocks in this sequence include both flow and pyroclastic types of intermediate to mafic compositions. Most are aphanitic to fine grained and have fair to good cleavage. Layering is commonly distinct, the individual layers usually being a few inches to several feet in thickness. Cleavage generally parallels layering where both are present. The rocks include chlorite and sericite phyllites, nearly massive metafelsites and felsophyres, and epidote-actinolite greenstones with little foliation. Clastic texture is clear in some rocks and indicates both crystal and lithic tuffs (Fortson, 1958, p. 50-55). Bulk composition indicates they were chiefly dacitic and andesitic. Mafic metavolcanic rocks (chlorite phyllite, greenstone, and actinolitic amphibolite) seem to predominate along the western side of the Cary belt near the Jonesboro fault. Notable occurrences are at Burt, along Coles Branch west of Cary, north of Cary where SR 1650 crosses Crabtree Creek, in western Umstead Park, near the intersection of N. C. Highway 98 and SR 1805 (in Durham County), and on N. C. Highway 50 just south of the Neuse River. These more mafic rocks, however, also occur commonly interlayered with felsic and metasedimentary rocks at various places in the Cary sequence; for example, in southeastern Cary along SR 1415 and north of Cary along SR 1652 three-quarters of a mile southwest of its junction with SR 1650.

Metasedimentary rocks in the Cary sequence include a variety of fine- to medium-grained rocks that generally have good cleavage and distinct layering. Most are gray and consist largely of quartz and fine muscovite. Some include round quartz and feldspar particles of sand and pebble size embedded in a phyllitic matrix (Fortson, 1958, p. 41-44). This metaconglomerate has been noted in central Umstead Park, along SR 1747 in northern Cary, and in southwest Cary in the vicinity of Briarcliff School. In easternmost Durham County it is also exposed along SR 1901 at SR 1902, in the deep road cut a mile north of this intersection, and in the creek bed just east of Perry Pond. Kyanitic quartzite at the fork of SR 1831 and SR 1805 near Rogers Store in westernmost Wake County is within metaconglomerate.

Some of the dark green, poorly foliated, fine-grained rock composed chiefly of quartz and epidote was possibly derived from a calcareous siltstone or mudstone (ibid., p. 47-49). Globular and lenticular masses of epidote several inches in thickness are numerous in places; they may have been concretions.

An unusual quartzite with abundant magnetite and ilmenite occurs in and near the northeastern corner of Umstead Park. No outcrops have been found, but float is sparse to abundant along two belts. One belt crosses U. S. Highway 70 just west of the park entrance (ibid., p. 44-46 and pl. I); it has been traced about 1200 feet northeastward. This belt has no expression on the aeromagnetic map. The larger belt is marked by a strong ridge-like magnetic high having local relief of more than 300 gammas. This belt begins abruptly at U. S. Highway 70 at a point about 1200 feet southeast of the park entrance and extends in a S. 40° W. direction some 2 miles. The two belts may be faulted segments of one stratigraphic unit, displaced along the northwest-trending fault (fig. 8), that offsets the Triassic boundary about a mile farther west resulting in left lateral, strike-slip of about 1200 feet for both the quartzite and the Jonesboro fault. The equigranular quartzite is fine- to medium-grained. Quartz particles are subround to polygonal to elongate and fit tightly into a granoblastic mosaic. A few small flakes of muscovite are scattered through the rock. Opaque minerals (magnetite, ilmenite and hematite) form irregular masses that fit between and partly around quartz grains, as if occupying former pore spaces. The amount of opaque minerals varies abruptly from place to place; locally they are concentrated in discontinuous laminae and clusters. The rock may originally have been a placer deposit. Fragments of hematite ironstone in the Triassic fanglomerate a mile to the west probably come from a facies of this quartzite not yet found.

The common minerals in the Cary sequence rocks are chlorite, muscovite (sericite), quartz, and epidote, for the most part in microscopic-sized particles. Chlorite and muscovite form half or more of many rocks. They occur as tiny flakes arranged parallel to one another, thus accounting for the good rock cleavage. Biotite takes the place of chlorite in the eastern part of the belt. Quartz commonly forms discontinuous laminations and scattered particles between streaks of micaceous minerals. Epidote forms irregular patches in the darker varieties. Altered feldspar of indeterminate composition is present in some rocks. Opaque grains, largely martite and leucoxene, are common in small amounts; pyrite is sparse. Limonite stain from weathering is ever-present. Thick quartz veins (2 to 4 feet) are numerous in this belt between Cary and Leesville (Prouty, 1931, p. 483).

These mineral associations place most of this sequence in the lower part of the greenschist facies; that is, in the quartz-albite-muscovite-chlorite subfacies and the quartz-albite-epidote-biotite subfacies of regional dynamothermal metamorphism (Winkler, 1967, p. 95-106). This topic is discussed more fully in a later section. East and southeast of Cary the sequence lies partly within the upper greenschist facies.

The Cary sequence is a part of the Carolina slate belt of which the principal outcrop is farther west in the state (see Geologic Map of North Carolina, 1958). These rocks in western Wake County are in abrupt fault contact with Triassic sedimentary rocks to the west. To the east, however, they grade imperceptibly into underlying coarser, higher rank metamorphic rocks. The boundary here has been placed arbitrarily and somewhat subjectively where phyllite and associated rocks in which sedimentary and volcanic textures are generally distinguishable give way to typical gneisses and schists in which metamorphic recrystallization has masked primary features other than layering. The basis of separation, then, is largely metamorphic.

Phyllites of the Kennebec and Emit Areas

A great thickness of phyllites occurs in southern Wake County and in a narrow belt at its easternmost edge (pl. 1). For convenience of reference, those in the south are here named the Kennebec sequence because they are widely exposed along the valleys to the east, south, and southwest of that town (on N. C. Highway 55). Phyllites in easternmost Wake County (and adjacent parts of Johnston, Nash, and Franklin counties) are here referred to as the Emit sequence (from that town on N. C. Highway 39, 5 miles south of Wake County). The Emit sequence has been traced (see Geologic Map of North Carolina, 1958; Parker, 1968, fig. 1 and p. 119) through central Johnston County into the Kennebec sequence; stratigraphically they are the same. The Kennebec rocks are separated from the Cary sequence by gneisses and schists and a small granitic intrusion, and the critical area between them is covered for several miles by overlapping Coastal Plain sediments around Fuquay-Varina.

The phyllites are distinctly layered rocks with good slaty cleavage. They are so fine grained that individual minerals can rarely be distinguished even with a hand lens. Typically they break along smooth, closely spaced cleavage planes that commonly parallel the layering, though in places the cleavage planes clearly exhibit traces of oblique bedding. Fresh rock usually has shiny cleavage surfaces but the more common weathered rock is dull and appears slaty. The layering is distinct, shown by contrasts in color, composition, and grain size. The layers range in thickness from a small fraction of an inch up to several inches, and less commonly several feet. They range in color from white or buff to red or brown to greenish. The phyllites consist of muscovite, chlorite, and quartz. The semiplastic nature of weathered phyllite indicates significant amounts of original feldspar now altered to clay. Tiny black, opaque specks (martite?) are commonly abundant. Distinct small octahedral crystals of martite and cubical limonite pseudomorphs after pyrite are not uncommon.

Phyllites along Black Creek in southern Wake County, when traced northwestward, gradually increase in grain size and pass imperceptibly along strike into fine grained felsic gneiss and schist. This transition occurs parallel to layering; for example, graphitic phyllite near the Johnston County line becomes graphitic garnet schist at the intersection of SR 2753 with U. S. Highway 401. The general position of this change along a northeast belt between Banks and Willow Springs and to the southwest is mapped (pl. 1) with the symbol for a gradational contact. This relationship, then, is a metamorphic facies change representing higher grade to the northwest, the phyllites being in the greenschist facies. Further, it means that some of the rocks in the felsic gneiss belt are stratigraphically equivalent to some phyllites of the Kennebec sequence. The transitional belt extends obliquely across strike of rock units and inferred fold axes. Unfortunately the crucial area in which this transition occurs is largely covered by overlapping Coastal Plain sediments, so that relationships remain obscure.

The phyllites of the Emit and Kennebec areas must have been derived from sedimentary deposits. The uniform, distinct bedding and their compositions point to original shales and siltstones, though fine-grained volcanic ash may also have constituted some parent material. Volcanic flows and demonstrable pyroclastic deposits are absent from this belt in Wake County, but such material occurs in the belt around Princeton in southeastern Johnston County.

The total thickness is indeterminate but must be great. The phyllites crop out with steep to vertical dips over as much as 3 miles across strike, giving a possible thickness of perhaps 15,000 feet. Repetition of part or all of the section by isoclinal folding would reduce this figure. Lack of known stratigraphic marker beds, as well as inadequate exposures, make this impossible to assess.

Mica Gneisses and Schists with Interlayered Hornblende Gneiss

A thick sequence of gneisses and schists extends north-northeastward across Wake County west of Raleigh (pl. 1). It lies just east of the Cary sequence and west of the belt of felsic gneisses and extends to the northern and southwestern boundaries of the county. Similar rocks also occur southeast of McCullers. They are well exposed in road cuts on U. S. Highway 70 northwest of Raleigh, near the intersections of SR 1647 and 1835 and along N. C. Highway 50 between the intersections of SR 1830 and N. C. Highway 98. Mica gneisses and schists predominate in this map unit. Hornblendic layers are numerous though too thin or poorly exposed to map separately; they are estimated to make up less than a quarter of the whole unit. Similar hornblendic rocks that form large lenses are mapped and described separately.

The rocks of this group are medium- to coarse-grained and almost all have good foliation resulting from parallel arrangement of elongate or platy minerals (mainly micas and hornblende). The commonest rocks are gneisses in which feldspars and quartz are the predominant minerals, enclosing streaks and layers of mica and hornblende. The schists are made up chiefly of mica and hornblende and show little banding. Most exposures in this sequence show alternating layers of contrasting mineral composition or texture, the layers ranging in thickness from less than an inch up to tens of feet. Thinner beds of schist abound in the gneisses, and micaceous layers alternate with hornblendic ones. The orientation of the elongate or platy minerals is invariably parallel to layering, whether thick or thin. These rocks, then, have bedding foliation.

Mica gneiss in many places contains rock fragments. These have been observed in northern Wake County on New Light Creek at the junction of SR 1909 and 1913 and along Rocky Branch just east of Neuse River and north of N. C. Highway 98. They are also common in the southern part of the county in outcrops along Kenneth Branch southwest of Fuquay-Varina and in adjacent parts of Harnett County. Cobbles of sub-angular to sub-rounded quartz are most common, in sizes up to a foot across. Locally these form gravelly layers. Irregular chips and slabs of biotite schist and of hornblende gneiss range in thickness from a few inches to 20 feet. The matrix is light-colored feldspar and quartz with minor micas and commonly contains round quartz grains. These conglomeratic rocks generally have distinct foliation but some lack compositional layers. During reconnaissance work in preparation of the Geologic Map of North Carolina (North Carolina Div. of Mineral Resources, 1958) such rock near Fuquay-Varina was mistaken for granite. It is interpreted as a conglomeratic arkose or graywacke, probably a diamictite deposited in part by submarine slumping.

The gneisses and schists grade westward into the Cary sequence, the boundary being arbitrary. The former are obviously crystalline, being composed of grains readily distinguished without a hand lens, and they lack relic primary textures. Further, the mineral associations indicate higher temperatures of metamorphism; most of them lie in the upper greenschist facies, that is, the quartz-albite-epidote-almandine subfacies (B 1.3 of Winkler, 1967, p. 101). To the east these rocks give way abruptly to quartz-rich and biotite-poor types. This contact in the area west and northwest of Raleigh appears to be an angular unconformity. The younger more mafic gneisses and schists to the west cut obliquely across the northern ends of graphitic belts in the felsic gneisses. Relations in this area are described in further detail in connection with the Raleigh anticline.

Mica gneisses consist chiefly of feldspar and quartz, with lesser amounts of mica. The commonest feldspar is plagioclase (oligoclase usually), but orthoclase and microcline are common. Either quartz or feldspar may predominate. Both biotite and muscovite occur in most gneisses, and either mica may predominate, though biotite is commoner. Red garnets (almandine) are present in many gneisses, especially in the more easterly parts of the main belt. Accessory minerals include apatite, zircon, tourmaline, titanite, ilmenite, and pyrite. Zircon and tourmaline are rounded or angular, rather than euhedral, suggesting a detrital rather than an igneous or metamorphic source. Epidote, clinozoisite, chlorite, hematite, and limonite are common alteration products.

The mica schists are made up chiefly of coarse muscovite and biotite flakes in varying proportions; muscovite is the commoner mica. Fine-grained quartz and a little feldspar are subordinate. Garnets are especially common in mica schists.

Quartzite with varying amounts of muscovite is a minor component in this sequence. Layers a few inches thick are fairly common in mica gneisses.

The mica gneisses and schists indicate by their high quartz and feldspar contents and by uniform layering that they were originally sedimentary deposits of graywacke and associated types, probably including tuffs of intermediate and felsic compositions.

The hornblende gneisses and schists are dark, medium- to coarse-grained rocks, usually with good foliation. The gneisses contain layers and streaks of feldspar (oligoclase) and quartz, while the schists are made up almost solely of hornblende with evenly disseminated quartz. Hornblende and other elongate minerals usually are arranged in parallel. Biotite is commonly present and composes as much as a quarter of some rocks; muscovite is rare. Epidote is common and makes up half of some rocks. Minor components include garnet, titanite, zircon, apatite, and opaque grains. Secondary chlorite and calcite occur in small amounts.

Hornblende gneisses and schists are generally interbedded with layers of micaceous rocks. Their contacts are parallel and individual layers are uniform in thickness and character for distances of at least tens of feet. They give every appearance of having been laid down originally as parts of a conformable bedded sequence. The original material probably was in part mafic volcanic tuff and in part siliceous dolostone. Rounded zircons in some rock favor the latter interpretation.

A body of sharply discordant hornblende gneiss within mica gneiss occurs on N. C. Highway 50 half a mile south of N. C. Highway 98 (Dickey, 1963, p. 24). This undoubted intrusive dike is described later with other igneous rocks.

Commercial use of rocks in this belt has been minor. A small quarry (described later) in metagraywacke was formerly worked in the southeastern part of Umstead Park.

Felsic Gneisses and Schists

Felsic gneisses with interlayered schists compose a band about 4 miles wide lying east of the mica and hornblende gneiss and schist belt and west of the injected layered gneisses and schists. The felsic gneisses and schists lie on both sides of the axis of the Raleigh anticline. This belt passes north-northeastward through the western part of Raleigh and extends through Falls of the Neuse into Franklin and Granville counties. These rocks are well exposed along U. S. Highway 70 and N. C. Highway 50 near their junction and in the Crabtree and Falls quarries. To the south the belt passes under Lake Wheeler and extends into the southern part of the county. In this area the felsic gneisses appear to grade southeastward into the Kennebec phyllites (as described earlier). Interpretation of structural relationships in this area depends greatly on aeromagnetic data (described in a later section).

This belt includes several light-colored rock types all of which are characterized by high quartz content, the usual presence of microcline, very little mica, and the predominance of muscovite over biotite. Interlayered with these typical rocks are bands of mica-garnet schist and of hornblende gneiss, but these darker rocks are much less abundant than in the belt to the west. Graphite-bearing members in this unit are treated separately in the following section.

Lying farthest west in this belt is a distinctive gray to pink rock informally referred to as quartz disk gneiss. The best exposure is the Crabtree quarry. The typifying feature of this unusual rock is the presence of flat disk-shaped bodies of quartz that range from about 0.1 to 0.5 inch in diameter and up to 0.1 inch in thickness. These disks compose nearly a third of the rock and lie parallel to one another and to thin films of greenish scaly muscovite. Disks are barely visible in fresh rock but stand out plainly as bumps on weathered surfaces. Because they resist weathering better than the matrix, they are innumerable in the soil. Outcrops on the west-flowing tributary of Richland Creek, a quarter of a mile south of SR 1649 (Ebenezer Church Road), contain distinct round pebbles up to 0.25 inch in diameter.

This rock splits readily into wedge-shaped slabs along the mica films. Slender prismatic crystals of black tourmaline up to an inch long are numerous on these micaceous cleavage surfaces. In most places the tourmaline needles are arranged roughly in parallel, giving the rock a lineation that plunges at low angles to the south-southwest.

Microscopic examination indicates that quartz forms half or more of the rock, with microcline and oligoclase each making up about a fifth. Muscovite and a little biotite constitute most of the remainder. Calcite is common between grains and in cracks. Few small grains of opaque minerals and tiny round zircons are present. The disks consist predominantly of quartz with a little feldspar or muscovite. Each disk is made up of numerous grains of quartz fitting together in a tight mosaic. Most grains are clear and unstrained. The contacts of the disks with the matrix are distinct though irregular in fine detail. Other lenticular areas of size and shape similar to the quartz disks consist of sericitized feldspar grains that have been crushed and the fragments strained and rotated. Disks of both kinds seem to be flattened pebbles. The matrix consists chiefly of feldspars with quartz and mica. Tiny mica flakes form streaks of abruptly varying width that curve between and around the quartz disks and crushed feldspar grains. Bedding has not been observed in outcrop, but in thin sections vague streaks richer in mica or opaque minerals can be seen. The quartz disk gneiss seems to be a meta-arkose containing flattened pebbles.

Discordant dike-like masses of biotite schist in the quartz disk gneiss are believed to have been igneous intrusions; they are interpreted as early mafic dikes and discussed later. Quartz veins in this rock at the Crabtree quarry have yielded an interesting suite of rare minerals; these are described later in the section on quartz veins. Granitic pegmatites are not present in this rock, though they are numerous farther east in this belt.

Associated with the quartz disk gneiss and lying just to the east is similar rock having rough quartz prisms rather than disks. Road cuts in the Laurel Hills subdivision in northwest Raleigh commonly display such rock. The prisms are not prismatic crystals of quartz but are aggregates of fine-grained quartz. They are roughly square or rhombic in cross section, approximately 0.1 inch thick and 0.5 to 1.0 inch long. All lie about parallel to one another, thus imparting a strong lineation which at various places is near horizontal or plunges as much as 15 degrees to north-northeast or to south-southwest. Elongate disks occur in places with prisms. The prisms, like the disks, are more evident in saprolite than in solid rock.

The eastern half of the belt of felsic gneisses is largely made up of quartz-microcline gneiss having strong lineation of mica streaks. This type is widely exposed in west Raleigh, especially well where Brooks Avenue crosses the Southwest Prong of Beaverdam Creek. It is best examined in quarries 1.5 miles southwest of Falls. Its outcrop in the Neuse River is responsible for the well known Falls of the Neuse. This light gray rock is mostly fine grained and equigranular. Horizontal outcrop surfaces show rigidly straight streaks. Vertical surfaces parallel to these streaks have exactly the same appearance, but vertical surfaces at right angles appear massive and structureless. The rock thus lacks foliation (planar structure). Tiny elongate flakes of mica are concentrated in streaks rather than in planes. Loose pieces of weathered rock look remarkably like petrified fossil wood.

Though most of the lineated gneiss has little or no planar foliation, two kinds of layering are seen here and there. At the quarries southwest of Falls, layers of finer grained rock occur in the coarser grained. The mineral compositions of the two types are the same and only the texture differs. These layers range in thickness from a few inches to 3 feet. Both types have lineation with minor foliation, and the lineation strictly parallels the layers of contrasting texture. At many other localities, however, distinctly banded rock is made up of layers having contrasting compositions. Some layers are much more micaceous or more quartzose than the rest. These layers range from laminations a fraction of an inch thick to beds a foot or more in thickness. Contacts are sharp, and beds are uniform for tens of feet along strike. Evenly bedded muscovite quartzite is extensively exposed along the Southwest Prong of Beaverdam Creek in northwest Raleigh. There can be no doubt that these rocks were originally a sedimentary sequence. Mica flakes in these rocks lie parallel to the compositional layers.

Microscopic study of the lineated and laminated gneisses shows them to consist mainly of quartz and microcline; oligoclase is usually minor. In some rocks quartz greatly predominates over feldspar, and in others they are about equal. Muscovite exceeds biotite in most rock, and together they usually total less than 5 percent. The texture is a granoblastic mosaic with most grains being somewhat elongate parallel to the lineation or foliation. Small amounts of opaque minerals, seemingly magnetite and ilmenite, are scattered through the rock but occur chiefly in short streaks. Tiny round zircons are sparse. Calcite is common in small irregular masses between and surrounding other grains. Kyanite in this belt of gneisses seems to occur mainly in interlayered mica schist and in quartz veins. The probable tectonic significance of lineated quartzitic gneiss is discussed later in connection with structure.

Mica-garnet schist forms layers within the felsic gneisses ranging in thickness from a few inches to several hundred feet. Schist is well exposed at the dam in Laurel Hills, on the Leesville Road at the junction of SR 1822 and SR 1826, and in the northern part of the county along SR 1922 both north and south of Horse Creek. The mica schist is medium- to coarse-grained with easy cleavage along wavy surfaces. It consists of tiny quartz grains (50 to 60 percent) with coarser flakes of muscovite and biotite; muscovite generally exceeds biotite in amount. Garnet is almost invariably present in well formed crystals as much as 0.5 inch in diameter. Small amounts of graphite, sphene, and tiny round zircons are present. Kyanite is an important constituent in mica schist bands toward the eastern side of the felsic gneiss belt. It occurs mainly as tiny blades about 0.05 inch wide and 0.5 inch long. These blades resist weathering, so kyanite is most readily identified where loose crystals have been concentrated in low spots by rain wash. Quartz veins and pods in these schist bands may have blue kyanite crystals several inches long. Kyanite is most abundant in the Horse Creek area noted above. Most of this belt belongs to the almandine-amphibolite facies (B 2.1 and B 2.2 of Winkler, 1967, p. 106 and 110), but the west side north of Raleigh is in the upper greenschist facies.

Hornblende gneiss forms comparatively few layers in the felsic gneiss belt. Most occurrences are only a few feet or few tens of feet thick. Such rock is common west of Wake Forest along the eastern limit of this map unit. The petrographic character is the same as that already described for the belt to the west.

Pegmatite dikes and sills, including some thick ones, are common in the felsic gneisses in the northern half of the belt, but they are less common than in the injected gneisses to the east. Most are about parallel to the foliation or lineation of the gneisses but a few are sharply crosscutting. They are described in a later section.

Felsic gneisses have been quarried as building stone for more than a century at a number of localities. These are described later.

Graphitic Schist in the Felsic Gneisses

Graphite-bearing mica schist occurs in two parallel belts trending northward through the middle of the county, passing 3 to 4 miles west of the center of Raleigh. These belts are components of the felsic gneiss map unit (pl. 1). The graphite, also known formerly as plumbago or black lead, is so noticable in road cuts and in the soil that this rock has been known since the early settlement of the area. Maclure (1809, p. 421) mentioned the occurrence of black lead in Carolina and other states, without citing localities, but Olmsted (1824, p. 4-10; 1825) described and mapped the "Plumbago of Wake." Subsequent descriptions have been published by Mitchell (1842, p. 141), Emmons (1856, p. 222-227), Kerr (1875, p. 132 and 296), Pratt (1904, p. 45-52), and Harrington (1947, p. 516-521).

The northern end of the graphitic belts, as presently known, is near Bayleaf, and the southern end is at Panther Lake near the Johnston County line, the known length being about 30 miles. The belts are broadly curved, trending north-northeast in the northern half and south to southeast in the southern part (pl. 1). Individual exposures are short and generally spaced widely along strike, so that some uncertainty exists in tracing and correlating them, particularly in the southern half of the county. However, graphitic rock is remarkably persistent in its strike direction and is restricted across strike to narrow belts, thus constituting a significant stratigraphic marker.

In the area west of Raleigh, graphitic schist is exposed at close intervals along strike for a distance of about 4 miles and across strike for a width of more than 2 miles; it may be traced with some assurance. Each of the two parallel belts consists of two main zones of graphite-bearing rock that crop out parallel to one another at distances across strike of about 1300 to 2000 feet, depending on steepness of dip. Additional zones, apparently thin and discontinuous, have been noted here and there. The thicknesses of the main graphite zones in each belt range from about 10 to 175 feet. The number of graphite layers in a zone ranges from 1 to at least 18 and their thicknesses from less than a foot to about 45 feet. A detailed measured section is presented in figure 2.

Both graphitic and non-graphitic rock consists chiefly of fine-grained quartz (40 to 80 percent) and muscovite (10 to 30 percent). Garnet is almost invariably present, and kyanite and staurolite occur commonly in the eastern belt. Tourmaline was noted at one locality. Amorphous graphite is estimated to compose 15 to 20 percent of much rock and rarely one-third.

The two graphitic belts are regarded as being stratigraphically the same and repeated in outcrop on the east and west flanks of the Raleigh anticline (pl. 3), which is described later. Kerr (1875, p. 132 and 296) also thought the two beds probably formed "a sharp anticlinal", though it is uncertain whether he knew of and referred to the two belts herein described or to the two zones within one belt.

The more westerly of the two outcrop belts ends northward near SR 1650 (Reedy Creek Park Road). The more easterly extends some 10 miles farther north and ends near Bayleaf. The locations and extents of these two graphitic belts coincide with moderate linear magnetic highs. These graphitic belts and the intervening felsic gneisses seem to be obliquely cut off by unconformable overlapping of the younger mica gneiss and schist unit to the west. This interpretation implies, of course, that initial folding of the Raleigh anticline occurred prior to deposition of the rocks of the mica gneiss and schist unit.

The graphitic schists prior to metamorphism seem clearly to have been carbonaceous sediment of silt, clay, and carbon of presumed organic derivation. The graphite is disseminated through the rock in thin layers of great persistence along strike and is interbedded with well-stratified, quartz-rich rocks of metasedimentary composition. Its lack of crystallinity, the absence of graphite veins, and the presence of cross-cutting quartz veins that have no graphite seem to preclude that the carbon was introduced into

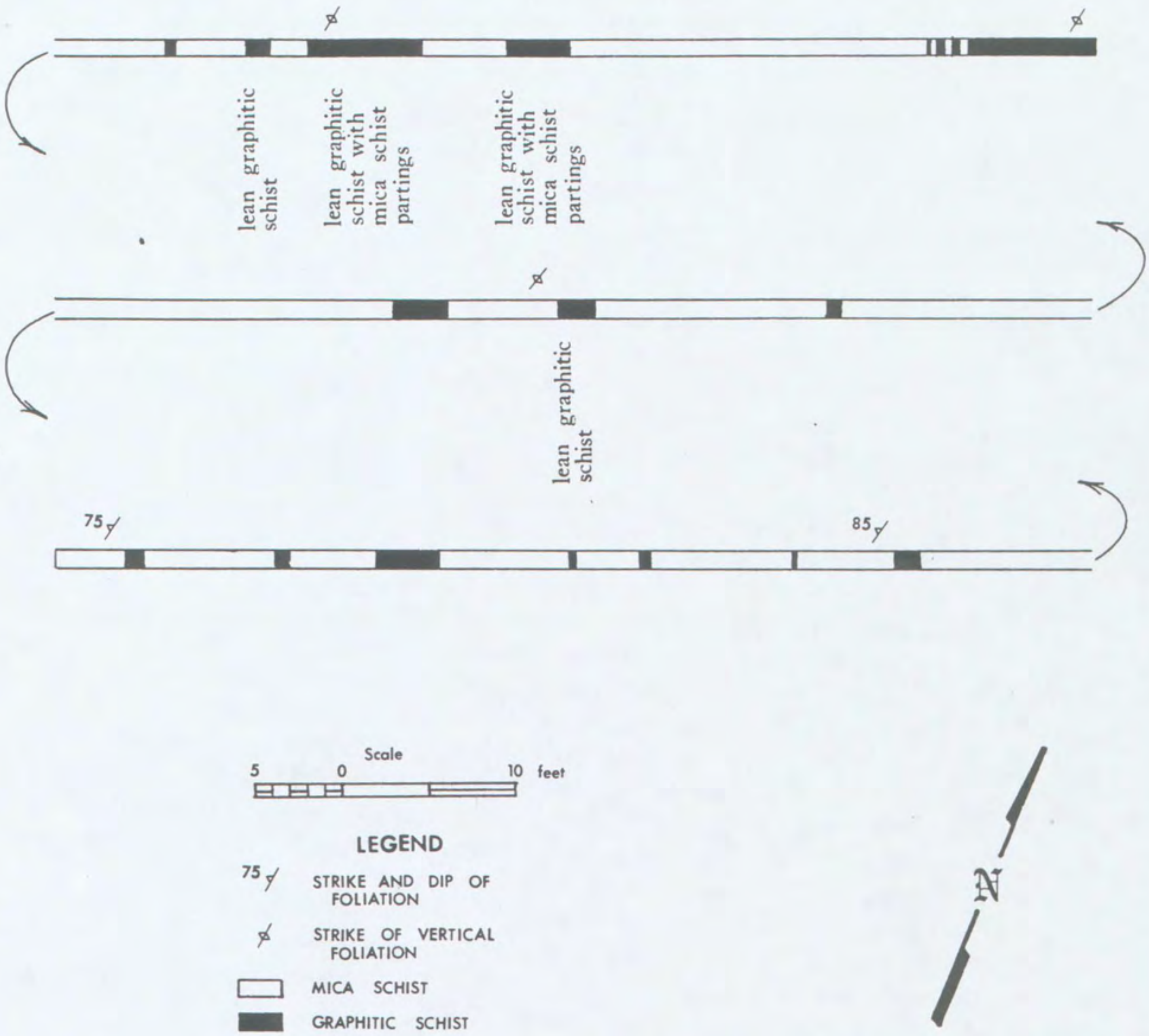


Figure 2. Cross section strip map of graphite zones in felsic gneiss; at intersection of Beltline and Ridge Road, northwest Raleigh, N. C.

the rock after its accumulation. Emmons (1856, p. 222-224) argued for introduction into the rock after accumulation, while Harrington (1947) held the sedimentary view. The environment of deposition of the original carbon-rich sediment seems likely to have been that of coastal lagoons. The elongate extent of the deposits, the uniformly fine grain size and high quartz content of the associated rocks, the range of carbon content in different layers, and their patchy distribution within a narrow stratigraphic interval seem more consistent with lagoonal conditions than with shallow or deep marine basins or with continental coal-forming swamps.

Metamorphic changes and industrial development of the graphite are described in later sections.

Injected Gneisses and Schists

East of the felsic gneiss belt lies a thick sequence of mica and hornblende gneisses and schists containing numerous sills and dikes of granite, pegmatite, and aplite. Injected igneous material makes up a quarter to a third of the total thickness in the eastern half of this belt. These injected rocks underlie a belt 2 to 4 miles wide that extends north-northeastward through eastern Raleigh to Wake Forest and southward through Garner into Johnston County. The boundary with the felsic gneisses to the west is drawn arbitrarily where injected rock appeared to compose more than a few percent of the whole. To the east these rocks grade into the Rolesville batholith. They are well exposed in the Greshams Lake quarry, along the railroad spur north of Six Forks Road in the Crabtree Industrial Center, and in Pigeon House Branch (fig. 3) beside Downtown Boulevard north of the Fairview Road interchange. In eastern Wake County similar rocks occupy a belt 1.0 to 1.5 miles wide just east of Zebulon, along the east side of the Rolesville batholith.

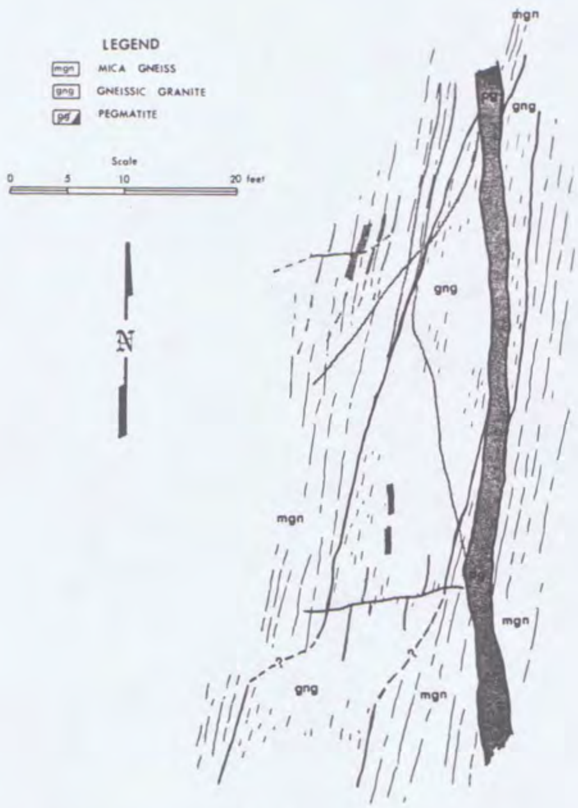


Figure 3. Dikes of granite and of pegmatite in mica gneiss; in Pigeon House Branch, beside Downtown Boulevard and 800 feet east of Fairview Road intersection, Raleigh, N. C.

This belt is made up chiefly of layered mica gneisses. Along the western side they are fine-grained, lineated, and laminated gneisses like the adjacent felsic gneisses. To the eastward they are coarser grained with distinct, uniform layers. They range from light to dark with variations in biotite content. Garnet is common in these rocks; kyanite has not been observed. Mica schist and hornblende gneiss are commonly interlayered with mica gneiss. Most hornblende gneiss layers are exactly parallel to the adjacent layers of mica gneiss. Sharply discordant and interfingering relationships, however, were observed in Rocky Branch south of Central Prison in Raleigh (fig. 4). The dark layers here probably were conformable originally but were disrupted during deformation and intrusion by granitic bodies. Watson and Laney (1906, p. 33-34) described a quartz diorite mass along the west side of the old City Quarry (no longer visible) which seems likely to have been hornblende gneiss or amphibolite.

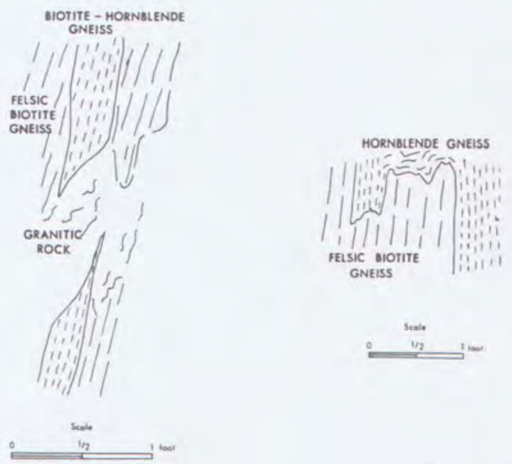


Figure 4. Mica and hornblende gneisses in injected gneiss; beside Rocky Branch at intersection of Western Boulevard and Cabarrus Street, Raleigh, N. C.

Layering in the gneisses is for the most part nearly vertical, but strongly deformed areas are common, resulting in local low dips. Here the layers are intricately folded and disrupted and usually contain igneous injections.

Granite masses up to 50 feet or more thick cut through the gneisses, mostly as irregular sills parallel to the steeply dipping foliation. They contain inclusions of gneiss as much as several yards long. Most contacts are sharp, but in places they are gradational. The granite commonly has fairly distinct foliation due to roughly parallel arrangement of biotite flakes dispersed through the rock. Injected granite is largely restricted to the eastern two-thirds of the belt.

Conformable and disconformable pegmatites and aplites are found throughout the belt and become increasingly numerous to the east. Most of them are roughly tabular in form and parallel to the layering of the gneisses, but others fork or break out across the foliation in highly irregular masses. Some even have right angle margins as if filling a space from which a square block of gneiss had moved out. Contacts are almost invariably sharply distinct. Pegmatites and aplites commonly cut across granite sills and are distinctly younger. Pegmatite thicknesses generally range from a few inches to 25 feet; some few are considerably thicker. Aplites are only a few inches thick. Both consist mainly of microcline and quartz; they are described in detail later. The character of the dikes and of the injected gneiss is splendidly displayed in the walls of the state capitol building.

Though in general the injected material forms clearly discrete sills and dikes, locally the injection is on such a small scale and the rock components are so intimately mixed that the rock is a migmatite. Such rock may be seen at the old Greshams Lake quarry and along the railroad spur north of Crabtree Industrial Center on Six Forks Road in Raleigh.

This belt seems to lie in the kyanite-almandine-orthoclase subfacies (B 2.2 of Winkler, 1967, p. 110) of the almandine-amphibolite facies, though kyanite has not been reported here.

Commercial stone has been produced on a large scale from this belt since at least the early 19th century. Operations are described later.

Early Mafic Dikes

Discordant, irregularly tabular masses of biotite schist and hornblende amphibolite occur in various gneisses in west-central Wake County. They have been metamorphosed in the same manner as the enclosing rocks and are believed to have been small igneous intrusions emplaced prior to deformation of the region.

In the Crabtree quarry northwest of Raleigh, along U. S. Highway 70 in that vicinity, and in the Sycamore Creek quarry in Umstead Park, biotite schist dikes occur in various gneisses (Fortson, 1958, p. 56-58). Each is a warped sheet of abruptly varying thickness, ranging from a few inches to about 2 feet. Some pinch out locally and begin again a few feet away. In most places they cross-cut the foliation and layering of the enclosing gneisses at various angles, but locally they lie parallel. The rock consists chiefly of fine-grained, black biotite flakes in parallel arrangement with considerable carbonate and a little pyrite.

Hornblende amphibolite forms an irregularly branching dike-like body in road cuts on N. C. Highway 50 at a point 0.65 mile south of the intersection with N. C. Highway 98 (Dickey, 1963, p. 24 and pl. II). This complex discordant body cuts mica-garnet gneiss (fig. 5). The amphibolite consists almost solely of hornblende plus secondary epidote and chlorite with a little quartz and traces of sphene and opaque grains. Foliation is faint in the amphibolite, but where it seems to be present, it parallels that of the adjacent gneiss.

Most of the hornblende gneisses and schists in the county are strictly conformable with the interbedded mica gneisses and are interpreted as altered sedimentary or volcanic rocks, but it is possible that at least some of these, especially in the northern half of the county, were originally igneous sills, perhaps related to the early dikes. An instance was described in the section on Injected Gneisses and Schists (fig. 3).

Hornblende Amphibolite

Hornblende amphibolite and gneiss occur in masses large enough to map separately in several places in the metamorphic belts. These discontinuous amphibolite lenses occur at various stratigraphic positions. Additional smaller areas are known that could not be satisfactorily mapped for lack of outcrops and hence are included as undifferentiated components of mica gneiss belts. The 1958 Geologic Map of North Carolina showed several large, interconnected irregular belts of hornblende gneiss. Though this rock occurs in the belts shown, it is now known that the size and continuity of hornblende gneiss were misjudged during reconnaissance mapping. Future large-scale, detailed work may succeed in delineating some smaller amphibolite bodies. More than one mode of origin seems to be represented among the amphibolites.

The hornblendic rocks vary from layered and foliated, medium-grained hornblende gneiss to coarse-grained, nearly massive hornblende amphibolite. In places the hornblende crystals are not only arranged in planes but also aligned to constitute a distinct lineation, which in most places is nearly horizontal. Hornblende gneiss and amphibolite lenses are conformable to the adjacent mica gneisses and schists in the

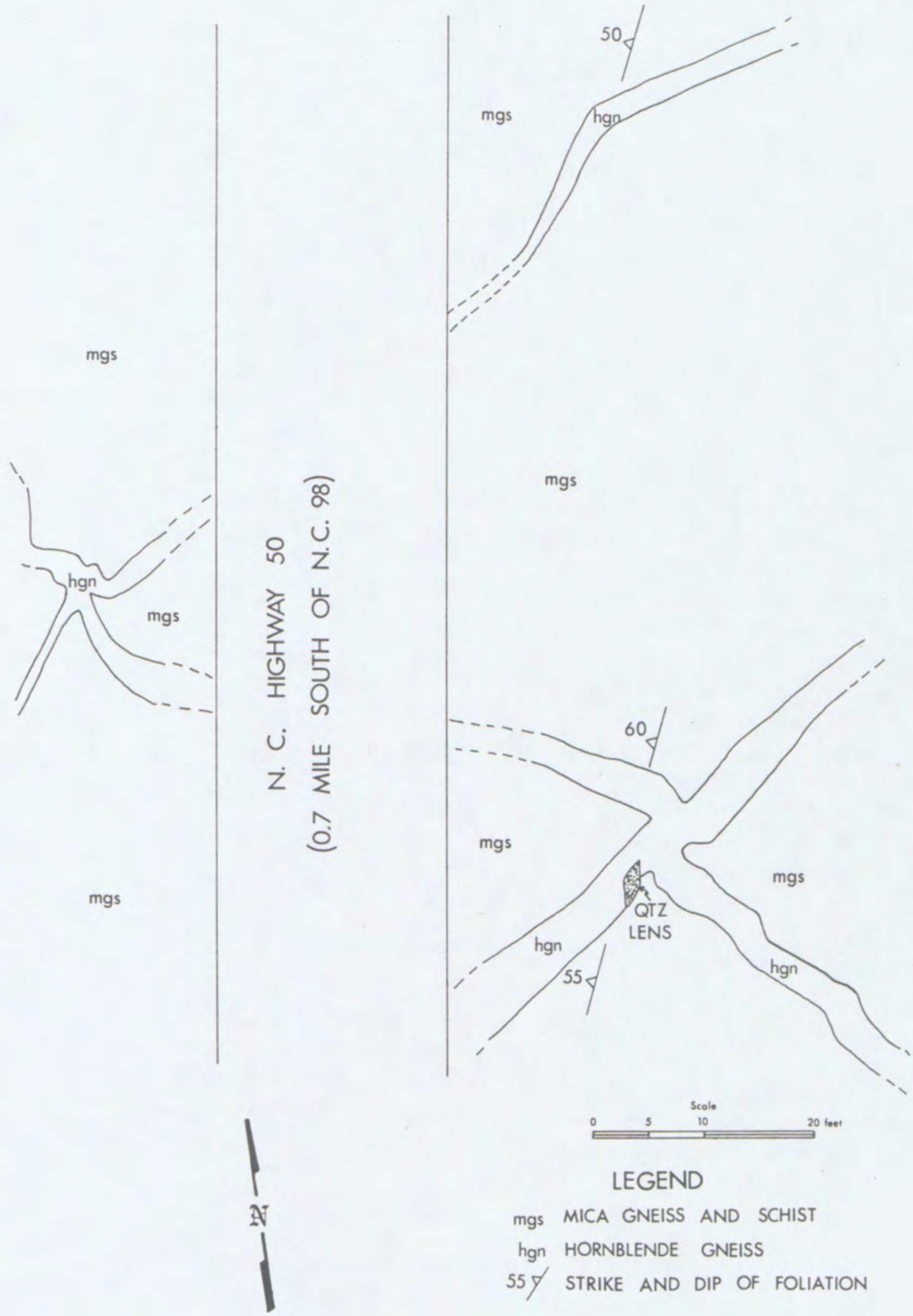


Figure 5. Dike of hornblende gneiss in mica-garnet gneiss; roadcut of N. C. Highway 50, 0.65 mile south of intersection with N. C. Highway 98, northern Wake County, N. C.

vast majority of occurrences. They give the impression of being parts of a continuous sequence of deposits. A few discordant examples were described as early mafic dikes.

Fresh hornblendic rock is black with varying proportions of light colored streaks of feldspar and/or quartz. Hornblende composes 60 percent or more of the rock. Sodic plagioclase and quartz may occur in roughly equal amounts or either mineral without the other. Epidote, clinozoisite, biotite, chlorite, and sericite are common. Sphene, apatite, and opaque grains are usual minor components; garnet is rare. Quartz grains commonly are equant, somewhat rounded, and of roughly the same size, thus suggesting a detrital origin.

Weathering transforms the rock to plastic, limonite-stained clay, almost without grit. If biotite is present, the flakes become a lusterless golden brown. Black spots and streaks of iron-manganese oxides are common. Pieces of saprolite resemble old weathered bricks. Black-coated, slickensided fractures are especially common in amphibolite saprolite. Most of the mapping has had to rely on such saprolite.

The conformable and layered mode of occurrence of most amphibolites and their mafic compositions indicate that they were derived from mafic volcanic tuffs or perhaps from silty dolostones. The latter is an especially likely origin for those containing much quartz. The possibility cannot be ruled out, however, that some were originally basaltic or andesitic lava flows. At least one is likely to have been an intrusive gabbroic sill. Geochemical and further petrographic studies are needed, as well as detailed mapping.

The largest amphibolite body mapped is in the southeastern part of the county. This huge crescentic lens (pl. 1) extends from north of McCullers south and southeast along Panther Branch and Middle Creek far into Johnston County. Its maximum outcrop width is about 1.5 miles, and its length in Wake County is about 10 miles. Much of this body is covered with Coastal Plain sediment, so it is little known. Its mapped outline depends in part on aeromagnetic data (pl. 2) described later. It lies along the boundary between a mica gneiss and schist unit to the east and the felsic gneiss unit and Kennebec phyllite sequence to the west. For convenience of reference it is here called the Panther Branch amphibolite. It has high magnetic values, reaching a maximum of more than +500 gammas near the intersection of N. C. Highway 42 and SR 1006 (Old Federal Road), by far the highest value in the county. The magnetic intensity drops abruptly in the next 1.5 miles southeastward to a low of -385 gammas, the minimum value in the county. Its unique magnetic strength points to a high content of magnetite and a probably igneous origin. It may have been a sill of gabbro or perhaps a mass of basaltic lava flows. Its strong magnetism suggests the possibility of an iron ore deposit.

Two other mapped amphibolite lenses occur in the belt of mica gneisses and schists west and southwest of Raleigh. The Turkey Creek body, largely in eastern Umstead Park (pl. 1), trends north-south and lies just west of the felsic gneiss belt. It is about 5 miles long and 0.5 mile wide. The rock is like the hornblende gneiss layers previously described in this belt but not mapped separately. This lens has no magnetic expression (pl. 2). It extends across a broad magnetic low in which the weak trends are east-west. This rock is likely to have been silty dolostone or perhaps volcanic tuff.

The Camp Branch lens between Apex and Macedonia extends southward from near U. S. Highway 1-64 to about the junction of Camp Branch and Middle Creek. Its maximum width is about 0.7 mile and its length 6 miles. No outcrops of hard rock were observed in this lens, so its petrographic nature is unknown. It is expressed on the aeromagnetic map (pl. 2) as a distinct ridge-like high with 100-200 gammas relief. It is speculated that this lens was a basalt flow.

Along upper Hare Snipe Creek east of Leesville and along SR 1826 much of the saprolite is dark, reddish brown, featureless plastic clay. This may have been derived from amphibolite, but outcrops have not been found adequate to identify the rock.

Beaverdam Diorite-Gabbro Complex

A complex igneous intrusion consisting largely of quartz diorite and hornblende gabbro lies in northwestern Wake County adjacent to the Triassic belt. It extends (pl. 1) from the Granville County line southwestward along Little Beaverdam and Beaverdam Creeks, across Neuse River and into the headwaters of Upper Barton Creek, partly in eastern Durham County, a distance of some ten miles. The northwest side and northeast end are cut off by the Jonesboro fault east of N. C. Highway 50. To the southwest the intrusion splits into several tongues with nearby lenticular sills. Its maximum exposed width is about one mile. Its structural position relative to the enclosing rocks indicates that the bottom is the southeast side.

The 1958 geologic map of the state shows in this area a small body of granite adjacent to a dunite mass, reflecting the brief reconnaissance mapping available at that time. Charles (1959) mapped part of the complex as sheared diorite and part as basic schists. Dickey (1963) showed the southeast edge of this body as granodioritic gneiss, at the northwest corner of his geologic map. May and Thomas (1968, fig. 5) showed much of the area as granodiorite with two adjacent soapstone bodies.

The complex varies in composition considerably and abruptly but seems to be generally more mafic to the northeast. Parts are quartz-rich and felsic, while elsewhere large masses of coarse hornblendite and actinolitic soapstone occur. Xenoliths are numerous. These variations have not been mapped in detail but, where known, the location of ultramafic rock is indicated. Comprehensive petrographic study is lacking. On the aeromagnetic map, the complex is marked by a string of lows less than -300 gammas. The complex provides an interesting topic for future detailed investigation.

The northeastern part of the complex in the Little Beaverdam Creek area east of SR 1906 seems to be chiefly hornblende gabbro. The rock is medium to coarse grained, dark green to black, partly massive, and partly with distinct foliation due to streaky distribution of minerals. Typical rock is chiefly hornblende with subordinate plagioclase. Clinopyroxene, orthopyroxene, and sphene are minor constituents. Opaque minerals are scarce. The rock is much altered to clinozoisite, epidote, chlorite, and actinolite.

A preliminary petrographical and chemical investigation of this northeastern part of the complex has been made by Spence and others (1976). They found that most of this part is mafic gabbro originally made up of pyroxene, now altered to hornblende, and calcic plagioclase, now transformed to oligoclase and clinozoisite. Five northeast-trending zones of pyroxenite, now altered to hornblendite, were distinguished but proved too poorly exposed to trace along strike. A series of samples collected along a 2500 foot line extending northwest from SR 1907 were analyzed by X-ray fluorescence. Chemical and petrographic data indicated that at least this part of the complex may be a rhythmically layered differentiated gabbroic intrusion. Parent magma composition was comparable to high alumina basalt with tholeiitic tendencies.

Farther to the southwest, from the vicinity of SR 1906 to Neuse River, the complex becomes more felsic. Dark gabbroic rock gives way to greenish diorite (?) with white feldspar grains. Quartz-bearing types become increasingly abundant southwest of Little Beaverdam Creek. Much of the rock looks in the field like granite and probably is felsic quartz diorite or leucotonalite. Southwest of the intersection of N. C. Highway 50 and 98 the rock is almost entirely quartz diorite or perhaps granodiorite. Definite contacts between the various phases have not been detected.

In the quartz diorite, the mafic constituents decrease to 15 percent or less, and biotite, partly altered to chlorite, takes the place of hornblende. Opaque constituents are minor. Plagioclase is oligoclase partly altered to epidote, clinozoisite, and sericite. Potassium feldspar is almost lacking. In places quartz is inconspicuous, but in general it makes up a quarter or more of the rock. Sphene is very common; apatite and zircon are present in trace amounts.

Inclusions of dark, fine-grained foliated rocks are numerous throughout the complex though perhaps are most common in the southwest half. They range in size from a few inches to many feet in width. Contacts are sharply distinct. The margins commonly are frayed, indented, and crosscut; the inclusions are clearly xenoliths. Where identifiable, they are hornblende schist or amphibolite. They seem to consist chiefly of hornblende and biotite, but they have not been studied microscopically. Some are fairly coarse grained and appear to be transitional to the very coarse hornblendic and related rocks described below. The inclusions resemble many of the greenschist wall rocks along the northwest side of the complex near N. C. Highway 50 and in the projection of gneisses just north of the intersection of N. C. Highways 50 and 98.

Large bands of massive, coarse-grained, hornblende-rich rock occur at a number of localities in the complex, especially near the southeast side. Along SR 1907 half a mile north of Freewill Church are large boulders of coarse ultramafic rock. Some consist chiefly of stubby hornblende crystals up to half an inch thick with little feldspar. Prismatic crystals of black tourmaline about 0.3 inch long occur in places. Other rock has been altered to actinolite, clinozoisite, and chlorite. Brecciated rock containing veinlets is common. Spence and others (1976) interpreted this rock as altered pyroxenite forming the basal layer of the differentiated intrusion. A large crag on the right bank of the Neuse River half a mile south of the mouth of Beaverdam Creek consists of hornblende crystals 0.5 by 1.0 inch with biotite or chlorite. A belt of altered ultramafic rock with actinolite, chlorite, serpentine, and talc crosses N. C. Highway 50 about 0.6 mile north of its intersection with N. C. Highway 98 and extends northeast at least half a mile. These very coarse and mafic rocks are likely to be recrystallized xenoliths, though they may in part be igneous differentiates. Some resemble the soapstone-serpentinite farther east and southeast but they are believed at present to be distinct.

The spatial relations of the diorite-gabbro complex to its wall rocks and the numerous inclusions of metamorphic rocks in it indicate that the complex was intruded after the initial regional metamorphism or during its late stages (see later section on polymetamorphism). The Beaverdam rocks have more pervasive gneissic foliation than the granitic rocks of the Rolesville batholith, suggesting that the former are more deformed and older than the latter. The widespread change of plagioclase to clinozoisite, the replacement of hornblende by actinolite, and the replacement of biotite by chlorite indicate a later episode of retrogressive metamorphism in the area.

Ultramafic Intrusions

A swarm of dark intrusive rocks characterized by predominance of magnesium- and iron-rich minerals occupies a considerable area in north-central Wake County and adjacent parts of Granville County. They are scattered chiefly over a belt 5 to 6 miles wide that lies east of N. C. Highway 50 and north of Six Forks in the belt of mica and hornblende gneisses. The number and the exact form of individual bodies remain uncertain because of poor exposures. Few contacts are visible and mapping has depended on scattered outcrops and on boulders and float in the soil, found mostly in wooded areas. They are generally conformable to the enclosing gneisses but appear in places to cut across foliation for short distances. At least two dozen bodies are known, ranging in area from a few acres to more than a square mile. The original rocks were peridotite, dunite, and perhaps pyroxenite, but most are now greatly altered, the chief minerals being serpentine, talc, epidote, chlorite, and amphiboles. Alteration in many places is so extreme that the original rock type is doubtful. The general distribution of such rocks in the eastern United States has been shown by Larrabee (1966). Local details are reported by Dickey (1963), Farquhar (1952), George (1939), Norwood (1972), and Stuckey and George (1940).

The altered ultramafic rocks include soapstone, serpentinite, talc-chlorite schist, and actinolite-chlorite rocks. Most individual bodies comprise more than one type of rock, and it has not proven practicable to characterize them individually on the present mapping scale. Dickey (1963, p. 34) found that talc-chlorite schist and soapstone were most abundant and that serpentinite tended to occur along the western portions of the bodies with talc-quartz rock on the east. This distribution, however, is by no means consistent.

The ultramafic rocks constitute sheet-like, lenticular, and bulbous masses, locally conformable to the surrounding gneisses. As a group they strike north or a little west of north due to local folding, while the regional strike is north-northeast. They range in thickness from about 100 to 1000 feet, and some extend lengthwise across country for at least 2 miles. It is possible that some of the longer ones may not in fact be as continuous as is shown on the geologic map (pl. 1) but consist rather of a chain of pods along strike. Some of the lenses near and to the north of N. C. Highway 98 occur in gently dipping rocks, so their mapped widths are much greater than their thicknesses. In fact, the siliceous soapstone body that crosses SR 1919 at 0.6 mile east of SR 1918 seems to be a nearly horizontal plate less than a hundred feet thick underlain by mica gneiss. The ultramafic bodies are characterized magnetically by ovate highs reaching values above +100 gammas at Stony Hill.

<u>Serpentinite</u>. Serpentinite in this area is light green to bluish gray, fine to medium grained, and massive. It consists chiefly of antigorite with variable amounts of carbonate, chlorite, talc, and actinolite, plus relic grains of olivine, augite, and enstatite. Some rock is roughly banded by streaks of chromite and magnetite. Octohedral crystals of chromite as much as 0.5 inch across have been observed on Adam Mountain. A few small veins of cross-fiber chrysotile asbestos have been noted.

<u>Soapstone and talc-chlorite schist</u>. Most of the ultramafic bodies seem to consist chiefly of massive to poorly foliated soapstone. Talc commonly composes half or more of this rock, mixed with chlorite and smaller amounts of actinolite. It is fine to medium grained and ranges in color from dark to light green, depending chiefly on the amount of chlorite present. Carbonates and opaque minerals are common. Actinolite in some rock forms slender prisms 2 or 3 inches long embedded in talc and chlorite. In places, smaller actinolite crystals form rosettes. A little ruby corundum has been found in the body that crosses SR 1842 north of Pleasant Union Church.

Talc-chlorite schist is light green to almost white and is mineralogically like soapstone but has good cleavage due to parallel arrangement of the flaky minerals. It forms outer sheaths of the larger soapstone bodies and is essentially the sole rock in the smaller lenses. It may, in fact, be the most abundant type in the area.

A peculiar quartzose rock occurs in much of the large irregular body that underlies Adam Mountain near Bayleaf. This buff to brown rock consists of fine-grained crystalline quartz (40-60 percent) criss-crossed with veinlets of colloform chalcedony (30-50 percent). Talc, chlorite, actinolite, and opaque grains are minor constituents. Vugs with small quartz crystals are common. Similar siliceous rock crops out prominently on the knob behind Stony Hill Church and in the ultramafic bodies to the west and north. The origin of the siliceous rock has not been determined.

Relatively small bodies of massive chloritite consisting almost solely of medium- to coarse-grained chlorite flakes in random arrangement are encountered in the soapstone. Some veins in the soapstone consist of large chlorite flakes arranged crosswise to the walls. Other veins are quartz containing vugs with tiny quartz crystals. Other small masses in the soapstone consist mainly of coarse crystals of actinolite or hornblende randomly arranged, with more or less chlorite and epidote. These rocks seem to occur in marginal areas and are likely to be altered wall rock. Massive chromite rock is known from the Adam Mountain and the Pleasant Union Church soapstone bodies. Chromite and other potential mineral products obtainable from the ultramafic bodies are described later.

The ultramafic rocks are so highly altered and exposures in place are so few, especially exposures of contacts, that no data are available bearing on the question whether they were emplaced as magma, crystal mush, or solid rock. Their age relative to other intrusions and to tectonic events is uncertain. Because they are confined to the mica gneiss and schist unit, are generally conformable to foliation and layering, and are folded in the same way, they probably formed after the felsic gneiss unit was initially deformed.

The whole group of ultramafic bodies trends north while the Beaverdam Creek igneous complex trends northeastward, so that they converge toward one another at the north edge of the county. They lie on opposite flanks of an anticline. These spatial relations and their partly similar compositions suggest the possibility of a common origin. The two groups, however, are markedly different in magnetic properties. Though southernmost Granville County has not yet been mapped, it is clear that the Beaverdam Creek complex ends at the county line (see pl. 1) while the ultramafics and their wall rocks swing to the northeast and continue beyond the end of the diorite-gabbro complex. Both are cut off by the Jonesboro fault. Tentatively, the two types are regarded as not related in origin, though probably they are not greatly different in age; their relative age is entirely speculative at present.

Granitic Intrusions

Granitic rocks of several kinds make up one large and several small bodies in Wake County. The majority are not granite in the strict petrographic sense, because sodic plagioclase is generally a major constituent, but all of them look like granite and have been commonly so called for readier public understanding. They consist chiefly of feldspars and quartz with varying amounts of mica, and most have typical granular texture. In the strict sense, they are chiefly adamellite but also include granite and granodiorite. Tonalite in the Beaverdam igneous complex (already described) is similar. Most seem to have been emplaced during or after deformation and metamorphism of the region, but a few evidently were emplaced earlier.

The largest granitic mass occupies much of the eastern third of the county (pl. 1). This is part of the Rolesville pluton (Parker, 1968, p. 121-122) that extends farther north and south into adjacent counties. Pegmatite and aplite dikes are numerous in and near this pluton. A granitic lens with an associated group of sills lies northeast of Cary. Similar small bodies are partly exposed east and south of Holly Springs.

Rolesville adamellite batholith. Granitic rocks of several kinds underlie eastern Wake County (Parker, 1937). Together they constitute the southwestern part of a compound pluton some 50 miles long that extends north and south beyond the county boundaries (Parker, 1968, fig. 1). Its western contact extends from Garner to Wake Forest, passing just east of Raleigh. The eastern side is at Zebulon, giving a width of about 15 miles. This body has been referred to as the Rolesville granite by Stuckey (1965, p. 115), named from the town near which an unusually large quarry in this rock was operated for many years.

The east and west contacts are relatively straight or smoothly curving and lie parallel to the foliation of the enclosing metamorphic rocks. The southwestern side from Garner to the Johnston County line, however, is irregular; tongues of granite interfinger with projections of the gneisses. Similar irregularity continues eastward in Johnston County from this point around the southern end of the batholith (Parker, 1968, fig. 1), where a projection of gneisses separates the intrusion into two unequal lobes.

The contacts are to a considerable extent gradational (Dumas, 1959). Many sills of granite are contained in the wall rock gneisses, and inclusions of gneiss are common within the granite. Further, the marginal parts of the pluton, for hundreds of feet inward from the walls, have well-defined planar structure due to streaks of elongate minerals arranged parallel to the walls. The mapped position of the contact was placed, as best as the scanty outcrops permitted, where predominant gneiss was deemed to pass into predominant granite. Granite sills are encountered in the injected gneiss belt as far as 2 miles west of the granite. Exposures to the east of the batholith are too few to give an adequate idea as to the extent of injection by sills; it is certainly less than on the west side because the bordering gneiss belt is much narrower.

The composition of the batholith obviously differs from place to place, by variation in the amount of biotite and in grain size. Typical outcrops are medium-grained, gray rock made up mainly of feldspar with an estimated 25 to 30 percent quartz and about 10 percent biotite. Many exposures have little biotite, however, and some are coarse grained or porphyritic.

Bowman (1969) has shown that most of the pluton south of U. S. Highway 64 in Wake County is adamellite. The ratio of potash feldspar (microcline, orthoclase, and perthite) to plagioclase ranges between 0.46 and 1.5; on the average the two kinds of feldspar are about equal in amount. Total feldspar ranges from 55 to 70 percent. The composition of the plagioclase falls within the oligoclase range, and some shows compositional zoning. Myrmekite is common. Quartz forms 23 to 35 percent of the rock, and accessory minerals, largely biotite, range from 5 to 20 percent, averaging 10 percent. Minor constitutents include muscovite, apatite, zircon, allanite, magnetite, and ilmenite, with a little secondary epidote, chlorite, and sericite. Mineral percentages showed little systematic variation across the area studied, but insufficient sampling has been done to establish this conclusion.

Mertie (1953, p. 18-19 and pl. 1), in his reconnaissance study of monazite in the southeastern Atlantic states, has shown that a belt of monazite-bearing granitic rock extends through the Rolesville adamellite. In Wake County the belt is about 3.5 miles wide and extends from Garner through Milburnie and Rolesville and northeastward into Franklin and Warren counties. Four monazite-bearing localities were found, and 19 barren samples were taken in and outside the belt in Wake County. The granite near Rolesville is reported by Mertie (1953, p. 29) to yield a heavy mineral concentrate made up of 77 percent ilmenite, 16 percent magnetite, 4 percent monazite, and about 3 percent zircon. The tenor of monazite in bedrock is reported as about 0.003 percent.

The splendid exposures in the large Lassiter quarry 2 miles east-southeast of Rolesville make clear that at least two kinds of granitic rock of different ages are intermingled. The older variety is a relatively fine-grained, medium dark adamellite, while the younger is a distinctly lighter and usually coarser granite. The lighter colored and younger rock, however, in some places is finer grained than the older, darker rock. Contacts between the two varieties are sharp and distinct in fresh rock, though not readily apparent in most outcrops. The relative ages are clear because the lighter granite cuts across the foliation of the darker rock, sends dikelets into it, and contains inclusions of it. The lighter and darker rocks are intimately mixed in irregularly tabular masses ranging from a few inches or feet to a few tens of feet in thickness. Most big blocks of rock as thick as 10 feet show some of each type. Both commonly show faint or distinct foliations that are subparallel. The rock in many outcrops, however, is essentially massive. The older and darker rock appears to be the more abundant type, but this has not been established.

Porphyritic rock with rectangular feldspar (microcline perthite) crystals up to an inch long forms irregular masses a few tens of feet wide, with vague gradational contacts. Parallel orientation of feldspar tablets commonly imparts a distinct foliation. The age relation of porphyritic granite to other types is uncertain.

Throughout the batholith a minor but common component is dark, biotite-rich gneissic rock. Some irregular thin streaks appear to be schlieren, in places being a boundary phase between the darker and lighter granitic types. Elsewhere tabular sheets of uniformly layered or laminated gneiss suggest that they are inclusions or septa (screens) of metamorphosed bedded sediments. Thin sheets and isolated angular patches of coarse-grained biotite schist are likewise common, even in the interior of the pluton. Inclusions of hornblende gneiss are comparatively rare.

Muscovite granite in which biotite is lacking or subordinate to muscovite occurs at many places in a zone extending some 6 miles southward from Wake Forest. This granite forms much of a separate forked lens (pl. 1) at Wyatt that lies about half a mile west of the Rolesville batholith; similar rock is encountered in the western part of the main pluton. The rock is medium grained, massive, pink and gray and commonly has considerable garnet. Some rock is almost free of micas and has more than the usual amount of microcline. Contacts of the muscovite granite with other types within the batholith have not been seen, so relationships are conjectural. The Wyatt lens is described further in connection with quarrying.

The internal structure of the Rolesville batholith is complex, and further study is needed to clarify the details; indeed, the scarcity of outcrops may make this impossible. The variety of rock types observed in the good exposures described above shows that the batholith grew in at least two stages by injections of magma into previously consolidated and fractured granitic rock, forming irregular masses of varying sizes. As far as is now known, these earlier and later rock masses are generally elongate in a northerly direction.

Planar features in the batholith include schlieren, parallel orientation of mica flakes in homogeneous (non-laminated) rock, wall rock inclusions, and contacts between earlier and later phases; the orientations of these elements at numerous sites are plotted on the geologic map (pl. 1). The great majority of these trend north-northeast and dip steeply (70 to 90 degrees) both eastward and westward. Dips of 40 degrees or less are most exceptional. The strike of these elements for 2 miles inward from the east and west contacts is mostly about parallel to those contacts. Toward the southwest the granitic foliation swings southeastward, a change that corresponds with the contact at the southwest end of the pluton in the adjacent parts of Johnston County. Near Knightdale a considerable area shows northwest and east-west trends, constituting a swirl, possibly related to the lobate southern end of the intrusive.

The variation in gravity within and near the outcrop area of the Rolesville batholith has been investigated by Glover (1963), who prepared a Bouguer gravity anomaly map and ten gravity profiles. The regional gravity variations are available from Mann (1962) and U. S. Air Force (1968). Glover showed that the batholith corresponds with a low gravity area; that is, the granite is less dense than average crustal rocks. The lowest values lie near Wendell. The western and southwestern contact of the pluton corresponds closely with the -10 milligal isanomaly line, while the eastern side lies near the -30 milligal line. Glover regarded the large area of negative gravity values as evidence that the pluton is a true magmatic granite intruded from plutonic depths, rather than granitized upper crust. The fact that the gravity low is near the east side of the batholith was interpreted as indicating that the pluton dips eastward; the gravity profiles are unsymmetrical and tend to confirm this interpretation. The deepest part of the pluton near Wendell was computed (Glover, 1963, p. 33-34) to extend downward 45,000 to 50,000 feet.

Butler and Ragland (1969, p. 174) classified the Rolesville batholith as probably syn-tectonic and syn-metamorphic. Its relation to metamorphic zones is discussed later. The batholith has not yet been radiometrically dated.

Pegmatite and aplite. Pegmatite and aplite dikes and sills are encountered in almost all sizable outcrops in the eastern half of Wake County. They are most abundant in the Rolesville batholith and in the injected gneisses on both sides but are also common in the eastern part of the belt of felsic gneisses that extends through west Raleigh. The majority of the pegmatites are a few inches or a few feet thick, though some thicknesses are 50 feet or more. Most aplite bodies are less than a foot thick and are commonly a part of or offshoots from pegmatites. The larger pegmatites seem to occur in the western half of the belt of injected gneisses and the adjacent part of the felsic gneiss belt, but this is not firmly substantiated.

Most pegmatites in the gneisses are tabular and concordant with the steeply dipping layers, though they crosscut in detail. Many pinch and swell. They generally trend northward, but a few strike about east-west. Essentially all are vertical or steeply dipping. Discordant and highly irregular pods are also common. The larger pegmatites commonly fork at their ends into several thinner dikes that ramify in an irregular network through the wall rock. Inclusions of gneiss are abundant in marginal and terminal areas. In the Rolesville batholith pegmatite dikes criss-cross the adamellite and one another in all directions, forming an intricate network. Most of these are only a few inches thick, but a few are as much as 2 feet thick.

Most pegmatite contacts are sharply distinct. Where they cut obliquely across gneissic layers or across granite sills and quartz veins, these features are commonly offset perpendicularly to the contacts, thus indicating that the pegmatites are dilation dikes. Space for the intruded material was made by separation of the walls of a fracture (fig. 3). In many instances, however, contacts of smaller pegmatites are irregular and gradational, and the opposite walls do not fit one another. Sterrett (1923, p. 268) reports that an irregular pegmatite in granite at the Coggins mine 3 miles southwest of Wake Forest graded "into the surrounding granite by diminishing coarseness of texture." These latter observations suggest that space has been provided in part at least by replacement of host rock.

The great majority of pegmatites are of simple mineral composition, being made up mainly of pink or brown perthitic microcline (estimated about 60 percent) with quartz (25 percent), smaller amounts of white plagioclase, and a little mica. Biotite is present in many pegmatites, commonly forming narrow strips several inches long; in some it is concentrated along the edges. Muscovite is less common, but some pegmatites in the vicinity of Wake Forest carry muscovite books up to 5 inches wide and even a foot wide, rarely. Garnet is found in many pegmatites in small amount. A little beryl and tourmaline are present in pegmatites west of Wake Forest. Secondary epidote and carbonate are rare.

A second variety of pegmatite occurs at the Greshams Lake quarry, made up of gray plagioclase and quartz with a little muscovite. It is much less common than the microcline-bearing type and forms dikes about 6 inches thick that cut sharply through the microcline pegmatites as well as through the gneiss.

Grain size varies with thickness of pegmatite, the larger ones having some microcline crystals nearly a foot thick. Large blocks having graphic intergrowth of quartz in microcline are not uncommon. Much pegmatite is rudely foliated by streaks of biotite. Pegmatites usually have finer grained border zones a fraction of an inch thick, often showing a tendency to comb structure. Dikes 2 feet or more thick commonly have central pods of gray quartz. Those pegmatites having potential economic importance for production of mica or feldspar are described in a later section.

Aplite is much less common than pegmatite but is closely associated with it. Some dikes contain both aplite and pegmatite irregularly intermingled. Both also occur in separate dikes in the same outcrop. Some larger aplite dikes have pegmatitic border zones, and some small ones have pegmatitic cores. Discordant aplite masses of irregular shape commonly have gradational contacts and contain distorted, vaguely defined gneissic inclusions. Pegmatite cuts aplite in places; elsewhere aplite cuts pegmatite, indicating that both formed during the same intrusive episode.

In the belt of injected gneisses, granitic sills cut across quartz veins, while pegmatites cut across both quartz veins and granitic sills. The relative ages here, then, are gneisses oldest followed in decreasing age by quartz veins, granitic sills, and pegmatite plus aplite. In some outcrops of adamellite, on the other hand, thin quartz veinlets cut across pegmatite and aplite; these quartz veinlets must be younger than most of the veins in the metamorphic rocks and presumably of igneous origin.

<u>Reedy Creek adamellite lens and sills</u>. A small lenticular pluton of adamellite lies about 2 miles northeast of Cary in the Reedy Creek section (pl. 1). It trends nearly north-south, is 3.5 miles long and up to 0.8 mile wide. Its north end extends a little north of Crabtree Creek in W. B. Umstead State Park (Fortson, 1958) and its southern tip just reaches N. C. Highway 54. Interstate Highway 40 crosses near its middle. The mapped outline of the pluton conforms to the local foliation of the enclosing gneisses, but no actual contacts have been observed.

Sills of similar rock in great numbers have injected the adjacent gneisses for a known distance of 1.5 miles eastward and at least 4 miles to the north. They have not been observed to the west and south. The sills range in thickness from less than a foot to at least 100 feet. They are too small to be shown in the accompanying geologic map (pl. 1), but local detail is given by Fortson (1958, p. 58-61 and pl. I).

Contacts of the sills are usually knife-edge sharp, in part straight and parallel to foliation of the wall rocks and in part minutely irregular and discordant. Locally the contacts are gradational over a few inches width. In places small irregular dikes extend outward from the sills. These relationships are well exposed in the spillway below High Rock Lake in Umstead State Park.

The adamellite is a medium-grained, gray rock of granitic aspect, consisting mainly of feldspar and quartz with variable amounts of mica. Much of the rock in the smaller sills is fine grained and commonly somewhat foliated. Feldspar makes up about 60 percent of the rock and includes approximately equal amounts of oligoclase and microcline. Some myrmekite is present. Quartz forms from 30 to 40 percent of the rock. Both muscovite and biotite are present, the former appearing to predominate. Mica flakes lie roughly parallel to one another in much rock, imparting a faint planar structure. Magnetite and apatite are minor constituents. A little epidote and chlorite occur in patches of biotite.

No pegmatite or aplite dikes have been observed in association with the Reedy Creek intrusives, though injections of medium- and fine-grained adamallite are numerous in the vicinity. Some of the latter at the High Rock spillway have small pegmatitic patches.

The Reedy Creek lens lies in the belt of mica and hornblende gneisses and schists with low magnetic intensity (pl. 1). Its outline is not distinguishable on the aeromagnetic maps.

Granitic sills occur throughout most of the interval between the Reedy Creek lens and the southwest end of the Beaverdam igneous complex, thus suggesting the likelihood that all these intrusions are genetically related.

Buckhorn Creek granitic stock. A small granitic stock is partly exposed along Buckhorn Creek in southwestern Wake County adjacent to the Harnett County line; it lies west of Wilbon and north of Duncan. Its eastern and southern sides are largely covered by overlapping Coastal Plain sediment, so the overall shape is uncertain. It extends northeastward about 3 miles and ranges in width from about half a mile to more than a mile. The western contact appears to be a comparatively smooth curve. The stock seems to come to a rounded point at the north but widens in an abrupt bulge in the southern third. It probably extends southward only a short distance into Harnett County. Good exposures may be seen along Buckhorn Creek just north of SR 1119 and along the Norfolk and Southern Railway for nearly a mile west of SR 1119. The stock occurs in the metavolcanic and metasedimentary rocks of the Cary sequence. It has developed a narrow contact metamorphic aureole of medium-grained gneiss and schist.

Most of the stock consists of medium-grained, gray, massive biotite granite or adamellite. Near the middle of the west contact, the rock is variable; it includes dark rock with irregular biotite streaks, as well as some finer grained, light rock, giving the impression of local contamination by adjacent iron-rich phyllite. Hornblendic granite is found near the north end on the east side. A poor, irregular foliation exists in places.

Joints are numerous in some outcrops, but generally the rock is massive and unbroken. Many joints contain films of epidote or thin quartz veins. A few larger quartz veins as much as 3 feet thick are evidenced by loose blocks protruding through the soil.

Three exploratory diamond drill holes were put down in early 1970 in the southwestern part of this stock to test the area for possible underground storage of liquified petroleum. The cores are preserved in the core depository of the North Carolina Geological Survey Section. Most of the rock is typical, medium-grained granite with a few small quartz veins and biotite schist inclusions as much as 18 inches thick.

This stock is marked by a rudely triangular positive magnetic high reaching a peak of +138 gammas. It must be different from the other granitic bodies that have negative magnetic values.

During reconnaissance mapping in connection with preparation of the 1958 Geologic Map of North Carolina, the author correlated several poor exposures of granitic gneiss just west of Fuquay-Varina with the Buckhorn granite. These combined with other exposures in northern Harnett County were shown as a single intrusive largely covered by sediment. More detailed study since then indicates that the Buckhorn rock is distinct from the others, which are felsic metasedimentary gneisses.

Sunset Lake stock. A small poorly exposed stock lies 1.5 miles east of Holly Springs. Granitic rock may be seen in the spillway below the dam at Sunset Lake and along SR 1393 southeast of Bass Lake. Aplite crops out along SR 1152 west of Middle Creek. The body is so largely covered by the lakes, floodplain alluvium, and Coastal Plain sediments on the uplands that its form and extent are not known. The aeromagnetic map (pl. 2) shows a pronounced north-trending magnetic trough here that reaches a minimum of -353 gammas; it covers less than one square mile.

Quartz Veins

The most commonly observed rock in Wake County is vein quartz. Chunks of hard white crystalline quartz abound in the soils across much of the county, and most road cuts show hard tabular quartz veins extending up through various weathered rocks. The abundance and obviousness of vein quartz results from the tremendous number of veins in the region and the resistance of quartz to weathering, as well as its conspicuous light color.

Veins of quartz occur in place throughout the crystalline area of metamorphic and igneous rocks but are completely absent from Triassic sedimentary rocks and the various upland sediments. Quartz pebbles derived from erosion of veins in the crystalline rocks are important components of the later sediments. Because of their small size and lack of continuity, the quartz veins could not be traced, and most are not mapped (pl. 1).

Quartz veins fill fractures in the enclosing rocks. The contacts are sharp and vein material breaks away cleanly from the host rock. Rarely, where a vein forks, a piece of wall rock is enclosed. Veins range in thickness from a small fraction of an inch to at least 7 feet. Many are tabular and uniform in thickness for tens of feet; others are highly irregular pods. A prominent vein in a road cut on one side commonly does not appear on the opposite side. In the quarry 1.5 miles southwest of Falls, quartz veins may be seen to pinch out both upward and downward, as well as along strike.

Most veins dip steeply, but low dips are not rare. In foliated rocks, veins usually are discordant, but many parallel the schistosity. Irregular, cross-cutting, pod-like veins often occur in places where foliation has been locally buckled and broken. Dickey (1963, p. 37) reports an unusual instance of an aphanitic quartz vein cutting across two phaneritic veins.

Quartz veins are most numerous in quartz-bearing gneisses and schists. They are less common in the more mafic rocks such as hornblende gneiss, amphibolite, and greenstone. Thick veins (2 to 4 feet) seem to be especially numerous in the Cary sequence rocks a little east of the Jonesboro fault, as was noted by Prouty (1931, p. 483). The largest vein encountered in the county is in the belt of felsic gneisses near the graphite zones. It is located 1.1 miles S. 10° W. of Six Forks and about 700 feet east of Lead Mine Road (SR 1820). The vein is 7 feet thick and traceable for some 300 feet. Veins are less numerous and thinner in adamellite than in the gneissic areas.

Vein quartz ranges from clear to white to gray to smoky; iron stain from weathering is common. A little amethyst has been found near Wilders Grove in the adamellite. Quartz constitutes all but a fraction of one percent of the veins. The rock consists of a mosaic of interlocking quartz particles that usually are 0.1 inch or less wide. Normally all space within the vein is filled but irregular small vugs are not uncommon. These vugs are lined with roughly parallel, subhedral to partly euhedral, quartz crystals forming comb structure. The interiors of the vugs are often coated with thinly laminated buff chalcedony. Fairly good crystals with good terminations at one end have been obtained in the upper House Creek valley and in the Six Forks areas. The largest quartz crystal known to have been found in the county is 19 inches long and 8 inches thick; it was collected about 1947 from a prospect pit near the Thompson mica mine (described later).

In addition to quartz, the most common mineral in the veins is probably muscovite. This is usually in tiny scaly flakes but also occurs in flakes and rough crystals up to 0.5 inch in width. Coarser muscovite is seen at intervals in a belt extending from near Macedonia through the State Fairgrounds to the Deblyn Park area. Feldspar appears in places, especially near pegmatites. In the graphitic belts, graphite is present in a few quartz veins. Tourmaline occurs in some veins through the middle of the metamorphic belt. Gray and blue kyanite are present in some veins in rocks of appropriate metamorphic grade (described later). Platy crystals of ilmenite and small amounts of pyrite and chalcopyrite are observed in a few places. Vein-like quartz-epidote masses are abundant in mafic rocks.

Quartz veins in the Crabtree quarry northwest of Raleigh contain an interesting and unusual suite of minerals. The quarry is just north of Crabtree Creek and west of SR 1664 (Duraleigh Road). The host rock is a distinctive quartzose felsic gneiss largely composed of quartz disks; it is believed to be a meta-arkose containing deformed pebbles. The quartz veins and pods are small and irregular in form, in places branching into veinlets and enclosing gneiss fragments. Maximum thickness is about 6 inches and length rarely more than 10 feet. They pinch out both horizontally and vertically. The most common veins consist of quartz alone or of quartz with flakes and small crystals of muscovite and irregular masses of carbonate. Most of the quartz is gray or smoky. Slender, tapering crystals of clear quartz extend into rare vugs. The dark muscovite crystals are perfectly formed hexagonal books ranging up to half an inch wide. The carbonate ranges from white to buff to brown to greenish brown in color and probably is ankerite. Slender black tourmaline crystals up to about 0.1 inch in diameter and 0.5 inch long are also fairly common in the veins. Some tourmalines are broken and slightly displaced, and the gaps are filled with quartz. Less common are masses of mixed sulphide minerals with quartz; rarely these have a little muscovite and carbonate. This material is pockety and is usually disseminated a few inches into adjacent gneiss. The sulphide masses are mostly an inch or two thick and a foot long. The sulphide minerals are chiefly pyrite and chalcopyrite. Of special interest are the rare antimony and bismuth species; these include tetrahedrite, bismuthinite, kobellite, jamesonite, cosalite, and aikinite. Harris and others (1968, p. 371-382) investigated the kobellite and determined chemical, crystallographic, and optical details. Other minerals reported by competent mineral collectors include galena, molybdenite, gold, garnet, monazite, apatite, rutile, and possibly albite and barite.

The quartz veins are sharply discordant to foliation in the metamorphic rocks. They have not been deformed, though they are fractured, and some are slightly offset by eastward dipping thrust faults. In the gneisses some quartz veins are cut through by pegmatites; hence, they were formed prior to the intrusion of the Rolesville batholith. The lack of continuity both horizontally and vertically of the better exposed veins argues for a local rather than a deep seated source of the quartz. From these considerations it appears that most quartz veins in the metamorphic rocks were formed as late concentrations of silica released during metamorphic recrystallization. They are to be regarded as a special part of the rocks that enclose them rather than as later introduced material. In granitic rocks, on the other hand, quartz veins cut through pegmatites, as may be observed at the Teer quarry 3 miles southwest of Wake Forest. Such quartz veins presumably represent the last fluid phase of the intrusive magma. Though quartz veins in the gneisses near the batholith must be of two different ages and origins, no petrographic difference has been recognized.

Because of their small size and lack of economically valuable minerals, the quartz veins have not been mined. Their only present monetary value is as a sporadic source of mineral specimens.

STRUCTURE AND METAMORPHISM OF THE CRYSTALLINE AREA

The old rocks of the crystalline area in Wake County have undergone deformation and recrystallization during regional dynamothermal metamorphism of the Piedmont province. They display a series of structural and petrographic features acquired at various stages in their long history. Some are primary features formed during accumulation of the original sedimentary and volcanic deposits, apparently during Late Precambrian or Early Paleozoic time. Other features were superimposed by subsequent tectonic deformation, by intrusion of several kinds of magma, and by recrystallization during regional metamorphism. Still others resulted from later crustal movement, probably during several periods of time. The relative ages of most of these features at any one locality are generally definite, but the age equivalence from place to place is not always clear. The absolute ages of the rocks and structures are considered in a later section of the report.

Structures and petrographic features that may be seen in individual rock samples and outcrops are described first, and then the larger aspects that may be deduced from their spatial distribution are outlined.

Foliation and Lineation

The planar and linear features considered in this section include:

1. Primary stratification or layering in metasedimentary and metavolcanic rocks (designated conventionally as S_1, the subscript indicating sequence in time of origin).
2. Bedding schistosity (S_2).
3. Flow cleavage parallel to axial planes of minor folds (S_3).
4. Strain-slip cleavage (S_4).
5. Lineation due to parallel orientation of elongate minerals and mineral streaks (L_1).
6. Lineation due to axes of minor folds in gneiss and of crenulations or chevron folds in schist and phyllite (L_2).
7. Lineation from traces of bedding on flow cleavage (L_3).

Several of these structures result from close folding and crenulation of earlier planar features and are not present throughout the county. The most widespread structures are bedding and bedding schistosity. Only preliminary consideration of these features and their tectonic significance is possible now. Quantitative petrofabric investigations are needed.

Stratification (S_1). Most of the metamorphic rocks are distinctly stratified; that is, layers of differing mineral composition or grain size, or both, succeed one another through the rock mass. In places mica schist is interbedded with quartz-microcline gneiss, graphitic schist alternates with graphite-free rock, or hornblendic layers alternate with micaceous layers. Elsewhere layers of quartz-feldspar gneiss differ only in percentage of mica. Thicknesses of layers range from less than an inch to many feet. In the phyllites distinct laminations only a tenth of an inch thick seem to vary in color only. The uniform thickness throughout the lateral extent of each layer points to a stratigraphic origin during deposition of sediment or a sequence of volcanic and sedimentary units, even though the present mineralogic composition must have been acquired during later events.

Bedding schistosity (S_2). Flaky and platy minerals compose important fractions of most of the metamorphic rocks. Mica or chlorite flakes, flat disks of quartz and feldspar, and hornblende needles are oriented with longer dimensions parallel to one another and to the layering, thus giving the rock a good cleavage. This bedding schistosity occurs both where the rocks lie nearly flat as well as where they dip steeply. Both layering and schistosity are parallel to one another at numerous localities of low dips along the crestal belt of the Raleigh anticline (described later). Quartzitic gneiss at the old Tucker graphite mine on Lead Mine Road (SR 1820) just north of Lynn Road (SR 1812) has isoclinal folds with flank lengths of a few feet. At the hinges of the folds, the mica flakes follow around the flexed bedding rather than paralleling the axial planes. In many places where laminated schistose rocks have been finely crenulated, mica flakes may be seen by both macro- and microscopic examination to bend around the folds.

The parallelism of the stratification with the mineral orientation plane indicates a genetic dependence of the latter feature on the former. As the rock recrystallized during metamorphism the flaky and prismatic minerals grew preferentially parallel to bedding, perhaps imitating the orientation of primary clay flakes and detrital micas, and in part responding to the restraint of gravitational pressure perpendicular to bedding. Whether this could have occurred under static burial pressure, or required initial deformational stretching parallel to bedding as folds developed, remains uncertain. Tentatively, then, it is suggested that bedding schistosity was developed prior to or early in the deformation of the area.

Axial plane flow cleavage (S_3). Cleavage at an oblique angle to layering occurs in some laminated felsic gneiss that has been closely crenulated. This may be best observed in outcrops along Blue Ridge Road just west of its junction with U. S. Highway 70 south of Crabtree Creek. Thinly laminated quartzitic gneiss has been wrinkled into folds less than an inch wide. Mica flakes lie parallel to the laminations in much of the rock but in the sharp fold hinges they are oblique to layers and parallel to the fold axial planes. This has imparted only a slight tendency of the rock to cleave parallel to the axial planes; the bedding schistosity still predominates.

Similar oblique relationships between cleavage and bedding are observed rarely in the phyllite east of Zebulon and in western Johnston County. At the Privette manganese prospect (described later), loose chips of phyllite showed traces of bedding on cleavage planes, but rock in place had bedding and cleavage parallel. Likewise, near Hardee some 6 miles east-southeast of the southern tip of Wake County, phyllites have an irregular flow cleavage crossed by laminations. Bedding has been bent so that it lies at various angles to the cleavage.

Axial plane flow cleavage in the county seems to be local and incipient only, separate from and later than the pervasive bedding schistosity generally observed.

Strain-slip cleavage (S_4). Schist and phyllite that have been crenulated show in some thin sections tiny asymmetric folds that have alternate longer and shorter flanks; this has been noted mainly in graphitic schist. Mica has become concentrated in the shorter flanks, and some slip has occurred along the axial planes, thus imparting a slight strain-slip cleavage. This feature has not been much studied and may be more important than is presently realized. This cleavage is likely to have been formed contemporaneously with the axial plane flow cleavage; both are modifications of bedding schistosity.

Phyllite exposed along U. S. Highway 70 just east of the Jonesboro fault near the junction of SR 1837 shows extensive chevron folds. Cracking of the rock along the sharp zig-zag bends imparts planes of weakness. This condition may be related to Triassic movement on the Jonesboro fault.

Mineral lineation (L_1). Strongly lineated quartzitic gneiss is the most striking component of the felsic gneiss belt. The rock is fine grained and equigranular, consisting chiefly of quartz and microcline. Mica occurs in tiny elongate flakes and streaks, rather than in laminations. Though planar schistosity is evident in places, it is mostly obscure and discontinuous. The rock breaks into roughly rectangular prisms parallel to lineation rather than into wider slabs, and the surfaces are roughly corrugated with only discontinuous mica films.

Lineated gneiss is associated, along fold axial belts (described later), with laminated gneiss of similar composition that has complex minor folds. In some of this crumpled rock incipient axial plane cleavage has formed. Though the origin of the lineation is uncertain, the associations suggest that small scale folds have been so tightly compressed and sheared out that earlier bedding schistosity has been disrupted, leaving only linear remnants in the recrystallized rock.

The quartz prism gneiss that lies east of the quartz disk gneiss has a similarly oriented lineation resulting from the myriad roughly prismatic quartz aggregates. These polycrystalline prisms may have been formed by elongation of quartz disks during close folding.

This lineation (L_1), though the earliest linear feature observed, must be synchronous with the incipient axial plane flow cleavage (S_3), because both seem to have developed as a consequence of local tight folding of bedding schistosity (S_2).

Fold-axis lineation (L_2) Schists and phyllites, and less commonly gneisses, have locally been compressed so that the schistosity has been crumpled and puckered into folds ranging from a fraction of an inch to a few feet wide. The axial lines of these folds provide a lineation that in most localities is near horizontal and parallel to the strike of foliation. This lineation is arbitrarily designated L_2 but doubtless it was formed at the same time as L_1.

Plane-intersection lineation (L_3). Phyllites and schists having axial plane flow cleavage possess a lineation due to traces of bedding on cleavage surfaces. This condition was observed rarely in easternmost Wake County and in northwestern Johnston County. This lineation (L_3) presumably is contemporaneous with L_1 and L_2.

Folds

The broad belt of northward-trending rocks that lies between the Rolesville batholith and the Jonesboro fault is closely folded and has an over-all westward dip; it constitutes the west flank of the Wake-Warren anticlinorium (Parker, 1968, p. 126-127 and fig. 1). The eastern half of this belt is folded isoclinally, and the rocks stand nearly vertically. West of Raleigh they dip westerly (northwest, west, and less commonly southwest). The axis of the Raleigh anticline (Fortson, 1958, p. 82; Parker, 1968, p. 127 and fig. 1) extends about along the line of House Creek, where dips commonly range from zero to ten degrees both east and west (pl. 1 and pl. 3). The fold is outlined by the two graphitic schist belts, each with its two component graphite zones of unequal thickness, which are repeated in reverse order to east and west of the axis. This fold is strongly asymmetrical, the west flank having moderate to low dips and the east flank being essentially vertical.

To the north of Raleigh only the easterly graphite belt is present and the axis is plotted roughly parallel to it through localities of low and variable dips. Near the northern end of the graphite belt, the axis appears to veer westward and may be truncated by unconformably overlying rocks. In the southern half of the county, south of SR 1009 (Old Tryon Road), graphite exposures are sparse and widely spaced, because of broad cover by upland sediment, and the continuity and correlation of graphite schist are less certain. Consequently, to the south the graphite is unreliable in helping to fix the fold axis. The aeromagnetic map suggests it may pass southward about two miles east of Fuquay-Varina and then bend southwestward.

Along most of its length the axis coincides with the belt of felsic gneisses, but near the southern edge of the county it passes into the Kennebec sequence of phyllites. Quartz prism gneiss with nearly horizontal lineation commonly occurs along the fold crest. On its east flank laminated felsic gneiss in places is closely folded. An easily accessible example is in the road cut on Blue Ridge Road (SR 1670) just west of U. S. Highway 70 and south of Crabtree Creek. This locality lies between the two graphitic zones of the eastern graphite belt. The gneiss dips steeply west over-all but is crumpled into many minor folds with flank lengths of a few inches, having axes that plunge about five degrees to S. 15° W. Small scale flowage (similar) folds with right angle to nearly isoclinal bends are noted at a few places. Similarly, mica schist layers within the felsic gneiss unit are locally crenulated with fold axes that plunge usually 0 to 15 degrees, and rarely as much as 40 degrees, to north and to south.

Folding of the Raleigh anticline is believed to have taken place initially before deposition of the mica gneiss and schist unit to the west, because the latter cuts obliquely across the felsic gneiss unit and truncates the graphitic belts. The fold must have been modified, perhaps drastically, by later folding.

An easterly synclinal axis is inferred to lie east of the Raleigh anticline in the belt of felsic gneisses. Its existence is postulated as a necessary adjunct of the anticline on the west flank of the Wake-Warren anticlinorium. It may lie along the belt of strongly lineated quartzitic gneiss extending through Falls, Lassiter Mill, Southeast Prong Beaverdam Creek, Lake Raleigh, and Lake Trojan. This belt coincides with a strongly magnetic linear high that extends into southern Wake County. The lineated gneiss alternates across strike with laminated gneiss of comparable composition, and with minor mica schist and hornblende gneiss, in a belt half a mile wide. The lineation is rigidly uniform in its north-northeast trend and it rarely varies more than five degrees from horizontal. The associated laminated gneiss commonly has tight minor folds with near-horizontal axes. The belt is on the vertical isoclinal flank of the anticlinorium. It is suggested that the lineation formed in a complex of tight folds where minor folds were so compressed, rotated, and sheared out that planar structure was destroyed, leaving only linear remnants or fold mullions. The core of an isoclinal syncline would seem to provide suitable conditions.

This belt of lineated gneiss and the coincident linear magnetic high seem to disappear in southern Wake County near Banks. The synclinal axis tentatively inferred to coincide with them presumably passes southward into the phyllite sequence. A little east of Kennebec a sharp divergence of structural trends occurs, where northwest-striking phyllites bend abruptly to south-southwest and where the rocks commonly are crumpled. The synclinal axis probably lies here and corresponds to the Angier syncline (Parker, 1968, p. 127), which during reconnaissance prior to aeromagnetic mapping was placed too far west in southern Wake County.

The breadth of the folded belt is least in the area west and southwest of Raleigh; it widens in northern and in southern Wake County and the adjacent counties. The narrow stretch of the folded belt near Raleigh suggests that the rocks were crowded from the east by the Rolesville batholith. This crowding might be attributable to magmatic pressure during intrusion of the batholith or to tectonic movement preceding and accompanying the intrusion. The pluton is regarded by Butler and Ragland (1969, p. 174) as probably synmetamorphic and syntectonic in relation to regional deformation.

North of a line from Neuse Station to Leesville the various belts of metamorphic rocks and the west margin of the Rolesville batholith swing more to the east. Where the rocks spread out here, belts of low and reversed dips and loops of the contact between felsic gneisses and the overlying mica gneisses and schists seem to mark diverging fold axes. Two anticlines and an intervening syncline are plotted here (pl. 1). These folds are most evident in the mica gneiss and schist unit. Their axes converge southward and seem not to correspond with fold axes deduced for the crowded area west of Raleigh. The more easterly group of ultramafic bodies occurs in the mica gneiss and schist unit in the syncline, while the western group lies in the same unit along the west flank of the more westerly anticline. The ultramafic bodies are locally conformable, but as a group they trend obliquely counterclockwise from the regional strike because of the divergence of these fold axes.

Certain locally contorted areas seem to be related to the intrusion of granitic magma. In the vicinity of Lake Benson and to the southeast into Johnston County, attitudes of the gneisses vary abruptly from outcrop to outcrop. The western border of the Rolesville batholith in this area bends from south to southeast, and several large projections of granite intertongue with prongs of gneiss. Furthermore, a little farther west, the north end of the Panther Branch amphibolite body at McCullers hooks sharply from north to northeast.

These local small scale folds are presumed to be related to the space required for intrusions. Similar intricate folding is commonly observed elsewhere in the belt of injected gneisses, accompanied by sharply discordant granitic dikes.

Metamorphic Facies

The belt of metamorphosed sedimentary and volcanic rocks extending northward through central Wake County displays a systematic variation in mineral composition that follows the Barrovian-type facies series of regional dynamothermal metamorphism (Winkler, 1967, p. 94-115). Along the west side, a narrow strip of rocks is characterized by chlorite with other compatible minerals stable at lower metamorphic temperatures and pressures. To the east biotite appears in rocks of suitable chemical composition. Still farther east other belts -- characterized by the appearance successively of almandine and hornblende, staurolite, and kyanite -- mark various higher degrees of temperature and pressure of metamorphism. Though the facies sequence is established for the area (Fortson, 1958, p. 83-89; Parker and Broadhurst, 1959, p. 3-5; Parker, 1968, p. 120), the positions of the isograds (pl. 1) are still approximated, especially in the southern part of the county. In this area more than usual difficulty has been encountered in obtaining rock fresh enough for the minerals to be identifiable. Much work remains to be done throughout the county on the microscopic petrography of the rocks and on the chemical variations in feldspars, amphiboles, and garnets.

Greenschist facies. The lowest temperature of metamorphism is represented by rocks of the quartz-albite-muscovite-chlorite subfacies (B 1.1 of Winkler, 1967, p. 95) that occur just east of the Jonesboro fault. These metavolcanic rocks of the Cary sequence are best exposed in western Umstead Park and vicinity, along Coles Branch west of Cary, along SR 1301 just east of the Durham and Southern Railway (about two miles north of Holly Springs), and at Burt. The belt is generally less than a mile wide, though near Cary it may be about 2 miles. It is bounded on the east by the biotite isograd. Kyanite-quartz rock is known at two localities in this belt; one is in the southeast corner of the Raleigh-Durham airport, and the other is just south of the Southern Railway about a mile northwest of Cary. The anomalous presence of kyanite, typically a mineral of higher temperature facies, in the chloritic belt may be due to the presence of unobserved granitic sills related to the Reedy Creek quartz monzonite, many of which are known near that pluton. However, no high temperature aureole has been detected around the Reedy Creek intrusive. These two occurrences of kyanite remain without satisfactory explanation.

The quartz-albite-epidote-biotite subfacies (B 1.2 of Winkler, 1967, p. 98) is marked by the first appearance of biotite. This belt is mostly about 1 mile wide, being limited on the east by the appearance of almandine garnet or hornblende. In northwestern Wake County this subfacies narrows as the garnet isograd swings west of the Beaverdam diorite-gabbro complex.

The highest temperature part of the greenschist facies, that is, the quartz-albite-epidote-almandine subfacies (B 1.3 of Winkler, 1967, p. 101), is marked by the appearance of almandine or of hornblende, depending on chemical composition of the rocks present. It is bounded on the east by the first known occurrences of staurolite, which marks the beginning of the almandine-amphibolite facies. The B 1.3 belt is about 2 miles wide west of Raleigh, but it spreads northward to some 5 miles wide in the northern part of the county. This wider part of the belt has rocks dipping at low angles in many places; it also corresponds with the more eastward bend of the west side of the Rolesville batholith.

Almandine-amphibolite facies. The west boundary of the almandine-amphibolite facies, and of its staurolite-almandine subfacies, is reasonably well fixed by the presence of staurolite in graphitic garnet schist at the junction of Buck Jones Road (SR 1315) and Bashford Road (SR 1314) in southwest Raleigh and also in garnet schist at the dam in Laurel Hills, west of the city. Staurolite has also been identified north of

Falls and near Purnell. In most occurrences the mineral is of microscopic size, so its distribution may well be wider than is now known. Schrader and others (1917, p. 236) in reporting good crystals of staurolite in North Carolina include "northern part of Wake County", so megascopic crystals may exist there at localities presently unknown. No staurolite has been found south of the Raleigh quadrangle; this isograd has been extended southwestward so as to include the kyanitic graphite schist at the junction of U. S. Highway 401 and SR 2753 near Willow Springs. It may be too far east or west. The eastern side of this subfacies has been placed to include staurolite occurrences in graphite schist near the Lake Johnson dam, at Method, at Lake Boone in Raleigh, and on Leesville Road (SR 1820) near Birchwood Drive. This gives a width of 2 to 3 miles. Inadequate knowledge of the distribution of staurolite prevents extrapolation of the eastern boundary farther north or south.

The kyanite-almandine-orthoclase subfacies (B 2.2 of Winkler, 1967, p. 110) is thus separately delineated only in west Raleigh. Kyanitic rocks are known across a width of some five miles in northern Wake County, but this mineral may exist in subfacies B 1.3, B 2.1, and B 2.2. More comprehensive petrographic work is needed, especially in the northern and southern parts of the county. It may be noted that almost all the ultramafic intrusives occur in the B 1.3 subfacies; only half a dozen small ones are in the adjacent part of the B 2.1 subfacies.

The sillimanite grade of metamorphism apparently was not reached in Wake County. This mineral has not been observed, though it has been looked for, but its possible presence cannot be denied. East of the kyanitic rocks lies the belt of gneisses with granitic and pegmatitic injections. This seems to be the culmination of alteration.

Interpretation of metamorphic gradations in the southernmost part of the county is left open. The widespread cover of younger sediment and the thorough weathering of the rocks, mostly fine-grained phyllites, so hamper investigation here that little more than guesswork is possible now. The picture in this area is complicated by the uncertain effects of the Buckhorn Creek pluton. Most of the rocks in the area south and southwest of Fuquay-Varina seem to be in the biotite grade, while near Kennebec and eastward they are chloritic. Southeast of the Banks and Willow Springs vicinity a change in metamorphic facies must occur obliquely across strike of the map units, with the isograds swinging more to the east. This is suggested on the geologic map (pl. 1) by the gradational contact line (hachures) between gneisses to the north and phyllites to the south.

In easternmost Wake County all the rocks are in the greenschist facies. The phyllites are in the quartz-albite-muscovite-chlorite subfacies (B 1.1). Just east of N. C. Highway 39 spessartite garnets occur (see later description of Privette manganese prospect). Farther west, toward Zebulon, the rocks belong to the quartz-albite-epidote-biotite subfacies (B 1.2). It is not certain whether the quartz-albite-epidote-almandine subfacies (B 1.3) was reached here.

Relation to Rolesville batholith. The isograds separating the various metamorphic facies and subfacies approximately parallel the western contact of the Rolesville batholith, changing their trends in conformity with the two principal bends in the contact. This general dependence continues around the southern end and along the east side of the intrusive (Parker, 1968, p. 119-121). The batholith was the locus of highest temperature though not necessarily the source of energy. The deformational structures in the rocks, as well as the large extent and characteristic mineralogy of the zone, clearly indicate that regional dynamothermal metamorphism occurred rather than contact metamorphism only.

The relationship of metamorphism in the Wake County area to that throughout the Appalachians is shown by Morgan (1972). The local area lies along an axis of higher metamorphic grade extending northeastward through the easternmost Piedmont from Georgia into Virginia. This is paralleled to the northwest by two other higher grade axes extending through the inner Piedmont and Blue Ridge belts.

Polymetamorphism

Certain fabrics and mineral relationships indicate that the effects of an earlier metamorphism have been modified by later events. To what extent these successive changes were separated in time is uncertain; some may represent earlier and later phases of one metamorphic event, and some are likely to have been superimposed much later.

The oldest metamorphic fabric is bedding schistosity. Parallelism between compositional layers (S_1) and the preferred orientation of mica flakes and other elongate rock elements (S_2) is observed in almost all outcrops. This is true where the rocks are vertical, moderately dipping, or essentially horizontal. This parallelism is to be expected in isoclinally folded rocks on the flanks of folds, but not at the hinge areas. Even allowing for incomplete exposures, it appears unlikely that no hinge areas would be seen. The impression is gained, then, that the rocks had attained bedding schistosity before they were folded into the Raleigh anticline; the schistosity as well as the layering seem to be arched over this structure. Expert opinion is that strong deformation is required to develop any schistosity (for example, Spry, 1969, p. 209). Local observations, however, suggest that bedding schistosity developed prior to the major folding. The earliest deformation probably resulted only in open folds.

A subsequent, poorly developed axial plane flow cleavage (S_3) along the hinge area of the Raleigh anticline is no doubt a result of tight folding. This asymmetric fold and the axial plane cleavage may have originated during a second tectonic episode.

Kyanite blades in mica schist cut sharply across the foliation in many places. In a crenulated graphitic schist on the east side of Adam Mountain, kyanite blades lie at various angles to the crumpled schistosity and to the axial planes of the microfolds. They are entirely undeformed though in a deformed rock. Post-tectonic crystallization of such porphyroblasts is normal (Spry, 1969, p. 257) and is usually attributed to the last phase of the metamorphic event.

An important aspect of this subject is the timing of the intrusion of the Rolesville batholith. In this body and in the granitic and pegmatitic injections near the batholith are numerous inclusions of gneiss and schist exactly like the wall rocks. Their similarity indicates that the wall rocks were already metamorphosed by the time of intrusion. The Beaverdam diorite-gabbro complex also seems to have been emplaced into metamorphic rocks. On the other hand, the arrangement of the metamorphic facies with respect to the west contact of the Rolesville batholith shows a genetic relation between the intrusion and metamorphic grade. Further, since the batholith was formed in two stages by two contrasting magmas, uncertainty arises as to whether one or both stages were responsible.

It is argued from consideration of these various observations that at least two tectonic-metamorphic events have affected the region. The first is believed to have developed bedding schistosity and some presumably milder folding at a lower metamorphic grade. The second must have accentuated the folds, crowded the middle portion of the anticlinal belt westward, and have been accompanied by granitic intrusion which overprinted higher grade metamorphic effects.

Retrograde Metamorphism

Many individual minerals in both metamorphic and igneous rocks throughout the county have been partly or wholly altered to other minerals formed at lower temperatures. These effects are independent of those brought about by weathering, though in some instances the two are difficult to distinguish. These retrograde, lower temperature, metamorphic alterations seem to be generally distributed across the county and not restricted to possible dislocation belts. They seem not to have been accompanied by any deformation of the rocks. Retrograde effects include the following:

1. Biotite in mica schist and gneiss is replaced by chlorite.
2. Hornblende in gneiss and amphibolite is replaced by biotite.
3. Pyroxene in the gabbro-diorite complex is replaced by hornblende.
4. Garnet is replaced by chlorite plus iron oxide.
5. Kyanite is replaced by muscovite.
6. Olivine and pyroxene in ultramafic bodies have been almost completely transformed to talc and/or serpentine and actinolite.

These retrograde effects probably were initiated by stresses during uplift of the region at various times during late Paleozoic and early Mesozoic periods. An estimate of the total amount of uplift may be derived from a consideration of the physical conditions required for crystallization of constituent minerals in the rocks now exposed at the earth's surface. The minimum pressure of crystallization of kyanite is 5 to 6 kilobars (Winkler, 1967, p. 177; Miyashiro, 1973, p. 72), equal to a depth in the crust of about 20 kilometers. The aggregate uplift, with concurrent erosion, in central Wake County, then, must have been at least 70,000 feet. As the rocks cooled following the last event of progressive metamorphism, they also passed at intervals into lower pressure realms, with partial readjustment of minerals to the changed conditions.

Faults in the Crystalline Area

Faulting has been widespread in Wake County, but with one important exception, the dislocations have been minor. The Jonesboro fault that separated the Triassic sedimentary rocks from the older crystalline rocks is a profound fracture that extends nearly across the state. It is separately described later in connection with the Triassic rocks, as are some small high-angle normal faults in those rocks and transverse faults that affect both Triassic and older rocks. Only those faults occurring within the crystalline area are described in this section. So far as is now known, all such faults have resulted in displacements of only a few feet and hence are too small to be shown on the geologic map (pl. 1). They fall into two categories, low-angle reverse faults and high-angle faults of variable slip. All faulting is younger than the metamorphic events because it offsets metamorphic features and because it indicates brittle reaction to stress rather than the plastic behavior characteristic of metamorphic temperatures and pressures.

Low-angle reverse faults. Many outcrops in the belts of felsic gneisses and injected layered gneisses have fractures dipping eastward at angles of 5 to 40 degrees along which the overlying rock (hanging wall) has been displaced westward and upward. These little thrusts offset quartz veins and pegmatite dikes as well as layering of the gneisses. Dip slip commonly ranges from a fraction of an inch to a few inches and rarely as much as a few feet. The faults are commonly only a few inches or feet apart and are paralleled by other fractures along which no slip can be discerned. In the cut of the railroad spur west of Industrial Drive, about 1200 feet east of the intersection of Old Wake Forest Road and Six Forks Road in Raleigh, at least eight eastward dipping thrusts offset foliation and sills of granite and of pegmatite. In addition, three or more thrusts dip west and seem to end against the eastward-dipping ones. Slip ranges from a few inches to about 2 feet. Similarly, in an excavated area back of warehouses east of the Raleigh Beltline half a mile southeast of its interchange with U. S. Highway 1-401, two west-dipping thrusts offset gneisses about 4 inches (fig. 6). Numerous tiny thrusts are exposed at Enloe High School in the creek bank next to Bertie Drive. The predominant eastward dip of these thrusts toward the Rolesville batholith and their distribution in rocks near it suggest they may be marginal thrusts related to the intrusion in some way (Parker, 1937). They definitely displace the pegmatites, however, so they certainly post-date magmatic processes.

An especially interesting thrust was formerly exposed in the railroad cut at Banks in southern Wake County about 500 feet north of SR 2724 (fig. 7). A southward-dipping, low-angle reverse fault displaced

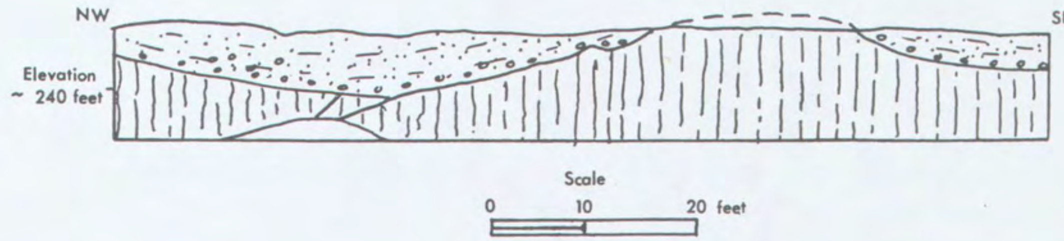


Figure 6. Cross section showing small thrust faults and terrace sediment overlying gneisses; northeast of Beltline and 0.5 mile southeast of North Boulevard, Raleigh, N. C.

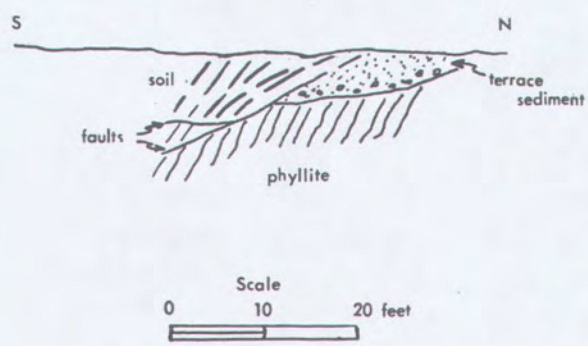


Figure 7. Cross section showing thrust fault in phyllite and upland sediment in railroad cut at Banks about 500 feet north of SR 2724, southern Wake County, N. C.

not only the layering of fine-grained gneiss and quartz veins but also the overlying pebbly sand terrace deposits. Minimum dip slip was about 8 feet. The bottom elevation of the terrace deposit was about 310 feet. This terrace on the north side of Middle Creek is likely to be of Pliocene or Pleistocene age. Though movement on other faults in Wake County may be as recent as this, no other instances are known where observation proves it. This exposure unfortunately has been destroyed by grading. White (1952) described several other similar post-Cretaceous faults in Virginia and North Carolina.

High-angle faults. Minor displacements have also occurred along near vertical fractures in various rocks across the county. Slip has commonly been essentially horizontal (strike-slip), though exposures generally are inadequate to rule out some vertical component. Such faults may be seen in a flat rock outcrop on the hillside northwest of the water filtration plant near Falls about 400 feet south of SR 2010. Two generations of faulting are shown here; quartz veins are offset slightly along a west-northwest fault that was later filled with pegmatite, while an east-northeast fault displaces both quartz veins and the pegmatite.

Vertical joint surfaces in the Lassiter granite quarry near Rolesville and in the Crabtree quarry in west Raleigh have rare slickensided surfaces with chlorite films. No consistent direction of movement is known. The amount of slip is uncertain but probably is a matter of inches at most. In the spillway of High Rock Lake in Umstead Park some fractures in amphibolite have steeply raking slickensides. These little faults presumably record minor readjustments of rock masses during periods of uplift.

Black-coated slickensided surfaces. In saprolite derived by thorough weathering of many kinds of rock, but chiefly in dark micaceous metamorphic types, may be seen numerous black, shiny surfaces that bear prominent grooves. These surfaces are nearly planar to gently curved and dip at low to steep angles. The striations normally rake nearly straight down dip. These surfaces in North Carolina have been investigated in detail by Gupton (1964); many of the data came from Wake County. He has shown that they are unrelated to faults or joints but that they tend to parallel foliation. Though slip has occurred along these surfaces, they are not strictly faults in the tectonic sense. Gupton concluded that they are superficial features representing local shear failure in saprolite formed in response to gravity during the process of weathering and erosion. They are of grave practical importance, however, because they constitute surfaces of weakness in excavated material. Many slumps and landslides in road cuts take place along these slippery surfaces, and fatal accidents in construction trenches have occurred because they were not recognized and shored up.

Joints

Fractures abound in most of the metamorphic and igneous rocks in the county. Many are irregular, rough breaks randomly oriented, but many others are more or less planar joints with locally restricted orientations. Very few joint surfaces display plumose markings or slickensides. Joints are most numerous and consistently developed in the brittle felsic rocks consisting largely of feldspar and quartz, that is, in gneisses and granitic rocks. Some fractures have been filled with quartz veins or pegmatite dikes. Though consistent joint sets are apparent at some outcrops, orientations vary erratically even within small areas. Jointing has not been studied systematically or in detail throughout the county.

Joints range considerably in age. The oldest joints are those filled by quartz veins (described earlier). Most of these trend more or less parallel to foliation, though many are oblique or at right angles. Some are straight for at least several tens of feet, but most are short and irregular. Later fractures that are filled with pegmatite dikes cut through quartz veins at several localities in the belt of injected gneisses. Still younger individual joints cut both quartz veins and pegmatite dikes. Diabase dikes in the crystalline area occupy fractures generally not parallel to the local joints.

The most numerous set of joints, observed generally in the gneisses, strikes on the average about N. 75 ± 10° W. and dips about 80 degrees north. These are transverse joints oriented about perpendicular to foliation (S_2) and to lineation (L_1). A longitudinal joint set striking about N. 5-25° E. with near vertical dip is also common. Many of these contain quartz veinlets, so they are not merely superficial openings along foliation planes. In the Rolesville adamellite, vertical joints striking N. 80-90° E. are prominent. Comparatively uncommon but widespread are scattered joints striking near northeast or northwest with varying dips.

Data are too few to justify any tectonic interpretation at present. Most joints not containing veins or dikes probably formed during times of uplift, long after the rocks were metamorphosed and intruded.

AGES OF METAMORPHIC AND IGNEOUS ROCKS

Determination of the ages of the metamorphic rocks in Wake County involves two questions: first, when were the original sedimentary and volcanic rocks accumulated, and, second, at what time or times were they transformed into their present metamorphic condition? Ages of the intrusive rocks overlap or follow those of their wall rocks. Answers to these questions are tentative at present and depend largely on relations of Wake County rocks to others in the Piedmont region where detailed investigations have been made.

Rocks of the Cary sequence are clearly a part of the Carolina slate belt; they are of the same kind and have been traced along the east side of the Triassic deposits in the Deep River basin to and around its north and south ends into the slate belt. Much recent work in the slate belt gives ages ranging from late Precambrian to early Paleozoic. Glover and Sinha (1973, p. 237-238) report zircon ages of 740 million years (m.y.) for mixed gneiss of volcanic parentage in the Roxboro-Virgilina area and of 620 m.y. for volcanic rocks. In the Albemarle area metarhyolites (Hills and Butler, 1969) have whole-rock isochron ages of 494 ± 14 and 535 ± 50 m.y., while zircons from felsic tuff (White and others, 1963) give ages of 440 ± 60 and 470 ± 60 m.y. Trilobite specimens (St. Jean, 1965 and 1973) are of Early or Middle Cambrian age. These data indicate that interbedded volcanic and sedimentary material accumulated in the region during late Precambrian through about Ordovician time.

Extrapolating this information into Wake County one may presume that the Cary sequence is Ordovician or older and that the higher grade rocks into which they grade eastward are early Paleozoic or late Precambrian. The oldest ones presumably are the felsic gneisses along the axial belt of the Raleigh anticline.

Estimation of the time of deformation and metamorphism in Wake County also depends on regional considerations. Folding in the Virgilina district is dated (Glover and Sinha, 1973) as between 620 ± 20 and 575 ± 20 m.y., that is, late Precambrian or early Cambrian. Careful evaluation of radiometric dates and structural relations in the southern Appalachians has led to the conclusion (Butler, 1972, p. 327) that regional metamorphism in the Carolina slate belt occurred between 520 and about 300 m.y. This is based on whole-rock isochron ages for the metamorphosed Farrington igneous complex (519 ± 125 m.y.) in the eastern part of the slate belt (Fullagar, 1971, p. 2854), the post-metamorphic Liberty Hill, S. C. pluton (299 ± 48 m.y.) on the east edge of the slate belt (Fullagar, 1971, p. 2856), and the post-metamorphic Castalia, N. C. pluton (316 ± 6 m.y.) just east of the Rolesville batholith (Fullagar, in Julian, 1972, p. 36). Evidence from the Charlotte belt places regional metamorphism at around 400 m.y. (Butler and Ragland, 1969, p. 180; Fullagar, 1971, p. 2860; and Butler, 1972, p. 326).

Potassium-argon dating of biotite from the Gresham's Lake quarry in Wake County, in the belt of injected gneisses within 3500 feet of the west side of the Rolesville batholith, gave a 238 m.y. age. Likewise, biotite from similar rocks on strike to the northeast in the Greystone quarry at Henderson gave 259 m.y. (Kulp and Eckelmann, 1961). The reliability of mica ages has been evaluated by Hadley (1964, p. 39), Fullagar (1971, p. 2857), and Butler (1972, p. 329), who conclude that these dates probably record a time of uplift and cooling, and, because of loss of radiogenic argon, may be as much as 100 to 150 m.y. younger than the culmination of metamorphism.

Dating the ultramafic bodies relative to other rocks is especially troublesome. They lie in the belt of mica and hornblende gneisses and schists. Farther north in Granville County, they are in the low-rank, metavolcanic rocks of the slate belt (Carpenter, 1970, pl. 1 and p. 61-66), as well as in higher rank gneisses, and are younger than biotite-quartz diorite. Those in Wake County fall in two metamorphic facies belts; most are in the upper greenschist belt (B 1.3), but a few on the east side extend into the lower part of the almandine-amphibolite facies (B 2.1). All have undergone extensive retrograde metamorphism. The ultramafic bands in the Beaverdam diorite-gabbro complex are petrographically similar, suggesting that these groups are genetically related. The ultramafic bodies are on the west limb of the Wake-Warren anticlinorium and occur in both steeply and gently dipping rocks. The question of the date of the ultramafic bodies remains open, but a middle to late Paleozoic age is likely.

The Beaver dam igneous complex is likely to be older than the Rolesville batholith. Its elongate form and generally gneissic character indicate deformation and suggest a pre- or syn-metamorphic date. It may have been intruded during an early Paleozoic orogeny.

The Rolesville batholith has not yet been radiometrically dated. It has been classified as syn-tectonic (?) and probably syn-metamorphic (Butler and Ragland, 1969, p. 174); my work supports this conclusion. It must be remembered, however, that the batholith is compound, consisting of two types of rock perhaps of substantially different ages. The younger component may be related to the Castalia adamellite (316 ± 6 m.y.).

In summary, evidence seems to favor an earlier period of deformation and presumed low-grade metamorphism, followed by more intense folding, intrusion of the Rolesville batholith, and higher grade metamorphism. From the regional and local picture outlined above, it is suggested tentatively that deposits of late Precambrian and early Paleozoic age in Wake County were initially deformed, metamorphosed, and intruded by mafic and ultramafic masses perhaps as early as Cambrian or perhaps as late as Ordovician time (Taconic orogeny ?) and that these rocks were further deformed, metamorphosed, and intruded by granitic plutons in the Devonian period (Acadian orogeny ?). Retrograde metamorphic effects may be related to late Paleozoic (Pennsylvanian ?) intrusion to the east (Castalia adamellite), to later uplifts during the long period of erosion that formed the pre-Late Triassic peneplain, or to uplifts during post-Triassic intrusion of diabase. Though these interpretations are speculative, they seem to accord with the tectonic history of the Appalachians that is pictured by Rodgers (1970, 1971).

TRIASSIC SEDIMENTARY ROCKS

General Description

Along the western side of Wake County lies a thick sequence of red to gray sedimentary rocks of Late Triassic age. These rocks dip easterly at low angles in most places and are abruptly bounded on the east by the Jonesboro fault. This great fracture extends northeast from near Corinth (in Chatham County) to Holly Springs, then more northerly to pass between Apex and Cary and west of Leesville, continuing to the Neuse River where it resumes a generally northeast course into Granville County (see pl. 1). The Triassic rocks extend 12 to 15 miles westward into central Durham and eastern Orange and Chatham counties. This area of Triassic rocks is the Durham basin, a term applied (Prouty, 1928) to that part of the Deep River Triassic belt lying northeast of its constriction near the Cape Fear River (see 1958 Geologic Map of N. C.).

The Deep River area is one of about a dozen large and small similar belts in eastern North America that extend northeastward from South Carolina to Nova Scotia; additional buried Triassic belts are known beneath the Coastal Plain. The sedimentary rocks composing them have been named the Newark Group (see Russell, 1892) from their occurrence at Newark, N. J. The Deep River basin has been studied in most detail in the Sanford (or Cumnock) basin (Campbell and Kimball, 1923; Reinemund, 1955) because of the minable coal there. Investigations in the Durham sub-basin that are pertinent in part to Wake County include those of Kerr (1874 and 1875), Shearer (1927), Prouty (1931), Johnson and Straley (1935), Murray (1937), Harrington (1951), Davenport (1955), Hooks and Ingram (1955), Ballard (1959), Charles (1959), Grannell (1960), Bain (1966 and 1972), and Custer (1966a, 1966b, and 1967).

The Triassic sediments in the Durham basin were deposited on a land surface formed by prolonged subaerial erosion of the metamorphic and igneous rocks of the region. Structures and topography that resulted from mid- to late-Paleozoic tectonic activity were worn down to develop a peneplain extending across the present Piedmont region. This fairly flat land surface was displaced in late Triassic time by great north-trending faults that created elongate basins in which enormous volumes of sediment were subsequently trapped. The sub-Triassic nonconformity now separates rocks of greatly contrasting character and age. The nonconformity is visible along the west side of the Durham basin but is deeply buried everywhere in Wake County.

Rock Types

The Triassic sedimentary rocks consist almost entirely of clastic types, ranging from conglomerate to claystone. Most of the sediment is poorly sorted, so that specimens contain a wide range of sizes and kinds of constituents. Predominant are silty sandstones and mudstones. Bedding is irregular in form and thickness, and various rock types commonly grade abruptly into one another both laterally and vertically. Coarser types in many places fill scoured channels whose bottoms cut sharply across underlying material. Cross-bedded sandstone is common.

Because of the variability of these sediments throughout Wake County and the extensive and general nature of the present study, it has not been feasible to divide them into formal stratigraphic units. Subdivisions based on gross lithology were made by Grannell (1960) for a strip extending westward from Raleigh-Durham airport. In Wake County he distinguished the Sanford Formation with upper, conglomerate division and lower, sandstone division and the Cumnock Formation nearby in Durham County. In the present report essentially the same three lithologic belts are delineated on the basis of distinctive, though not necessarily dominant, components. The belts recognized are, from east to west, a fanglomerate belt, a sandstone-mudstone belt, and a limestone-chert belt. They are proposed for local convenience and may not be valid at a distance, though they are consistent with studies in the Sanford basin and with a more intensive investigation now underway in the Durham basin (Bain, G. L., oral communication).

Fanglomerate belt. Characteristic of the rocks along the east border of the Durham basin is coarse and poorly sorted conglomerate. It consists of pebbles, cobbles, and boulders of many rock types jumbled together in an argillaceous, silty, sandy matrix. The rock fragments are subangular, subrounded, and rounded, and consist of vein quartz, phyllite, metavolcanic rocks, epidote-quartz rock, gneisses, and granite. All these types occur within a mile or two east of the Jonesboro fault. The presence in the fanglomerate of many fragile pieces of phyllite indicates they were transported relatively short distances and not subjected to vigorous abrasion in stream beds. The local abundance of any one type correlates with its presence to the east. For example, hematite ironstone blocks have been observed in the fanglomerate only along SR 1837 just north of U. S. Highway 70; this is three quarters of a mile west of the iron-rich quartzite in western Umstead Park. Rock fragments a foot thick are common. Prouty (1931, p. 480 and fig. 3) reported boulders more than 8 feet in diameter along Sycamore Creek, a locality now submerged by the upper lake in Umstead Park. Slabs of metavolcanic rocks as much as 8 by 11 feet may be seen along Haley's Branch, half a mile north of Interstate Highway 40 and west of SR 1650; these lie a thousand feet west of their nearest source. Granitic boulders up to 2 1/2 feet in diameter occur along SR 1805 a quarter of a mile north of N. C. Highway 98 in Durham County about three quarters of a mile west of the county line. The best exposure of the fanglomerate is at a quarry in the southwestern corner of the county on the west side of Buckhorn Creek a quarter of a mile north of the county line. Exposures are also good along the Southern Railway half a mile to a mile south of Morrisville.

Argillaceous sandstones and mudstones are interbedded with the conglomerate layers, and all grade into one another laterally and vertically. Some sandstone layers include isolated pebbles or cobbles. Bedding is indistinct in the conglomerates and irregularly lenticular in the finer grained sediments. Most of the rock in this belt is red from hematite.

The western limit of the fanglomerate belt (pl. 1) has been placed as far west as layers containing abundant pebbles were observed; the accidents of exposure have doubtless affected this delineation. Its width ranges from about a quarter of a mile near the northern edge of the county to about 4 miles west of Holly Springs. In the eastern portion of the belt, conglomeratic rock seems to make up more than half of the exposures; to the west this becomes perhaps a tenth.

Conditions of deposition for such coarse and variable red beds are regarded as being those of terrestrial alluvial fans along a steep scarp, where heavy rains alternated with drier times. The streams are presumed to have been intermittent and during flood so heavily charged with suspended fine sediment that slaty rock fragments were buoyed up and protected from complete disintegration during transport of several miles. The coarsest material may have moved essentially as landslides. The relief along this former scarp is discussed later in connection with the development of the depositional basin. The possibility of glacial conditions being responsible was considered by some early workers; Russell (1892, p. 47-53) evaluated and rejected this hypothesis.

Sandstone-mudstone belt. The fanglomerate belt merges westward, by decrease in coarse clastics, into a belt consisting chiefly of sandstone, siltstone, mudstone, and claystone. Here gray to buff sandstones become common, interbedded with typical red beds. The gray sandstones are better sorted than most of the red ones and contain much feldspar and muscovite mica (micaceous arkose). Gray and buff arkose is especially common in the area west and southwest of Apex, where it is a component in the fanglomerate belt as well as predominent in the sandstone-mudstone belt. Red mudstone and gray claystone are also common. Thin layers of moderately well sorted conglomerate containing subrounded quartz pebbles occur locally. In the southwestern corner of the county laminated clay and silt and purplish siltstone and shale are noted. The westward trend in Wake County, then, is toward finer grained and less iron-stained sediment and to more distinct layering. The sandstone-mudstone belt is 3 miles or more in width and in most places extends beyond the western edge of the county.

An extensive suite of minerals exists in the Triassic sediments, reflecting the wide variety of adjacent igneous and metamorphic source rocks. Duhling (1955) sampled Sycamore and Crabtree Creeks just west of the Jonesboro fault in Wake County and reported 24 minerals of which quartz was commonest. Ilmenite occurred in all fractions, while epidote and kyanite were ubiquitous in the heavy fraction.

The clay minerals in the red beds are predominantly illite and montmorillonoids (Hooks and Ingram, 1955); kaolin and vermiculite are minor. Hematite is the only crystalline iron oxide mineral present; it occurs as fine particles disseminated evenly in the clay and as irregular coatings on many sand grains. Variations in the reddish brown colors of the rocks are believed to be due to variations in particle size and degree of agglomeration of hematite. Hooks and Ingram (1955) conclude that the sediment was derived chiefly from red lateritic soils and partially weathered bed rock in a deeply dissected region.

The depositional conditions for the sandstone-mudstone belt are presumed to have been an alluvial plain along a complex of low-gradient streams with wide floodplains. The sediments formed as channel fillings, overflow sheets, and natural levees. Study of paleocurrent directions (Custer, 1966a, 1966b; Leith and Custer, 1968), utilizing cross-bedding, imbricate pebbles, and scour channel axes, indicates that the regional direction of stream flow in the Durham basin was to the northeast.

Limestone-chert belt. A narrow belt containing thin lenses of limestone and chert cuts across the western corner of the county in the vicinity of the common boundary of Wake, Chatham, and Durham counties, about 5 miles northwest of Morrisville. The predominant rock in the belt is red mudstone with fine-grained red sandstone. Discontinuous thin layers and lenses of impure gray limestone are best developed west and north of Nelson (in Durham County), where they have been known for more than a century (Mitchell, 1842, p. 131; Emmons, 1856, p. 243; and Kerr, 1875, p. 187-188). This limestone has been described by Grannell (1960, p. 26) and Custer (1966b, p. 15-16 and 1967). The fine-grained limestone has numerous brown and red specks. It is exceedingly impure, the insoluble residue of quartz, clay, mica, and organic matter averaging 32 percent. Microscopic curved laminations and round aggregates suggest organic structures. Impure limestone nodules are numerous in the old quarry of the Triangle Brick Company (in Wake County) east of N. C. Highway 55 and in roadcuts along that highway half a mile to the south. The irregular nodules range in diameter up to about 4 inches and occur in layers and in isolated clumps. In the quarry four layers were noted in a 25-foot section of mudstone (Parker, 1966, p. 92). Attempts by the author to trace the limestone west of N. C. Highway 55 failed; the deposit may pinch out here.

The sandstone in this belt has considerable calcareous cement. Hard, little-weathered specimens from the quarry display "luster mottling" as a result of coarse crystallization of the calcite cement. Areas of more than a square inch show a single cleavage surface studded with enclosed sand grains. Spherical concretions one to three inches in diameter of calcite-cemented sandstone are fairly common in the Triangle Brick Company quarry.

Lenses of gray chert and of red-brown jasper also occur in this belt. Some chert is directly in contact with limestone, but some occurs separately. This siliceous rock occurs mainly in Durham County, but one locality has been noted 2 1/2 miles north of Morrisville along N. C. Highway 54 and SR 1637. Dark gray to blackish shale is associated with the limestone and chert in places.

The limestone and chert are presumed to have been deposited in small, scattered lakes and swamps on the alluvial plain, perhaps through the agency of simple plants. Wheeler and Textoris (1971) report algal structures, ostracodes, and burrows. They regard the limestone as having originally been calcareous tufa formed in a playa lake.

Fossils

The Triassic sedimentary rocks in Wake County contain fossils in only a few places. The principal known localities are the quarries of the Triangle Brick Company 3 miles north of Carpenter on both sides of N. C. Highway 55. Abundant remains of plants and fish are associated with numerous, fragile ostracodes. Swain and Brown (1972, p. 1-3 and pl. 2) describe three species of the genus Darwinula, associated with the conchostracan Howellites berryi.

A cast of part of a psuedosuchian reptile (Stegomus sp.) was found in 1965 in the Triangle Brick Company old quarry east of N. C. Highway 55 (Parker, 1966, p. 92). This roughly conical segmented fossil is about 7 inches long and from 1 to 3 inches in diameter. The surface shows parts of nine overlapping transverse curved and laminated plates that are the remains of dermal scutes of the carapace. A few similar specimens have been described from Triassic rocks in Connecticut (Lull, 1953, p. 79-89) and New Jersey (Jepsen, 1951).

Prouty (1931, p. 478 and fig. 4) reported crustacean remains from a locality half a mile west of Nelson; this is in Durham County about 1 1/2 miles north of the county line. These fossils included smooth shelled ostracodes, as well as phyllopods (branchiopods) of the genus Estheria (Cyzicus). Hope and Patterson (1969b) mention the presence of Cyzicus in both the Durham and Sanford basins in the Pekin and Cumnock Formations but not in the Sanford Formation.

Plant remains are abundant in the Sanford sub-basin of the Deep River basin in association with the Cumnock coal at many localities and in the underlying Pekin Formation at the brick shale quarry 1 mile north of Gulf. They have been studied in considerable detail by Emmons (1856, 1857), Fontaine (1883, 1900), Hope and Patterson (1969a, 1970), Delavoryas and Hope (1971), and Schultz and Hope (1973).

Age and Correlation

The flora indicates a Late Triassic age for the rocks of the Deep River basin. The ostracode fauna is consistent with this determination. The rocks are assigned a Karnian, Norian, and possibly Rhaetian age (Van Houten, 1969, p. 8-9), a duration of 15 to 20 million years.

Correlation of the rocks of the Durham basin with the three formations recognized in the Sanford basin (Campbell and Kimball, 1923; Reinemund, 1955) will remain speculative until detailed work is done between the two sub-basins. In the Sanford basin, the Triassic rocks include the Pekin Formation at the base, the Cumnock Formation - with coal beds - in the middle, and the overlying Sanford Formation. In the Durham basin the limestone-chert belt is likely to be roughly equivalent to the Cumnock Formation, and, if so, the sandstone-mudstone belt and the fanglomerate belt are correlative with the Sanford Formation. The question of whether the three parallel lithologic belts are really superposed formations is to be discussed in considering the development of the depositional basin.

Structure

Regional and local dip. The Triassic sedimentary rocks in Wake County and throughout the Durham basin dip generally eastward (pl. 1). Bedding in most places strikes north-northeast and dips 5 to 10 degrees eastward. True strike and dip are commonly uncertain because of uneven bedding surfaces, lenticular and gradational layers, channel scours, and cross lamination. The strata are essentially horizontal in many places. At numerous scattered localities the rocks strike east-northeast and even northwest, and dips as high as 25 to 30 degrees are recorded. These abnormal attitudes seem not to be systematically distributed and are not the consequence of folding. They probably result from local drag related to minor normal faults (described later) and to diabase dikes. For example, a dike on N. C. Highway 55 about 1.5 miles south of Upchurch and 0.4 mile north of SR 1601 trends eastward through nearly horizontal strata; the beds north of the dike dip 5 degrees south for about 30 feet, and those to the south dip 15 degrees south for about 40 feet.

Prouty (1931, p. 482) states that the dip is steeper in the west portion of the basin than in the east. Reinemund (1955, p. 81) found the same situation in the Sanford basin. Stewart and others (1973, p. 100) conclude from their seismic reflection data that the beds at depth below the Triangle Brick Company quarry in western Wake County dip eastward at not less than 20-22 degrees and perhaps as much as 35 degrees but that the basement surface is horizontal. These conclusions are difficult to reconcile with one another and with surface observations. Near the east side in the border fanglomerates, low dips to the west occur sparingly.

The average angle of southeastward dip in the basin has been variously estimated as 20 degrees (Kerr, 1875, p. 141), perhaps 15 degrees (Russell, 1892, p. 94), at least 15 degrees near Durham (Prouty, 1931, p. 484), 15 degrees (Mann and Zablocki, 1961, p. 196), and about 15 degrees (Bain, 1966, p. 90). My own impression favors an average dip of about 10 degrees to east-southeast.

Form and thickness of the deposits. The body of Triassic sedimentary rocks of the Durham basin forms an elongate prism with triangular vertical cross-section; it tapers out to the northeast and thins to the southwest (beyond Wake County). Along its west side the prism thins to zero thickness in most places where the rocks lie nonconformably on older crystalline basement. On the east side the prism ends abruptly against the Jonesboro fault. The deposits are inferred to thicken eastward because at the surface the bedding planes dip almost consistently in that direction.

The thickness of these rocks is not known anywhere in or near Wake County because no well or drill holes have penetrated through them. A 285-foot well drilled at Raleigh-Durham airport and a 497-foot well at Triangle Brick Company were entirely in Triassic rocks (May and Thomas, 1968, p. 102 and 105). A well drilled about 1885 in Durham (Venable, 1887; Prouty, 1931, p. 481) to a depth of 1650 feet did not pass completely through the Triassic rocks.

An estimate of thickness may be made by considering the width of outcrop and rate of dip, though several uncertainties affect its validity. The strata in most places dip gently eastward, but the amount and direction of dip vary considerably in places. The average dip is estimated to be about 10 degrees a little south of east. The old deep well in Durham was some 2 miles from the west border of the Triassic rocks and hence indicates a minimum eastward dip of the basement of 9 degrees. The width of the basin being about 15 miles, a 10 degree dip would give a thickness at the east side of about 14,000 feet. As pointed out by Prouty (1931, p. 484), the normal faults that are known to be present may have repeated beds and increased the apparent thickness. Further, the beds that crop out in the western part of the basin may not continue down dip to the east side, but instead they probably grade into others. Hence, the true thickness may be more or less than 14,000 feet. McKee and others (1959, pl. 5) give the maximum thickness in the Durham basin as "10,000 ± feet".

Two gravity profiles have been run across the Durham basin in Wake County (Mann and Zablocki, 1961) along U. S. Highways 70 and 64. Interpretation of the residual anomaly values indicated that the maximum thickness of sediment near the east side of the basin was 3100 feet along U. S. Highway 70 and 6500 along U. S. Highway 64. Some uncertainty existed whether the value employed (0.1) for the difference in density between Triassic rocks and the metamorphic rocks outside the basin was appropriate, so the absolute thickness values may be in doubt. The data do imply that the thickness doubles in about 11 miles between the two traverses.

Stewart and others (1973) made a seismic measurement of depth to basement at the Triangle Brick Company quarry at the western edge of Wake County. Their results, though tentative owing to uncertainty as to velocity values for the rocks, indicate the thickness of sediments at that point to be 6000 ± 500 feet. If this thickness of 6000 feet is accepted, the rate of thickening from the west edge of the Triassic rocks to this point is about 860 feet per mile. This is almost the same as the minimum value indicated by the old deep well in Durham. If this thickening rate is projected eastward to the Jonesboro fault, the thickness at the east side will be about 12,500 feet. More recent investigation by seismic reflection-refraction traverses (Bain and Stewart, 1975), however, indicates that the thickness adjacent to the Jonesboro fault is 6000-7000 feet and that the maximum thickness, probably in excess of 9000 feet, appears to be in the middle of the basin rather than along the east side.

The Triassic sedimentary rocks, then, probably are 12,000 to 13,000 feet thick in the vicinity of the Raleigh-Durham airport. The thickness must gradually decrease northward along the east side of the sedimentary prism into Granville County where the rocks taper out. To the southwest the thickness seems likely to be about the same through much of Wake County until the constriction near the Cape Fear River is approached. Reinemund (1955, p. 38-39) estimated that the sedimentary wedge along its southeast side in the south end of the Durham basin on the east side of the Cape Fear River must be at least 6000 feet thick, ranging between limits of 5300 and 7100 feet.

Jonesboro Fault. The great fracture that borders the Triassic sediments on the east was named by Campbell and Kimball (1923, p. 55-60) for the town near Sanford in Lee County. They seem to have been the first to have recognized explicitly that the eastern boundary of the Newark rocks is a fault. Maps, sections, and texts of Emmons (1856), Kerr (1875), and Kerr and Hanna (1888) do not refer to the matter or do not make clear whether a fault or an unconformity is intended. Russell (1892, p. 94) states that the Newark rocks 1 1/2 miles west of Cary are "dipping westward and resting on the crystalline terrane from which they were derived." This seems to imply a non-conformity, not a fault contact.

The fault passes in a generally northeast direction some 38 miles completely across Wake County; it extends, in fact, nearly across the whole state. Its course in Wake County has two major changes in direction; the northern part (5 miles) north of the Neuse River trends northeast, the middle section (26 miles) north-northeast, and the southern portion (7 miles), southwest of Holly Springs, northeast again. Some stretches of as much as 10 miles appear to be straight or gently curving, but elsewhere short, sharp zigzags interrupt its course.

Angular bends in the border fault are especially well exposed in the vicinity where U. S. Highway 70 crosses the fault, at the intersection of SR 1837 (fig. 8). Though the positions of the fault trace as mapped may not be completely accurate, exposures are so closely spaced that only minor revisions are possible. The effect is an indentation as if the Jonesboro fault were offset westward about 900 feet along two transverse faults striking east-northeast and southeast. The inferred fault lying southwest of U. S. Highway 70 probably extends southeastward to displace the magnetite quartzite in northern Umstead Park. Both the Jonesboro fault and the quartzite show left lateral horizontal offset of about 1200 feet. No evidence has been detected for continuance of the inferred fault north of the highway into rocks west or east of the Jonesboro fault.

Irregularities are also clearly evidenced in northern Wake County along the Neuse River, Beaverdam, and Little Beaverdam Creeks. The trace of the border fault in much of this stretch lies beneath floodplain alluvium, so its exact position cannot be mapped. North and west of the Neuse River and Beaverdam Creek, from the county line to a point half a mile north of the junction of Little Beaverdam Creek, all exposures are of Triassic sediments, while to the south and east all are crystalline rocks. The fault boundary here takes several sharp bends, including a three-quarter mile stretch striking south of east.

The structural picture here is complicated by the merging from the southwest of the Lick Creek fault (Charles, 1959, map and p. 28, 34, 36) from within the Durham basin. Chief evidence for this fault is a prominent topographic lineament along Lick Creek in Durham County and Smith Creek in Granville County (though these two streams are not directly aligned). The courses of the Lick Creek fault and the Jonesboro border fault, thus, seem to coincide across the northern neck of Wake County. Charles suggests that the Lick Creek fault offsets the Jonesboro fault about 9 miles northeastward in this area. The abrupt zigzag

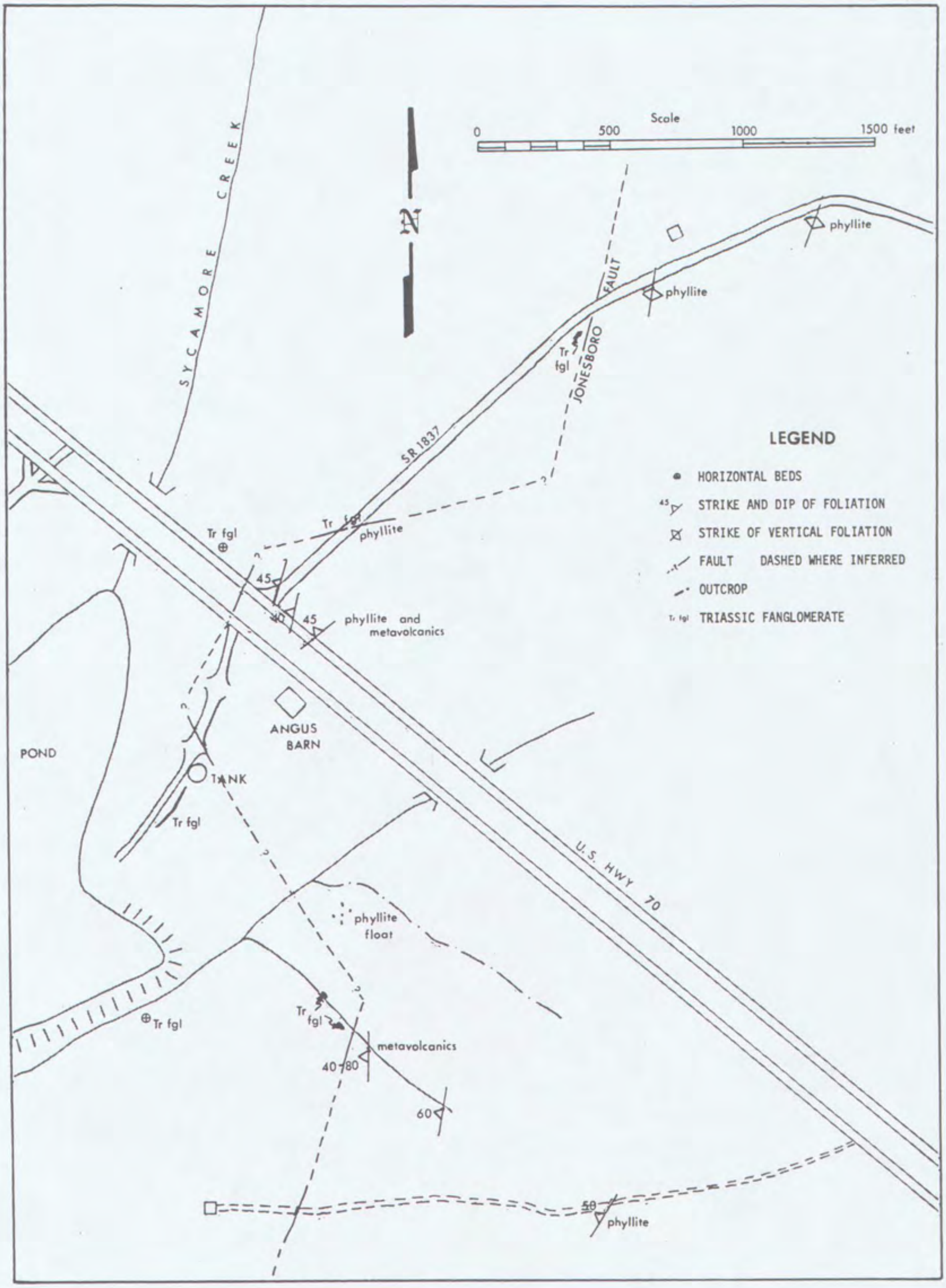


Figure 8. Geologic map of trace of the Jonesboro fault in the vicinity where it crosses U. S. Highway 70, at intersection of SR 1837, western Wake County, N. C.

bends in the border fault, however, argue strongly against significant strike-slip displacement here. Resolution of this problem is beyond the scope of this report since it involves extensive study in adjacent counties.

Russell (1892, p. 94) cited a notch in the outline of the Newark rocks as mapped by Kerr (1875) near Cary that Russell thought probably indicated faults. This notch was eliminated, however, in Holmes' revision (1887) of the map (Kerr and Hanna, 1888). This area was later investigated by Goldston and Stuckey (1930); their results are considered later under topographic features. The course of the fault at this locality is now mapped as straight.

Although some of the abrupt bends in the Jonesboro fault may have been caused by cross-faulting, it is likely that most of them, especially those at small angles, reflect irregularities in the original tensional fracture that initiated faulting.

The actual fault surface is exposed almost nowhere. Its trace was mapped (pl. 1) between exposures of Triassic sediments (to the west) and those of various metamorphic and igneous rocks, spaced a few tens to a few hundreds of feet apart. Thus, in many places considerable latitude remains for revision of its location and details of form. Its position is readily observed, however, in the ditches on SR 1837 about 500 feet northeast of U. S. Highway 70 (fig. 8) and along SR 1435 northeast of Apex.

The best exposure of the fault that is known is at the bend in SR 1902 in Durham County, 0.7 mile west of Wake County and about 500 feet east of Laurel Creek. Here shattered metavolcanic rocks may be observed in contact with steeply tilted Triassic pebbly sandstone and mudstone. The fault plane dips 80 degrees west over a vertical exposure of about 5 feet; no other site was found where its dip could be measured, though it is clearly near vertical. The fault contains 4 to 5 inches of clay gouge. The Triassic rocks abut sharply against the fault surface, where they are nearly vertical. However, within 20 feet to the west they dip about 35 degrees west, and within 1000 feet the dip is 5 degrees west. At this site the Triassic strata are clearly cut off eastward by post-depositional faulting. Though the basin of deposition is regarded as due to faulting - on the evidence of the fanglomerates, as discussed later - it is clear that some further displacement followed the laying down of the strata exposed here.

The minimum amount of dip slip on the Jonesboro fault is indicated by the thickness of Triassic sediments adjacent to it, some 12,000 feet in west-central Wake County. This value must be increased by whatever thickness of Newark rocks may have been eroded since their deposition, which may be considerable, though no basis of judgment seems to be available.

Evidence of strike slip is scanty. The possibility of extensive horizontal offset along the postulated oblique Lick Creek fault in northern Wake County (Charles, 1959) has been noted. Further, in Chatham County a mile east of Corinth and 3 miles southwest of Wake County near the crossing of N. C. Highway 42 and the Norfolk Southern Railway a large north-northwest striking diabase dike appears to have been offset right laterally about 1000 feet. (This locality was brought to the writer's attention by J. L. Stuckey.) Whether the diabase constitutes severed segments of a single dike, or two separate dikes each ending at the fault, has not been proven. If the former interpretation is correct, the observation documents a kind of tectonic episode hitherto unrecognized in the region.

Faults within the basin. The Newark rocks are visibly displaced by small faults at several places, and similar unexposed faults of various magnitudes are likely to be numerous. Observed faults are confined to single outcrops and cannot be traced along strike. They seem to be steeply dipping normal faults, and most strike nearly north or west.

A good exposure may be seen in western Wake County in the parking lot of Hennis Trucking terminal on the southwest side of U. S. Highway 70 half a mile east of the county line. The fault strikes N. 85° W. and dips 83 degrees north. Correlation of the strata on the two sides of the fault is not certain, but the hanging wall (north side) seems to have dropped about 12 feet. The strata strike N. 35° W. and dip 4 degrees southwest on the hanging wall and 14 degrees on the footwall. This abnormal attitude where faulting is known leads to the inference that such orientations elsewhere probably are local disturbances resulting from faulting or intrusion of diabase dikes.

Another small normal fault with dip slip of about one foot is exposed in a road cut on SR 1624 one mile west of Carpenter (on N. C. Highway 55).

An east-trending normal fault was uncovered during excavation at the Shearon Harris nuclear power plant site near the southwest corner of the county. The strata here dip 10-15 degrees eastward, and the fault dips about 75 degrees to the south. Several diabase dikes have been displaced as well as the Newark strata. Dip slip is reported (Carolina Power and Light Company, 1975, p. II - 7-8) to be between 80 and 100 feet and strike slip between 0.5 and 13 feet. This fault has been traced by trenching for more than a mile along strike.

Bain and Stewart (1975) deduced from seismic surveys that the bottom of the Durham basin is broken into horsts and grabens a mile or more in extent and having relief of more than 1000 feet. These faults probably also affect the overlying Newark rocks, which are considerably faulted.

Joints. The Newark rocks in Wake County are broken by a multitude of fractures. Though some exposures show many good joints, systematic jointing is on the whole poorly developed. In more firmly cemented sandstone layers some joints are approximately planar for a few feet, but these commonly merge into curved and irregular surfaces. Fractures in mudstone and claystone are curved and short. The range in strike and dip is usually considerable in any one outcrop or small area. No joints were observed that displayed plumose surfaces.

Watson and Laney (1906, p. 231-232) report that exposures of sandstone northwest of Morrisville have distinct sets of joints (N. 60° W., N. 45° E., and N-S at one place, and N. 30° W. and N. 60° E. at another). Likewise, Prouty (1931, p. 483) stated that two rectangular systems of joint sets exist in the Durham basin, namely, N. 15-35° E. and N. 45-70° W. and a less important one N. 65-70° E. and N. 10-15° W. Grannell (1960, p. 37-40) described a numerous and consistent set of vertical joints near Lowes Grove (in Durham County) that strikes N. 15° W. Throughout the rest of the area he mapped, mainly in Durham County, scanty data showed much scatter in strike with two concentrations at N. 45° E. and N. 80° E. My own experience indicates that the regularity of jointing in the Newark rocks in Wake County is too slight to merit detailed investigation.

The generally poor development of joints is probably accounted for by the high clay content of even the sandstones, which makes them less brittle, and because the region has been subjected to vertical warping movements since the Newark rocks were deposited rather than compression, which would be evidenced by associated folds.

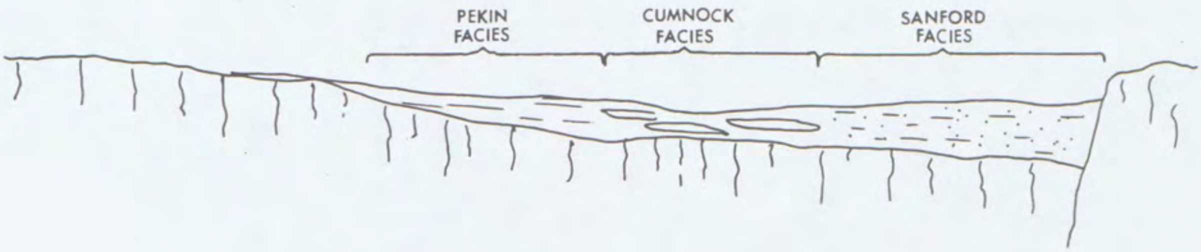
Development of the Depositional Basin

The elongate basin in which the Triassic sediments were deposited is regarded as having resulted from faulting. It seems to have been a half graben produced by intermittent dropping of the block west of the Jonesboro fault relative to the stationary or upraised block to the east. The sinking block tilted downward to the east and may have been recurrently bowed up along its western side. Rapid erosion of the higher lands both east and west of the half graben supplied sediment to fill the lowland. Intermittent slip on the bounding fault renewed the differences in elevation that energized the transfer of rock material from adjacent higher ground into the trough.

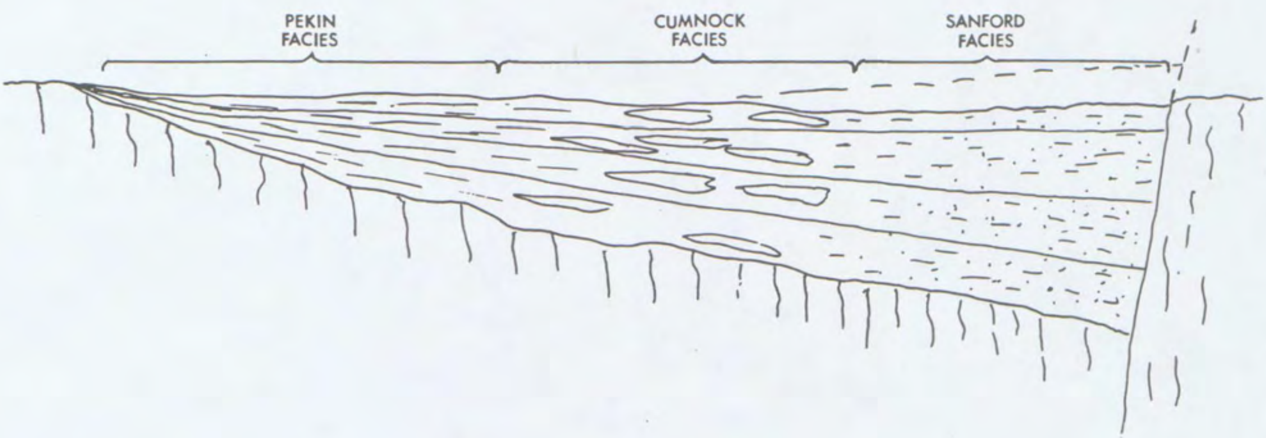
The possibility that the trough of deposition was produced by down-bending of the crust rather than by faulting has been stressed by Campbell and Kimball (1923, p. 60-61). Under this proposal, displacement on the Jonesboro fault post-dated all or most of the period of deposition. Had this been the situation, however, the Newark sediments must have first filled the bottom of the downwarped trough and in time must have spread farther and farther out to west and east dipping toward the basin axis. Furthermore, downwarping could hardly have produced the strong local relief needed for developing the fanglomerate known all along the east side and not elsewhere. Had the basin been a downwarped trough split lengthwise by post-depositional normal faulting, the upthrown eastern half being eliminated by later erosion, no possible location of the boundary fault through the center or eastern half of the basin would have resulted in the observed relations, that is, fanglomerates to the extreme eastern margin, finest sediment near the middle, and coarser sediment again on the west side. The coarse and poorly sorted sediment along the entire east side of the Durham basin clearly points to an abrupt scarp. The fanglomerate at the northern end of the basin in Granville County where the Triassic rocks thin out must be stratigraphically lower and older than that in central Wake County. The continuity of the fanglomerate along the east side of the basin seems to imply continuity of a scarp throughout the depositional period. Hence, it is argued that the basin was inaugurated and maintained by faulting. This interpretation is based, of course, on features observed at the present land surface. Should future data from depth indicate some different kind and sequence of deposits in the subsurface, modification of the half-graben concept will be required. A similar close dependence of sediment type on tectonic activity is described by Randazzo and others (1970) in the Wadesboro Triassic basin some 80 miles to the southwest.

Let us assume, then that the basin was initiated by faulting with a steep scarp along the east side, that it remained stationary for a long or short time while sediment accumulated, and that as time went on the basin was abruptly deepened or renewed many times by recurrent slip along the Jonesboro fault. During any one period of stability the basin would tend to fill up with coalescing alluvial fans spreading westward from the scarp, with finer fluvial and lake deposits in the middle, and with clastics of intermediate grain size on the gentle west slope (fig 9-A). As the successive scarps were reduced by erosion, the alluvial fans must have extended up on the margin of the upthrown block, but renewed faulting would have cut off these extensions along the fault line and their material would subsequently have been redeposited in the basin. The increment of sediment accumulated between times of faulting should be thickest in the east, and probably thicker in the middle (the low part of the basin) than on the west, where some earlier deposits would tend to be eroded and shifted farther into the trough. Original dips should be westward on the east side, horizontal in the middle, and eastward along the west flank. Renewed slip on the east border fault would tilt the trough down to the east and provide space for another similar incremental wedge of sediment on top (fig. 9-B). This inferred rotation of the trough, rather than a vertical drop, would steepen the eastward dips, lessen or reverse the westward dips (Prouty, 1931, p. 485), and tilt horizontal beds eastward; this accords with observations at the present land surface that the strata dip generally but variably eastward. The Durham basin, then, would have been filled by the stacking of a series of similar incremental wedges of varying thickness. The wedges are likely to have extended farther and farther westward with time as the basin filled but to have been cut off sharply on the east by the fault. Post depositional displacement on the Jonesboro fault seems clearly to have occurred also, as was described earlier. Discontinuous faults along the west side of the Durham basin (see Harrington, 1951) are presumed to be of this date.

According to this concept of the depositional and tectonic history, the stratigraphic division of the Triassic rocks in the Sanford basin into three formations (Pekin, Cumnock, and Sanford) would not apply in the Durham basin as time units. Each would be a lithofacies grading laterally into others and persisting upward through the whole sediment prism across time boundaries. The apparent superposition of the units, as now indicated by the generally eastward dips, would be an effect of progressive tectonic tilting during deposition. The eastward dipping sandstones at the west edge of the basin are no doubt older than those a little to the east that dip the same way, but it is suggested that those western layers do not persist across the bottom of the basin as components of a sandstone time stratigraphic unit. Instead it is felt



A. First depositional increment



B. Multiple increments and post-depositional erosion

Figure 9. Serial cross sections representing probable conditions of deposition of Triassic sediments in Durham basin, N. C.

that at each time level in the sequence "Pekin" facies grades eastward into "Cumnock" facies and that in turn into "Sanford" facies.

Peneplanation during later Mesozoic and perhaps subsequent times has beveled the Triassic deposits and removed an unknown thickness. Harrington (1951, p. 155) concluded from an analysis of normal faults along the west border near Chapel Hill that a thickness of 1300 to 1800 feet of Triassic rocks had been removed at that point. McKee and others (1959, pl. 9) indicate that 2-3000 feet were eroded from the Newark rocks in the Durham basin.

POST-NEWARK (POST-TRIASSIC) DIABASE DIKES

Dikes of dark igneous rock fill fractures in many of the metamorphic rocks, in the Rolesville batholith, and in the Triassic sedimentary rocks. Cretaceous and younger sediments overlie some of them unconformably. These dikes, then, record an episode of crustal fracturing and intrusion of basic magma during a time of crustal extension that occurred after accumulation of the Newark sediments and prior to their being eroded and transgressed by Coastal Plain deposits. Armstrong and Besancon (1970) give K/Ar dates for most of the dikes, sills, and flows studied in eastern North America of about 200 m.y., though some were older. This makes them Triassic and contemporaneous with sedimentation, a situation not confirmed by local observations. Paleomagnetic studies (De Boer, 1967) indicate that the dikes were intruded during the Jurassic period, a conclusion concurred in by Sutter (1976).

Though many of these intrusions in steeply dipping foliated rocks are locally conformable, sill-like bodies, all are here referred to as dikes because the general character of the group is discordant to older structures. Sills have not been observed by the author in the Triassic sedimentary rocks in Wake County, but they are known nearby in Durham and Granville Counties and in the Sanford area.

Many diabase dikes have strong positive expression on the aeromagnetic maps, some are only faintly expressed, and some have no effect. These relations are described in a separate section of this report. The aeromagnetic maps have been invaluable in tracing many dikes between widely spaced outcrops and through sediment-covered areas.

The dikes are generally distributed across the county. They seem to be equally numerous in the crystalline and Triassic areas, though large dikes are most common east of Raleigh. Their locations are shown on the general geologic map (pl. 1) and on figure 10, which also records measured thicknesses. Some two dozen major dikes have been recorded, and many other thin ones have been noted; many more can be found. Most of them trend north-northwest though a significant number strike north and nearly east-west. Without exception they dip almost vertically.

Thicknesses range from less than a foot to as much as 200 feet. The largest dike discovered has been traced along a smoothly curved, northward course through Garner, east Raleigh, and Millbrook for a distance of 15 miles. Its thickness varies from about 50 to 200 feet. Its southern end is in adamellite, but for most of its length, it lies in various gneisses to the west of the pluton. In Garner along U. S. Highway 70 several small dikelets a few inches thick parallel the east contact within 10 feet of it. At least three dikes in the Rolesville batholith are 100 feet thick in places. The longest dike known extends N. 10° W. from the Johnston County line near Shotwell for 18 miles to near Wake Forest.

No dikes have been traced to or across the Jonesboro fault in Wake County. However, a south-trending dike at Morrisville has been traced to within a mile of the fault. An east-trending dike north of Apex extends within 2 miles or less, and a south-trending dike in easternmost Durham County just north of N. C. Highway 98 extends to within at least a mile of the fault and may possibly cross it.

Most dikes are tabular with locally uniform thicknesses. Individual dikes show marked but gradual variations in thickness along strike. A few thin dikes in granite are irregular in form, having right angle bends in one or both contacts. Offshoots a few inches thick are not uncommon. In a few localities two or more nearly parallel dikes occur within a few feet of one another, probably the result of oblique splitting of one dike into two. Actual intersections of dikes have not been observed, but several instances of nearby dikes with strongly divergent trends indicate that this may occur, though forking seems more likely. Inclusions of wall rock are comparatively rare.

The diabase is black, massive, and generally fine grained; in the larger dikes the texture is medium grained, and in the thinner ones it is aphanitic. Large dikes have aphanitic borders and coarser interiors. The rock is distinguished from other dark rocks in the area - such as hornblende gabbro and amphibolite - by narrow, lath-like crystals of dark feldspar whose cleavage surfaces in fresh rock may be recognized with a hand lens. All exposures are weathered, and the diabase saprolite is typified by concentrically exfoliated rock spheroids embedded in dark brown, plastic clay. Most spheroids contain remnant cores of fresh rock. The outcrop strips of the dikes are marked discontinuously by dark spheroidal boulders in and on the soil that range in diameter from a few inches to several feet.

Diabase consists chiefly of plagioclase feldspar, pyroxene, olivine, and opaque minerals. Preliminary microscopic study indicates that labradorite originally composed about 50 percent of the rock, augite 30 to 35 percent, olivine 10 to 20 percent, and magnetite-ilmenite 3 to 5 percent. Secondary alteration has produced varying amounts of serpentine and chlorite at the expense of olivine and augite. The texture is intergranular or subophitic, with anhedral pyroxene and olivine lying between or partially enclosing tabular plagioclase. Radiating groups of feldspar crystals are common.

Hermes (1964) has shown that dolerite (diabase) in the Deep River basin varies greatly in composition. He recognized four classes; in these, olivine ranged from 0 to 54 percent, augite from 5 to 49 percent, plagioclase from 34 to 70 percent, micropegmatite from 0 to 27 percent, and opaque minerals from 2 to 6 percent. Weigand and Ragland (1970) distinguished four chemical types: (1) olivine normative; (2) quartz normative with low TiO_2; (3) quartz normative with high TiO_2; and (4) quartz normative with high iron. Variations in Wake County diabase have not been investigated in detail, but judging from preliminary petrographic study, minor color differences in saprolite, and marked differences in magnetic effects, they also must have a wide range of composition.

All dike contacts are sharply distinct. Contact metamorphic effects have been noted only near dikes in Triassic sedimentary rocks. The typical red color of sandstone, siltstone, and shale has been changed to black at and near the contacts. The effect is most marked near the dikes and gradually dies out at distances equal to about half the dike thickness. This is readily observed at the dike that crosses N. C. Highway 54 a quarter of a mile southeast of Morrisville. The change presumably is due to recrystallization of hematite pigment in the sediments to magnetite under higher temperature.

A dike 2 miles northwest of Apex that crosses N. C. Highway 55 at a point 1.3 miles north of U. S. Highway 64, includes a slab of sandstone that has been partially recrystallized. The vertical dike strikes east-west, is about 20 feet thick, and cuts through Triassic brown pebbly arkose and laminated claystone. The sandstone inclusion is 8 to 12 inches thick and stands vertically in the middle of the dike. It has been bleached white and is now a hard hornfels in which original clastic texture is still obvious. The fine-grained matrix, however, has been recrystallized so that sand grains and quartz pebbles are completely surrounded by fine fibers of sanidine radiating from their surface; small flakes of chlorite (?) fill the intervening space.

Detailed petrographic and chemical studies of similar dikes in neighboring counties to the west and southwest have been made by Hermes (1964), Justus (1966), Ragland and others (1968), Reinemund (1955), Singh (1963), and Weigand and Ragland (1970). Sills or possibly buried lava flows in Triassic sedimentary rocks in Granville and Durham Counties have been described by Koch (1967a; 1967b). A vein of laumontite about 4 inches thick is reported (Furbish, 1965) in a dike 3.5 miles west of Wake County.

The diabase dikes in the county show little consistent relation to other structures. The commonest joints in the metamorphic and igneous rocks are near east-west, while most dikes strike north-northwest. The dikes also seem independent of foliation, though in places they are concordant. In the Triassic rocks the dikes parallel the local joints in small areas but show much greater regional consistency in orientation than does the poorly developed jointing. This lack of consistent parallelism suggests that many or most joints (except those filled with quartz veins) were not present until after the time of dike intrusion. As previously suggested, jointing probably occurred at various times during recurrent regional uplifts.

The distribution of Triassic dikes in the eastern United States and their regional variations in orientations have been described by King (1961; 1971). He showed that between Alabama and North Carolina

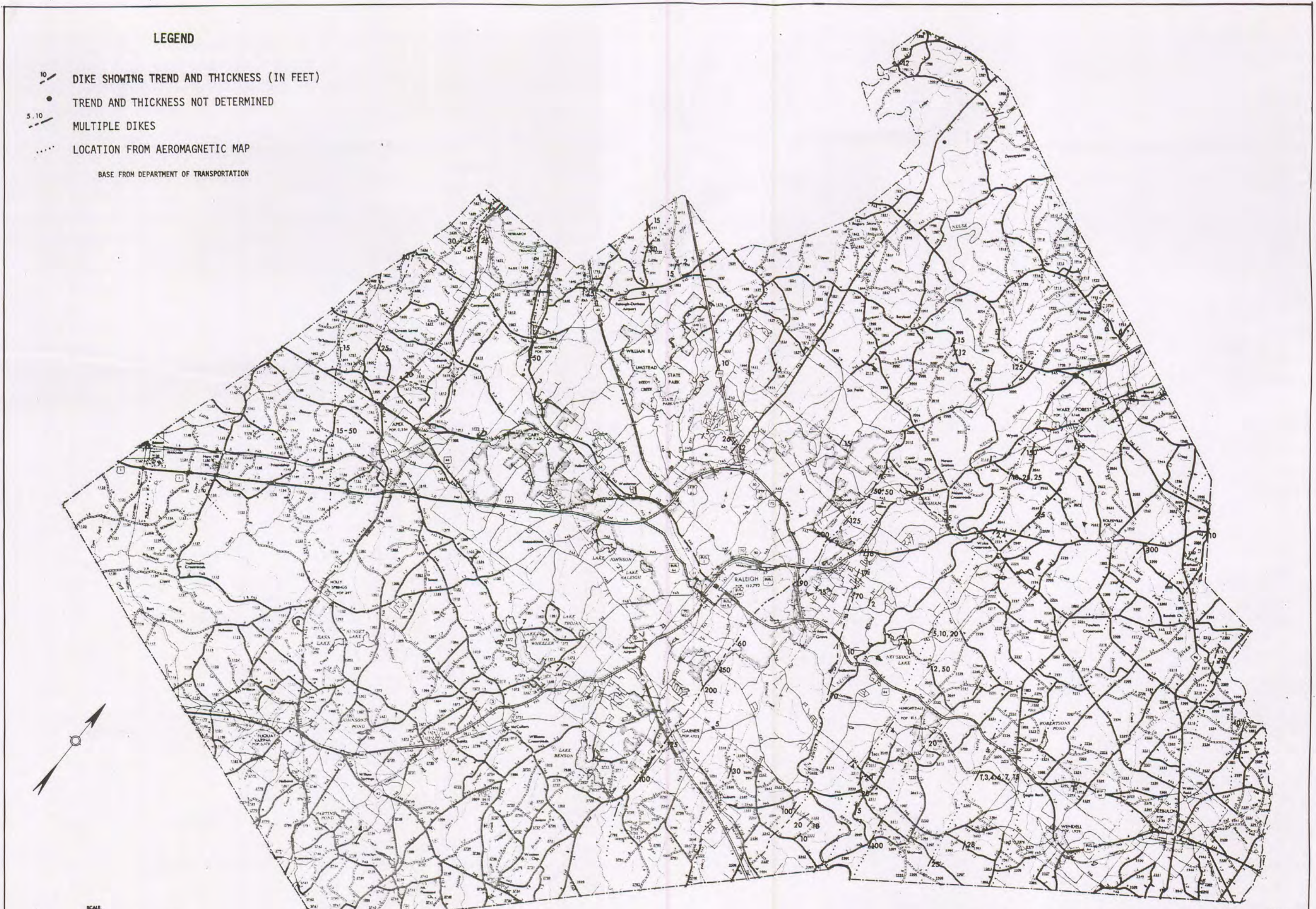


Figure 10. Map showing locations and thicknesses of diabase dikes in Wake County, N. C.

the dikes strike northwest, while farther to the northeast they swing consistently clockwise through north to northeast. They are sharply discordant to all earlier trends, even to Triassic trends. The Wake County dikes fit this regional pattern.

The presence of numerous north-trending dikes implies a substantial east-west extension of the earth's crust in this region at the time they were intruded. Tabulation of 22 principal dikes in a 10-mile wide strip extending 38 miles from east to west across the middle of the county gives an aggregate dike thickness of 945 feet. This total thickness indicates an average crustal expansion of 24 feet per mile (or 0.5 percent). This fracturing and extension is believed to be an aspect of continental rifting as North America and Africa separated when the North Atlantic ocean basin was initiated during the Jurassic period (De Boer, 1967; May, 1971).

GEOPHYSICAL SURVEYS IN THE WAKE COUNTY REGION

Information on the gravitational and magnetic properties of the region in which Wake County is situated has been obtained in recent years by geophysical measurements. A gravity survey was begun in 1957 by the geology department of the University of North Carolina at Chapel Hill, and a Bouguer gravity map of North Carolina was published by Mann (1962). A map showing the same major gravity features but differing substantially in many smaller details is part of the Transcontinental Geophysical Survey (U. S. Air Force, 1968). Aeromagnetic maps of half a dozen quadrangles along the northern border of North Carolina have been published (U. S. Geol. Survey, 1973). Similar maps (U. S. Geol. Survey, 1974) at scales of 1:62,500 and 1:250,000 covering Wake County and environs have recently become available on open-file from the North Carolina Geological Survey Section and the U. S. Geological Survey.

Gravitational Surveys

Gravity maps show how much the local intensity of gravitational attraction differs from the theoretical value that would exist if the earth's crust was homogeneous. The Bouguer gravity contours (in milligals) reflect the presence of more dense and of less dense rocks. The value at any point is an integration of the effects of all the rock types beneath that point. Rocks immediately beneath the surface have a greater influence than those that are deeply buried since the gravitational attraction varies inversely as the square of the distance separating the attracting masses. Thus, a strong correlation exists between gravity values and the outcropping rocks, especially where that type persists to great depth.

The gravity contours in Wake County and vicinity (fig. 11) trend generally northeastward, conforming to the strike of the rock units. A gravity minimum outlined by the -35 milligal contour centers near Wendell, and values rise steadily westward to a maximum of +15 milligals along the western edge of the county. The low gravity area in eastern Wake County extends northeastward and correlates with the Rolesville batholith, as pointed out earlier (Glover, 1963). The southwest end of this gravity depression extends to the limit of the batholith where the gravity gradient rises abruptly over the curved Panther Branch amphibolite body near McCullers. The upward gradient to the west of this depression, as shown on the small scale regional maps, crosses the belt of metamorphic rocks and the Triassic sediments in the Durham basin with no indication of the presence of the Jonesboro fault. Larger scale gravity profiles (Mann and Zablocki, 1961, fig. 6 & 7), however, show an abrupt drop across the fault.

The zero gravity anomaly contour on the 1968 U. S. Air Force map makes a long double east-west bend southwest of Raleigh crossing from the metamorphic belts into the Durham basin. This does not coincide with any known structure. The loop is mostly within the area of Triassic rocks and is likely to reflect transverse faulting in the Durham basin during earlier stages of deposition. This loop is not present on the 1962 map.

The +10 milligal contour in the northernmost end of the county makes a long east-northeast loop; this is shown on both the 1962 and 1968 maps. This loop, enclosing higher gravity values, corresponds approximately with the Beaverdam diorite-gabbro igneous complex.

Because of their small scale, the published gravity anomaly maps delineate only major, large-scale geologic features in the county.

Aeromagnetic Survey

The relatively large-scale aeromagnetic maps of the region show a wealth of detail on small variations in magnetic attraction. The intensities measured by air-borne magnetometer along parallel flight lines are a net summation of the effects of whatever rocks exist along and near the line. They are affected by the forms of the rock bodies and the slope of the bounding surfaces, as well as by their intrinsic magnetic properties. The magnetic intensity values (in gammas) so obtained are contoured and show a complex pattern

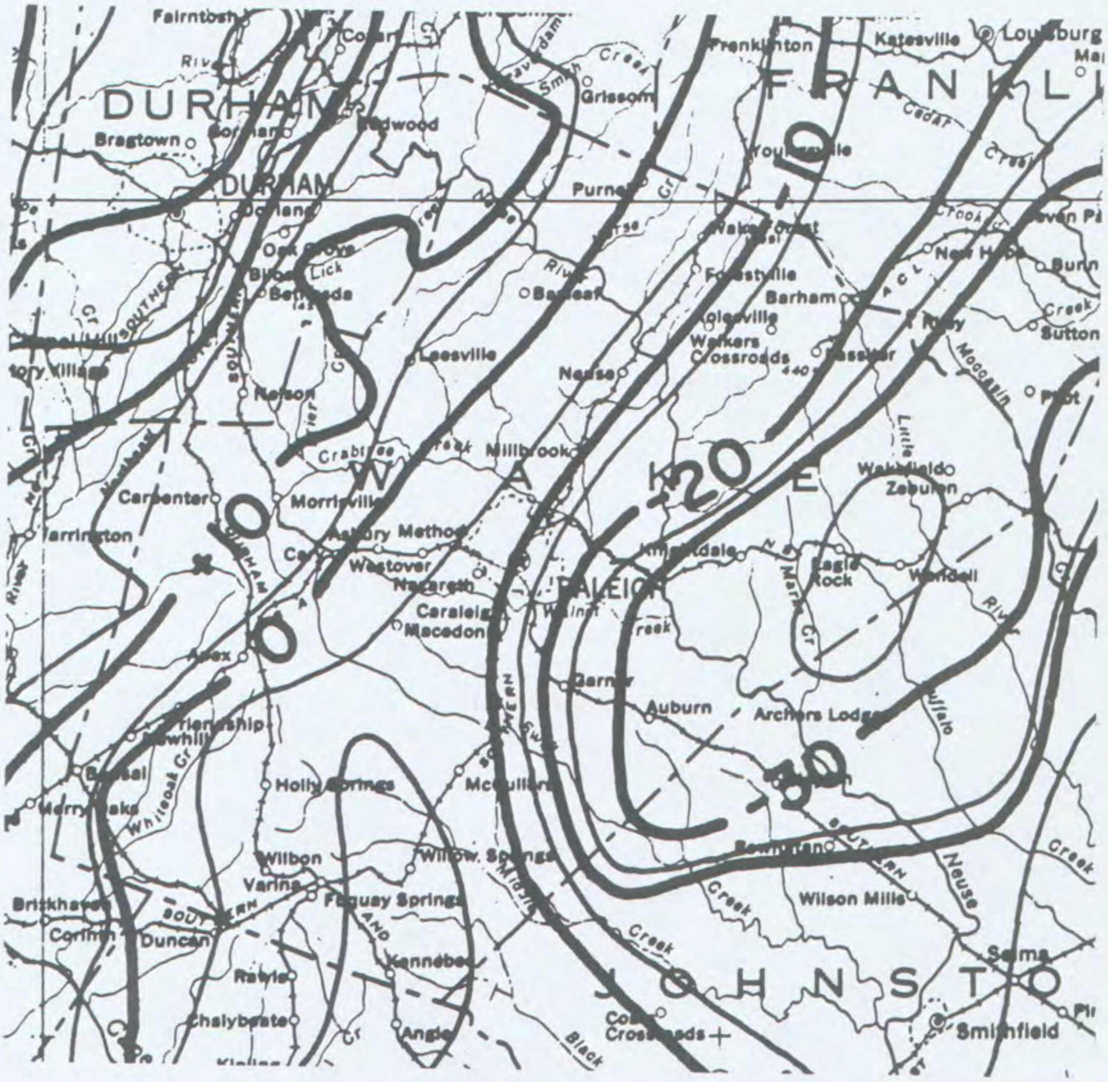


Figure 11. Bouguer anomaly gravity map of Wake County and vicinity, N. C. (after Mann, 1962)

of alternating higher and lower areas that range in shape from ridges and troughs to bumps and hollows. Some features of the magnetic intensity contours are readily interpreted in geologic terms, while the explanation of others remains obscure. The relatively thin surficial sediments are not magnetic, so the aeromagnetic contour pattern results from the buried metamorphic and igneous rocks. Thus, the maps are especially helpful in tracing and interpreting geologic features that cannot be observed directly.

The aeromagnetic map covering Wake County (pl. 2) has three northeast-trending subareas of strongly contrasting magnetic contour patterns. Within each of these major divisions many smaller features are apparent. The general features of the three portions are outlined first, and then details within each are described.

Extending through the middle of the county is a lobate area characterized by strong magnetic relief with values ranging from above +100 to below -300 gammas. The contour pattern consists of closely spaced linear ridges and trenches with irregularly ovate highs and lows. The area is about 9 miles wide in the northern part, narrows to about 5 miles wide south of Swift Creek, and then flares out to a width of about 13 miles along the southern border. Much of this central area corresponds generally with the belt of metamorphic rocks.

The eastern portion is a wide area of mostly negative values (-100 to -200 gammas), low magnetic contrast, and irregular pattern except for several prominent linear ridges extending north-northwestward. Much of this area, but not all, is underlain by granite.

The western portion has low negative values (mainly -200 to -300 gammas) and widely spaced, irregular contours that in many places trend east-west. It corresponds to part of the Durham basin of Triassic sedimentary rocks.

The eastern portion of the county is basically a magnetic plain averaging (estimated) about -200 ± 60 gammas in the southeastern half and rising northwestward to about -100 ± 60 gammas. The widely spaced contours enclose irregular highs and lows with relief commonly no more than 40 to 60 gammas. The east-west trending contours probably are an artificial effect due to the flight lines running in that direction. The data between them may be deficient. This eastern area corresponds to part of the Rolesville batholith, but it extends considerably beyond the granite outcrop both to east and west. The eastern limit is a line of elongate highs and lows trending north-northeast at the eastern corner of the county; they lie 1 1/2 to 2 miles east of the granite contact. On the west side the limit is a line of magnetic troughs (mostly -100 to -272 gammas) which is 1 to 4 miles west of the batholith. This western magnetic limit corresponds closely with the western edge of the belt of injected gneisses. The generally felsic character of these layered gneisses, combined with the great amount of injected granite and pegmatite, results in a magnetic pattern indistinguishable from that of granite.

Sharply contrasting with the general character of the eastern granitic area are the nearly straight, sharp, linear ridges that extend north-northwest for many miles across the otherwise featureless plain. These magnetic ridges are generally some 2000 feet wide and have a relief of 40 to 100 gammas. They result from diabase dikes, which are exposed at intervals along all such magnetic ridges. The dikes are not nearly as wide as the ridges, since half the anomaly is on either side of each boundary surface. Dikes of 50 to 80 foot widths may produce prominent magnetic effects. Several dikes are closely spaced at some places so the magnetic effect is cumulative. For example, three dikes of 10, 25, and 25 feet widths within a distance of 100 feet are exposed along SR 2045 just east of Smiths Creek about 3 miles south of Wake Forest; they produce a magnetic relief of about 70 gammas. The east-west dike near Greshams Lake also has sharp magnetic expression. Not all large diabase dikes, however, have pronounced effects. The largest dike mapped extends northward through Garner, where it is 200 feet thick; it shows only as discontinuous irregular spots of higher magnetic intensity. Likewise, the dike extending N. 20° W. through the Wilders Grove area is up to 70 feet thick, but it is marked only by discontinuous elongate magnetic highs of about 20 gammas. The dikes obviously differ considerably in composition, presumably in amount of magnetite.

The magnetic contours along the sides of the diabase magnetic ridges are generally spaced equally on the two flanks, and the magnetic relief is the same on the two sides. This confirms the belief that the dikes are about vertical. Slightly closer spacing and greater relief are noted, however, at a number of places on the east sides of dikes than on the west; these presumably indicate steep dips eastward.

The central magnetic belt underlain mainly by metamorphic rocks is complex, and not all its features are explicable at present in terms of surface geology. Its overall characteristics include elongate highs and lows trending north-northeast and north with strong magnetic contrast across strike and, to a lesser degree, along strike. Its eastern side is abruptly demarked from the eastern granitic area by the previously mentioned string of elongate lows. These troughs are closely bordered on the west by a continuous magnetic ridge rising to values above +100 gammas; together they constitute a major anomaly having a gradient from ridge into adjacent troughs of 250 to 300 gammas per mile. This ridge extends from the vicinity of McCullers northward to the county line near Purnell, at which point it coincides with hornblende gneiss, and values rise to a peak of +200 gammas. Coinciding with this ridge are prominent exposures of the lineated quartzitic gneiss; examples include those at Trojan Lake, Lake Raleigh, Glenwood Village in Raleigh, and Falls. This belt of rocks may mark the axis of an isoclinal syncline. It is in the kyanite metamorphic grade, and some rocks have a good deal of almandine garnet. Generally the belt is exceedingly felsic. The reason for its high magnetic intensity is not apparent from surface geology; rocks in the subsurface must be magnetite-rich.

South of McCullers the magnetic ridge merges into a massive crescentic high where values rise above +500 gammas. This high corresponds to the Panther Branch amphibolite which curves southeastward into Johnston County (where it reaches +744 gammas near Willow Springs). Within this amphibolite are several deep lows, one descending on a gradient of 900 gammas in 1 1/2 miles to a low of -385 gammas. This amphibolite body has the greatest concentration of magnetic intensity in the area. Unfortunately most of it is thickly covered by Coastal Plain sediment, so as yet little is known about it. The possibility of a magnetite iron ore body merits investigation.

Lying west of the magnetic ridge that extends from Purnell to McCullers is a belt 3 to 4 miles wide made up of alternating elongate highs and lows. In general, this belt has low values along the middle and a prominent ridge on both sides, and it corresponds with the steeply dipping and tightly folded felsic gneisses along the Raleigh anticline. The magnetic ridges commonly match with lineated felsic gneiss or with graphitic zones.

Interpretation of the aeromagnetic map south of Middle Creek is seriously hampered by the extensive cover of Coastal Plain sediments. The map makes clear, however, that the trends of rocks and structures in the eastern third of the central belt curve southeastward through some 90 degrees, while those farther west bend about 30 degrees to south-southwest. The low corridor between the curved magnetic ridges extends southward into a broadly flaring area mostly of low irregular domes and shallow basins. This is underlain by phyllites. The Angier synclinal axis seems to extend south-southeastward through it into Harnett County.

West of the belt of ridges and troughs that traverses the middle of the county is an area of low negative values with irregular bumps and hollows over the moderately dipping homocline that forms the west flank of the Raleigh anticline. The Turkey Creek hornblende gneiss body in this vicinity, extending northward through eastern Umstead Park, has no magnetic expression; it must be quite different from the Panther Branch amphibolite and is likely to be a metatuff or metasediment. The Reedy Creek pluton also lies in this area, but its outline is not apparent in the magnetic contours. This area of low values is interrupted to the north by various spot highs (described later) and to the south by north-trending ridges that cut obliquely across the strip. Poorly exposed hornblendic rocks in and south of Cary coincide with a definite magnetic ridge which is forked in its northern half.

The Buckhorn granitic pluton at the southwestern edge of the county shows up as a prominent high (maximum +138 gammas). Evidently its composition is different from the other granitic bodies. A north-trending low between Bass Lake and Sunset Lake correlates with a granitic body that is sporadically exposed in that vicinity though it is largely covered by sediment.

In the northern part of the county, the Beaverdam diorite-gabbro complex appears as a string of troughs as low as -355 gammas. The Jonesboro fault (or Lick Creek fault) cuts across the northwest side of this complex, and two similar magnetic lows adjacent to the fault on the northwest probably result from down-faulted and sediment-covered parts of this complex.

The larger ultramafic bodies in north central Wake County show prominent highs, commonly with relief of more than 200 gammas. Magnetite is a common constituent of these rocks. The highs trend north to north-northwest, in contrast to the north-northeast trends of the adjacent features.

The prominent magnetic ridge extending through northeastern Umstead Park results from the magnetite-ilmenite quartzite in that vicinity, but the high indicates a considerably greater extent than is known from surface observations.

Several magnetic highs require further investigation. A prominent spot high near Perry Pond on the Durham County line may also be related to magnetite quartzite, though this is not known. It lies just north of the anomalous occurrence of kyanitic quartzite at Rogers Store, perhaps a chance association. A broad high just northeast of Leesville also has no presently known cause.

The western edge of the central magnetic belt is in places strongly demarked from the western area of low negative values, while elsewhere the two show no contrast. The Jonesboro fault that separates the metamorphic belt from the Triassic sediments in the Durham basin is demarked by a steep magnetic gradient (down to the west) at most places north of Umstead Park and again southwest of Holly Springs. Along these segments of the fault, various rocks of strongly contrasting magnetic character (previously described) lie in the west-dipping metamorphic sequence. They stand in relief to both metamorphic rocks and sedimentary terranes. On the other hand, between Umstead Park and Holly Springs and also southwest of Burt, the magnetic contours cross the fault trace at high angles and without deviation. In these segments the west-dipping homocline of metamorphic rocks is not interrupted by magnetic highs; examples include the areas from west Raleigh toward Morrisville and also the area east and southeast of Apex. These areas have a low gradient for several miles westward from about -200 to -300 gammas. This presumably reflects increasing depth of those rock units responsible for the magnetic ridges to the east. West of the Jonesboro fault these more magnetic rocks must be several thousand feet deeper, and an abrupt drop in magnetic intensity along the fault would be expected. The Triassic rocks, however, are composed of material derived from the crystalline rocks to the east, so the same magnetic properties seem to be carried west into the Durham basin. The transition is not perceptible in the magnetic contours.

A series of broad shallow magnetic depressions of about -300 gammas characterize the Durham basin in most of Wake County. This basin is interrupted by a winding string of irregular highs extending east and northeast near Green Level and Carpenter that probably reflect variations in the pre-Triassic basement.

Fairly straight ridges trending north-northwest and having 20-60 gammas relief result from diabase dikes. The large dike near Morrisville, however, has little effect on the contours.

Diabase dikes have obvious and similar effects on the magnetic contours in the more homogeneous areas of low intensity, that is, in the Triassic sediments and in the granitic batholith. In the central meta-morhpic belt, however, the effects of the dikes are largely lost in the hetergeneous mosaic of strongly contrasting rock units. Furthermore, though diabase dikes are numerous in the central belt, no thick ones have been observed.

The aeromagnetic and geologic maps have been of great mutual value in interpreting one another, and together they form a powerful means of understanding subsurface conditions in the county.

CRETACEOUS AND CENOZOIC SEDIMENTS

General Description

The flat-lying sediments of eastern North Carolina spread northwestward along the Cape Fear-Neuse drainage divide into the area around Fuquay-Varina; therefore, Wake County lies across the boundary between the Piedmont region and the Atlantic Coastal Plain. This sheet of sediment dips gently southeastward and rests with profound nonconformity upon the deeply eroded metamorphic and igneous rocks. Toward the north and west the sediment thins, and the more highly dissected land surface rises, so less and less of the area is blanketed by sediment. Along the stream divides of Middle and Swift Creeks irregular, long, narrow strips of sediment cover the surface, while northeast of Swift Creek and the Neuse River only isolated outliers remain. Small hilltop patches of sediment are observed even into central, northern, and western Wake County. These sediments of various ages constitute the western extremities of the Coastal Plain. They occupy the highest parts of the local land surface and are discussed below in this report as "upland sediment." This term is used to imply position only and has no stratigraphic implications. Several subdivisions of the upland sediment are recognized locally but have not been mapped separately for this report (pl. 1 and 4); each of the types known is described below.

The limits of the upland sediment are exceedingly irregular and indefinite and have been only approximated in mapping. The positions of the contacts have been located wherever roadcuts or other excavations have revealed the boundary. Between such points the contacts have been interpolated by plotting subparallel to contour lines, since the base of the deposits is nearly flat and horizontal. In the Fuquay Springs quadrangle where topographic contour maps were unavailable until near the end of the survey, the soils maps (Cawthorn, 1970) on airphotos were used for some plotting. Locally, the upland sediment may be found to be a little more or less extensive than shown. The outlines of the larger areas are shown on plates 1 and 4, while the locations of many small patches are recorded on plate 4.

A second extensive type of sediment occurs along valley slopes as thin, flat lying or gently sloping veneers on stream terraces. These sediment sheets are below the uplands but above the valley bottoms and in places occur at more than one level. The third type of relatively recent sediment is floodplain alluvium along the bottoms of all major and most minor streams in the county. The surficial sediments of this region, as they relate to soils and geomorphic surfaces, have been investigated in detail for a decade by the U. S. Department of Agriculture, Soil Conservation Service, and the North Carolina Agricultural Experiment Station and Soil Science Department of N. C. State University. This continuing study, carried on by R. B. Daniels and his associates, has provided a basis of understanding of this complex topic. Published results to date have related mainly to adjacent areas farther east and south.

Upland Sediments

Nonconformity. The surface on which the upland sediments were deposited was a peneplain or surface of subaerial erosion of regional extent. The rocks underlying it vary greatly from place to place and include the various metamorphic and igneous rocks and the Triassic sedimentary rocks previously described. The presence of plutonic igneous rocks and high-rank metamorphic rocks at this surface -- rocks formed deep in the crust -- indicate that many thousands of feet of overlying rock were removed during prolonged erosion. This erosion occurred in part during later Paleozoic and earlier Triassic time while the pre-Newark peneplain (nonconformity) was being formed and in part during late Triassic, Jurassic, and earlier Cretaceous (pre-Tuscaloosa) time. In southern Wake County where mid-Cretaceous sediments lie on truncated crystalline rocks, the span of time represented by the surface of nonconformity was some 300 million years. The surface west of the present outcrop of Cretaceous sediments was no doubt further modified during intervals of nondeposition during the Cenozoic Era.

The nonconformity is a nearly flat, though not planar, former land surface that slopes variably to the southeast, its average inclination being some 10 to 15 feet per mile (pl. 4). Its surface is curved so that in eastern Wake County it slopes nearly east while in southern Wake County it slopes nearly south. This curve conforms to the configuration of the Cape Fear arch that affects the entire Coastal Plain in the region. Local relief is commonly as much as 10 feet in a few hundred feet, and for short distances may be much greater. The nonconformity may be observed in profile in many places in eastern and southern Wake County along roads that pass from uplands down across the deeper valleys. Especially good is the long exposure on U. S. Highway 401 on the south slope of the Terrible Creek valley near the junction of SR 2753 about 3 1/2 miles northeast of Fuquay-Varina. The old erosion surface coincides with the modern land surface for a few tens of feet locally, as where hard "flat-rock" granite surfaces extend out from beneath upland sediment along U. S. Highway 70 between Garner and Auburn.

"Tuscaloosa" Formation. In southern Wake County near Fuquay-Varina, the basal part of the upland sediment directly overlying the bedrock saprolite is the Cretaceous "Tuscaloosa" Formation (N. C. Div. Mineral Resources, 1958). These deposits consist of highly variable and irregularly bedded sands, pebbly and muddy sands, and clay lenses (Daniels and others, 1966, p. 161-163). Pebbly sands in the lower part of the deposit are commonly cemented firmly by limonite introduced from above by ground water. The formation is regarded as of fluvial origin.

The true age of the beds designated "Tuscaloosa" in Wake County remains uncertain because of absence of fossils and lack of detailed stratigraphic study. They may belong to either the Cape Fear Formation (lower part of Late Cretaceous) or to the Middendorf Formation (upper part of the Late Cretaceous) as defined by Swift and Heron (1969, p. 206-215), probably to the latter. They were designated as Upper Cretaceous on the Geologic Map of North Carolina (N. C. Div. Mineral Resources, 1958). Brown and others (1972, pls. 2 and 9), however, include these beds in their Unit F, which is upper part of Lower Cretaceous (Albian).

A good exposure of the "Tuscaloosa" may be seen on the road cut on N. C. Highway 50, 0.3 mile north of N. C. Highway 42 and half a mile south of Wake County. Resting on the nonconformity is a foot of sandy gravel with partly rounded quartz pebbles; this grades upward into 5 to 6 feet of limonitic sand and that in turn into 5 to 6 feet of blue-gray sandy clay. Above the "Tuscaloosa" here, and separated from it by a sharp disconformity, is 8 to 9 feet of mottled reddish brown sand with round quartz pebbles; this presumably is "Pinehurst" Formation.

A part of the "Tuscaloosa" is exposed in the road cut on N. C. Highway 42, 0.2 mile east of N. C. Highway 55, about two miles east of Fuquay-Varina. Two or three feet of gray, silty clay may be seen in the ditch; this is streaked and spotted with red and brown iron stain. This massive clay lacks lamination and it breaks into irregular blocks. Lying above the clay with a sharply distinct contact is 6 to 8 feet of brown sand of the Macks Formation (Miocene) and younger sediment.

The thickness of the "Tuscaloosa" Formation in northwest Johnston County (Daniels and others, 1966, fig. 3) is about 80 feet. This thickness decreases up dip to the northwest. Inconclusive data from water wells near Fuquay-Varina (May and Thomas, 1968, p. 110) suggest that the maximum thickness of upland sediment in southern Wake County is between about 40 and 80 feet, part or most of which is post-"Tuscaloosa."

Some basal upland sediment that rests on eroded crystalline rocks north and east of Terrible and Middle Creeks may be "Tuscaloosa" Formation, but most is probably overlapping younger deposits.

Eocene silicified limestone. Rock containing marine shells of Eocene age has been known for a century to exist in southeastern Wake County near Auburn. So far as can be determined, all fossiliferous rock found has consisted of loose blocks; no exposures of marine strata with Eocene fossils have been found in place. Locations of some earlier finds are not specific, and recent search has failed to confirm them. The present author's work (Parker, 1949 and 1965) leads to the conclusion that the fossiliferous rock is reworked Eocene derived from unknown but probably not distant sources and laid down as boulders and cobbles in much more recent upland and terrace sediments of various ages.

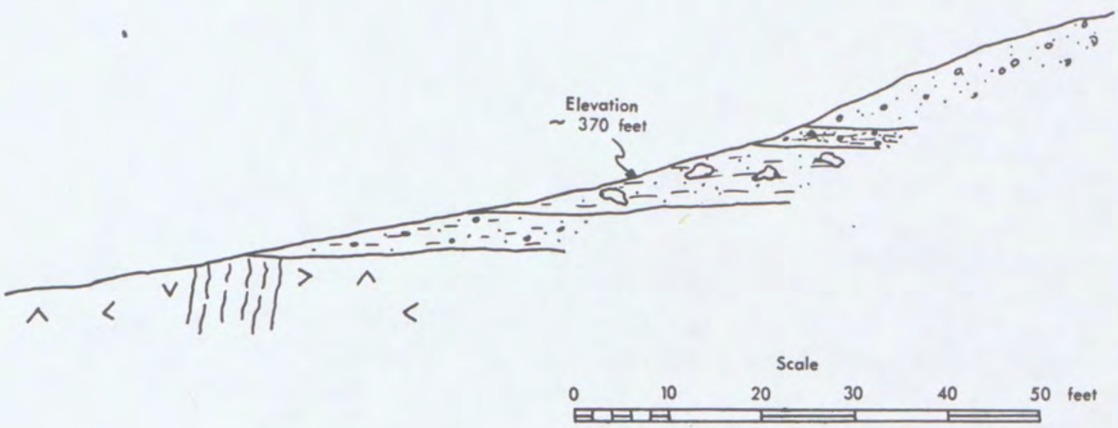
Kerr (1875, p. 150) reported a patch of Eocene fossiliferous rock "capping a hill 350 feet above the sea, on the railroad 7 miles east of Raleigh, a siliceous shell conglomerate of 2 or 3 acres extent and 6 to 10 inches thick." His geologic map of the state shows the locality a mile northwest of Auburn. Repeated search by the author in this vicinity has failed to reveal any fossils. Later, Kerr (1885, p. 79) repeated the description and stated that "fossils collected from this rock were identified as eocene (sic) by Conrad several years ago."

Clark and others (1912, p. 174-178) described similar rock near Auburn and provisionally referred it to the Trent Formation. A patch of Trent Formation was plotted on their map (ibid., pl. 1) just northwest of Garner, however, not near Auburn. Search in the Garner area has also failed to reveal fossils. Richards (1950, p. 14) reported fossils in the U. S. National Museum collected by C. W. Cooke and L. W. Stephenson from a road ditch near the railroad 1.6 miles west by north of Auburn. This must be near but a little west of Kerr's locality. It also has failed to yield fossils to recent search.

Silicified coquina has been known (J. L. Stuckey, oral communication) at least since the 1930's in western Johnston County almost on the Wake County line. The locality is 500 feet north of SR 1004 (old U. S. Highway 70) and 1200 feet east of the point where the county line crosses that road, near the head of a shallow valley at an elevation of 340 to 350 feet. Hard blocks of fossiliferous rock as much as 2 feet wide have been found partly embedded in the soil. Limonitic sandstone blocks are also common. Granite crops out a little lower in the valley and also at higher elevations to the west. Well-rounded quartz pebbles are abundant on the uplands. The fossiliferous rock is completely silicified (buhrstone) so that no carbonate remains. The poorly preserved shells are mostly fragments of pelecypods and gastropods, but coral and petrified wood are included. Richards (1948, p. 2-3; 1950, p. 14-15 and 75) tentatively identified and illustrated about a dozen species of probable Eocene age. The Geologic Map of North Carolina (N. C. Div. Mineral Resources, 1958; Stuckey and Conrad, 1958, p. 45) classifies the locality as Castle Hayne Limestone (middle and upper Eocene). Two small pieces of the same rock have been found half a mile to the south near the farm office of the State Agricultural Experiment Station on U. S. Highway 70 also at 350 feet elevation.

Another locality near the intersection of SR 2542 and 2555, a mile and a half northeast of Auburn was discovered (G. F. Needham, oral communication) in 1964 during construction of farm ponds (Parker, 1965). A patch of Coastal Plain sediment covers the high ground (about 410 feet elev.) in this vicinity for distances up to a mile from the crossroads and down to elevations of 350 to 370 feet, below which granite crops out extensively. Sediment containing fossiliferous cobbles is exposed in place along the spillway channel of the lower of two adjacent farm ponds at a point 1350 feet S. 13° E. of the crossroads. The section here is shown by Figure 12. The sediment rests nonconformably on granite that contains inclusions of metamorphic rock. The lower 11.5 feet consists of semi-consolidated, pebbly, sandy clay. Fragments of sandy, silicified rock with pelecypod fragments and petrified wood are common in the interval from 4 to 10 feet above the bottom. The elevation of the fossiliferous material is about 370 $\pm$ 3 feet. Bedding is indistinct, and the lower 11.5 feet seem to be an uninterrupted stratigraphic unit. Above this lies more than 10 feet of unconsolidated, pebbly, clayey sand which seems to be a distinct, younger deposit.

Loose pieces of buhrstone also occur in the patch of upland sediment at Garner at the junction of SR 2547 and SR 2613 at an elevation of about 390 feet. Buhrstone cobbles are likewise embedded in a terrace deposit on the northeast side of Swift Creek valley on SR 2704 at a point 0.15 mile south of SR 2703 at an elevation of about 340 feet.



LITHOLOGY	THICKNESS IN FEET	DESCRIPTION
	> 20	UNCONSOLIDATED PEBBLY CLAYEY SAND
	1.5	SEMI-CONSOLIDATED PEBBLY CLAYEY SAND
	6	PEBBLY SANDY CLAY WITH COBBLES OF EOCENE FOSSILIFEROUS BUHR-STONE
	4	PEBBLY SANDY CLAY
	?	GRANITE WITH INCLUSIONS OF METAMORPHIC ROCKS

Figure 12. Cross section of upland sediment, 1350 feet S. 13° E. from cross-roads of SR 2542 and SR 2555, near Auburn, N. C.

Daniels and others (1966, p. 168) report that a thin discontinuous layer of similar buhrstone occurs 6 to 12 inches above the base of the Macks Formation in western Johnston County about 9 miles southeast of Wake County and in neighboring northeast Harnett County within 3 miles of Wake County. This material also seems to be reworked, though some may be in place. The elevation of this buhrstone is about 240-250 feet. The Macks Formation is dated by fossils as lower part of upper Miocene (Daniels and others, 1966, p. 166).

A thin layer of probably Eocene silty clay is reported by Daniels and others (1972, p. 29 and fig. 17) immediately beneath the Macks Formation in Johnston County just west of N. C. Highway 50 about 0.2 mile north of SR 1305,

The nearest locality to Wake County where Eocene strata are still in place seems to be Paint Hill in southeastern Moore County, 2 miles east of Aberdeen. Bartlett and others (1969) describe a section over 30 feet thick of opal claystone, glauconitic sandstone, and buhrstone containing veinlets and geode-like fillings of wavellite and variscite. This deposit lies within 50 feet above the top of the Cretaceous Middendorf Formation, at an altitude near 400 feet.

In summary, then, cobbles and boulders of buhrstone containing Eocene fossils have been found at half a dozen places in southeastern Wake County and in adjacent counties. They are subrounded and range in size from a few inches to at least 2 feet. They are enclosed in variably sorted sediment consisting of quartz pebbles, sand, silt, and clay. The buhrstone has not been observed in Wake County as a stratigraphic unit in place but only as reworked fragments. The fragments occur near the base of deposits that blanket upland drainage divides and in terraces on valley sides at elevations ranging from 240-250 feet in Johnston County and up to 390 feet near Garner. They occur in upper Miocene deposits (Macks Formation) and other undated but presumably younger deposits (probably "Pinehurst" equivalent). The large size of some fragments suggests that they have been moved a relatively short distance. Their presence in flat-lying sediment laid down on an area of low relief suggests wave action as a plausible source of the considerable energy required for their erosion and transportation. It is speculated that Eocene deposits similar to those at Paint Hill formerly extended inland into Wake County. No trace of these deposits is now known. Marine transgression or stream bank undermining in later Cenozoic time may have ripped up these beds and deposited chunks of buhrstone in various sediments of post-Eocene age.

Macks Formation. In southeastern Wake County the Cretaceous sediments are unconformably overlain by the Macks Formation (Daniels and others, 1966, p. 163-168). This distinctive deposit is a massive, mica-bearing, very fine sandy loam and sandy clay loam. Silt uniformly exceeds 10 percent and averages 20 percent. The sand is almost entirely fine to very fine (0.25 mm). The upper part is usually more micaceous and finer grained than the lower. Discoidal quartz pebbles with rough surfaces occur in places at the base. The thickness in most places ranges from about 20 to 30 feet but in places the formation seems to have been cut out by post-depositional erosion.

Fossils have been found at a few localities in the Macks Formation (ibid., 1966, p. 167-168). They include molds and casts of pelecypods and gastropods and rare microfossils. These fossils indicate an age in the earlier part of Late Miocene (equivalent to part of the lower Yorktown Formation), and a marine environment of deposition.

The Macks Formation occurs in Wake County only in the southern corner near Fuquay-Varina and along the southeastern boundary (ibid., fig. 5). It is covered by younger deposits and so crops out only along valley sides and in excavations. Specific localities where it is exposed include the road cut of U. S. Highway 401 at the railroad overpass east of Fuquay-Varina and on SR 2741 half a mile south of SR 2740. The deposit seems to thin out northward and to disappear north of Middle and Swift Creeks.

"Pinehurst" Formation. The upland surfaces along the southeast side of the county, in a belt some 5 to 10 miles wide extending from Fuquay-Varina to Zebulon, are mantled by unconsolidated gravelly sand. In the Fuquay-Varina area this deposit has been shown (Daniels and others, 1966, p. 168-172) to overlie the Macks Formation and hence to be post-late Miocene in age. This uppermost sediment is similar in composition and topographic position to deposits mapped as the Pinehurst Formation in Moore County (Conley, 1962, p. 18-19), and that name is tentatively extended into Wake County. "Pinehurst" Formation is used in this report in a general sense to designate the uppermost loose, poorly sorted sands and not as restricted by Bartlett (1967, p. 73-89) to aeolian, cross-bedded deposits. Clark and others (1912, p. 258-266 and pl. XIII) included this material as part of the Lafayette Formation, a term abandoned in 1915 because it had been applied to deposits of various ages. Stephenson (in Clark and others, 1912, p. 260) did not study the inner (northwest) margin of the deposit but accepted Kerr's mapping (1875, Geological Map of North Carolina). Later such deposits were termed "high level gravel, sand, and clay" by Mundorff (1946, p. 27) in the five-county Halifax area to the northeast, and this name was adopted by Richards (1950, p. 35). Doering (1960) correlated these deposits with the Citronelle Formation of the eastern Gulf Coast; his small scale maps show only small patches of Citronelle in southeastern Wake County. Both Stephenson and Doering included (in Wake County) underlying material now known to belong to older formations. Conley (1962) classified the Pinehurst as Late Miocene but conceded that it might be Pliocene or Early Pleistocene. Bartlett (1967, p. 74-75) designated the Pinehurst in his restricted sense as post-Eocene, perhaps containing sediments as old as Miocene and as young as Pleistocene and Recent. Stephenson thought the Lafayette to be Pliocene (?) and Doering (1960) concluded that the Citronelle was Early Quaternary (preglacial Pleistocene). Mundorff (1946) thought the high level sediments might be of several ages, some perhaps as old as Cretaceous. My work supports this latter conclusion.

The composition of the "Pinehurst" Formation is variable. It consists of abruptly changing mixtures of gravel, sand, and clay; silt is notably low (Daniels and others, 1966, p. 168). The sand is mostly coarse or medium grained and commonly is pebbly. Gravel is most common near the base and usually is mixed with finer sediment. Bedding is generally irregular or lacking. The thickness is about 25 feet or less.

Clastic dikes cut through the deposit in places. Crossbedded clayey sand and gravel exposed for about 100 feet along SR 1375 (Lake Wheeler Road) about 0.4 mile north of SR 1010 have many dikes ranging from a fraction of an inch to a foot in thickness. The dikes have a roughly rectangular pattern trending north to north-northwest and at right angles. They consist of clay and limonite strongly laminated parallel to the dike walls. Some thin ones consist of limonite only and composite dikes have limonite next to the walls. They extend through the sediment (some 7 feet thick) and at least 6 inches down into the underlying saprolite. The dike material is presumed to have been introduced from above by ground water. Similar dikes in the North and South Carolina Coastal Plain are described by Heron and others (1971, p. 1801-1809).

The "Pinehurst" Formation constitutes the uppermost deposit in the Fuquay-Varina area, where it occurs up to elevations of 460-470 feet. It thins northwestward so that the sediment exposed at the surface in the Wilbon vicinity belongs to the "Tuscaloosa" Formation (R. B. Daniels, oral communication). The smaller deposits along the drainage divides north of Middle Creek and those in the Garner-Auburn vicinity (350-410 feet) and the Zebulon-Wendell area (290-360 feet) seem also to be "Pinehurst" equivalent, though it is possible that some are "Tuscaloosa." They rest directly on peneplained crystalline rocks. The upland sediment in these larger areas thins out to the north and west, as the land elevations rise, until it disappears. Still farther west are small, patchy outliers of uncertain affinity; these are described in the following section.

All observers agree that the "Pinehurst" Formation and its several named equivalents is of fluvial origin. Doering (1960, p. 200) conceived it to be a vast detrital apron derived from the Blue Ridge area and spread by rivers over a "peneplain or near-peneplain" eroded across Piedmont and Coastal Plain during Miocene and Pliocene epochs. Recent discovery (Daniels and others, 1966) of the Macks Formation of late Miocene age restricts such a period of erosion to the Pliocene. The presence of slabs of Eocene buhrstone at least two feet wide in "Pinehurst" (?) deposits, lying along upland crests at 350-370 feet elevations, might raise doubt whether streams on a peneplain could have moved such large clasts. Undermining of stream banks could have been responsible.

Undifferentiated upland gravel and sand. Throughout central, western, and northern Wake County are hundreds of small irregular patches of gravelly and sandy sediment on the uplands. They occupy the highest parts of the local drainage divides and are distinct from the terrace deposits on the valley sides, though their composition is similar. They overlie both crystalline rocks and Triassic sediments. They range in area from about a square mile down to less than an acre, being smaller and more widely spaced toward the north and west. The thickness in places is 10 or 20 feet but commonly is only 1 to 5 feet. The locations of many such patches are shown on pl. 4; to map all in detail would require an inordinate amount of time considering their slight practical importance. The presence of upland sediment in the northwestern half of Wake County was recognized a century ago by Kerr (1875, p. 153; 1881, fig. 2). His mapping was accepted by Stephenson (in Clark and others, 1912, pl. XIII), but his work seems to have been disregarded by most workers in recent years. The earlier small-scale mapping erred in showing this sediment as too continuous in southwestern and eastern Wake County and as absent in west-central parts.

The sediment in these patches is poorly sorted gravelly sand or sandy gravel, commonly with more or less silt and clay. Much is sandy red clay with scattered small rounded pebbles embedded in it. Most is heavily stained with iron and in places is semi-consolidated with limonite cement. Such cemented material is exposed a mile northwest of Leesville on SR 1839, a quarter of a mile east of SR 1840, and on U. S. Highway 70 at a point 0.6 mile southeast of SR 1837. The pebbles consist mainly of quartz, commonly iron stained and somewhat crumbly. Many cobbles and pebbles are subangular, with barely rounded edges, mixed with others that are subround to well rounded. Pebbles of ilmenite up to an inch in diameter occur in upland sediment along SR 2009 between SR 2002 and 2010, 2 miles west of Falls. Some sand is feldspathic, especially where the deposit overlies granite.

The bottom of the upland deposits is commonly a sharp nonconformity below basal gravel, and in places it is a definite channel. Less commonly, however, fine-grained sediment rests on saprolite with indistinct contact.

A characteristic feature of these upland sediment patches, including some larger areas of the "Pinehurst" Formation, is the presence of innumerable limonite nodules or concretions. In places they form a virtual pavement at the land surface where finer material has been washed or blown away, as was noted long ago by Emmons (1856, p. 213). These irregularly round lumps and disks range from about 0.1 to 0.5 inch in diameter. They are brown to almost black. They lack any internal concentric lamination other than some color variation. A little fine sand may be included. Sesquioxide nodules are mentioned (Cawthorn, 1970) as constituents of soils in the Faceville, Norfolk, Troup, and Wagram series, all associated with Coastal Plain sediments. The nodules are probably even more widespread. These nodules are presumed to be concretions formed by ground water, but no study of them has been made. Some sesquioxide nodules are plinthite (iron-rich soil aggregates that harden after several cycles of wetting and drying); these form in mottled soils under the influence of a fluctuating water table (R. B. Daniels, written communication; Daniels, Gamble and Cady, 1971, p. 81-84).

The presence of sediment in many of these upland localities is detected solely by observing rounded pebbles in the soil. The soils in many such areas have been mapped (Cawthorn, 1970) as Appling gravelly sandy loam and even as Appling sandy loam. These are stated (ibid., p. 9) to have been "weathered from granite, gneiss, schist, and other acidic rocks." Clearly, however, the round quartz pebbles could not have been derived from the saprolite of these crystalline rocks. The sediment is so thin in many places that cultivation may have mixed sediment and underlying saprolite from crystalline rocks. This condition is widespread between Zebulon and Rolesville.

The existence of even thin upland sediment in areas of metamorphic and igneous rocks is clearly demonstrable by the presence in the soil of innumerable rounded quartz pebbles which are not components of the underlying rocks or their saprolites. Upland sediment in areas of Triassic sediments, however, is less readily proven because the pebbles observed in the soil might have been derived from either Triassic sediments or from the upland deposits. Over a wide area at Apex and vicinity, thin deposits of unconsolidated quartz gravel and sand with varying amounts of clay underlie the upland flats at altitudes from about 480 feet to the summit a little higher than 510 feet. They overlie the typical Triassic deposits conformably or with only local channel disconformity. The relationships are especially clear northeast of Apex along SR 1435. Pebbly mudstone extends along the flat upland for 0.45 mile northeast of SR 1308. On the downslope at an elevation of about 480 feet the upper brown pebbly mudstone abruptly gives way to typical Triassic red fanglomerate. Pebbles in the upland sediment are exclusively quartz, while in the fanglomerate the pebbles are chiefly various metamorphic rocks.

These uppermost deposits near Apex were regarded by Stuckey (1965, p. 132) as post-Sanford floodplain deposits and a part of the Newark series. Similar deposits near Bonsal were believed by May and Thomas (1968, p. 100) to be Cretaceous (?) in age. Because the character of this uppermost sediment is like the upland sediment in nearby crystalline areas to the east and different from the local Triassic formations and because the topographic positions and elevations are consistent with one another, the author regards the uppermost Apex beds as post-Triassic and of either later Cretaceous or of Pliocene-Pleistocene age.

The elevations of the base of these scattered upland patches range mainly between 340 and 520 feet. Elevations increase generally toward the northwest though local diverse variations of 30-40 feet in a mile are common. Although essentially all larger interstream divides bear upland sediment, the deposits are not continuous along them. Gaps commonly occur at low spots.

Some high points along certain divides are not sediment covered. An instance is the knoll on N. C. Highway 50 a quarter of a mile south of SR 1829 (Strickland Road); sediment is lacking here at an elevation of 500 feet though it is present half a mile south at 470 feet. However, at Six Forks 1.5 miles to the east, gravel is present from about 490 feet to the local height of land above 500 feet. Similarly, the summit (+470 feet) of the conical hill (Iron Mountain) back of Stony Hill Church at the intersection of SR 1917 and 1918 in northern Wake County is an outcrop of limonite-stained siliceous rock in an ultramafic body. Gravel is present, however, 30 feet lower on the south side. Much of this divide from the church southward along SR 1917 for more than a mile to and along N. C. Highway 98 is covered with sediment containing coarse gravel, down to elevation of about 400 feet.

The basal elevations of the sediment also vary locally in steps along the larger drainage divides. These ridge crest upland terraces with sediment cover are described later with geomorphic features; elevations are given on pl. 4. They are well developed south and east of Leesville.

Of special interest is the large outlier of sediment in the vicinity of Leesville, the highest part of the county. The gently undulating upland ridges forming the divide between drainage southward to Crabtree Creek and northward to the Neuse River are mantled with sediment from elevations of about 500 feet up to high knolls of 545 feet. This outlier stretches some 3 miles north-south and 1 1/2 miles east-west. The sediment here is especially iron stained, and limonite concretions are a notable component of sediment and soils. This outlier, together with small patches at Purnell, Six Forks, Cary, and Apex, all at about 500 feet elevation (fig. 13), represents the highest sedimentary deposit in the region. The nearest Piedmont elevation of this height is 18 miles to the west.

Likewise, Adam Mountain near Bayleaf has peculiar interest. This steep-sided monadnock ridge has many boulders and outcrops of limonite-stained siliceous rock in an ultramafic body. Midway along the summit

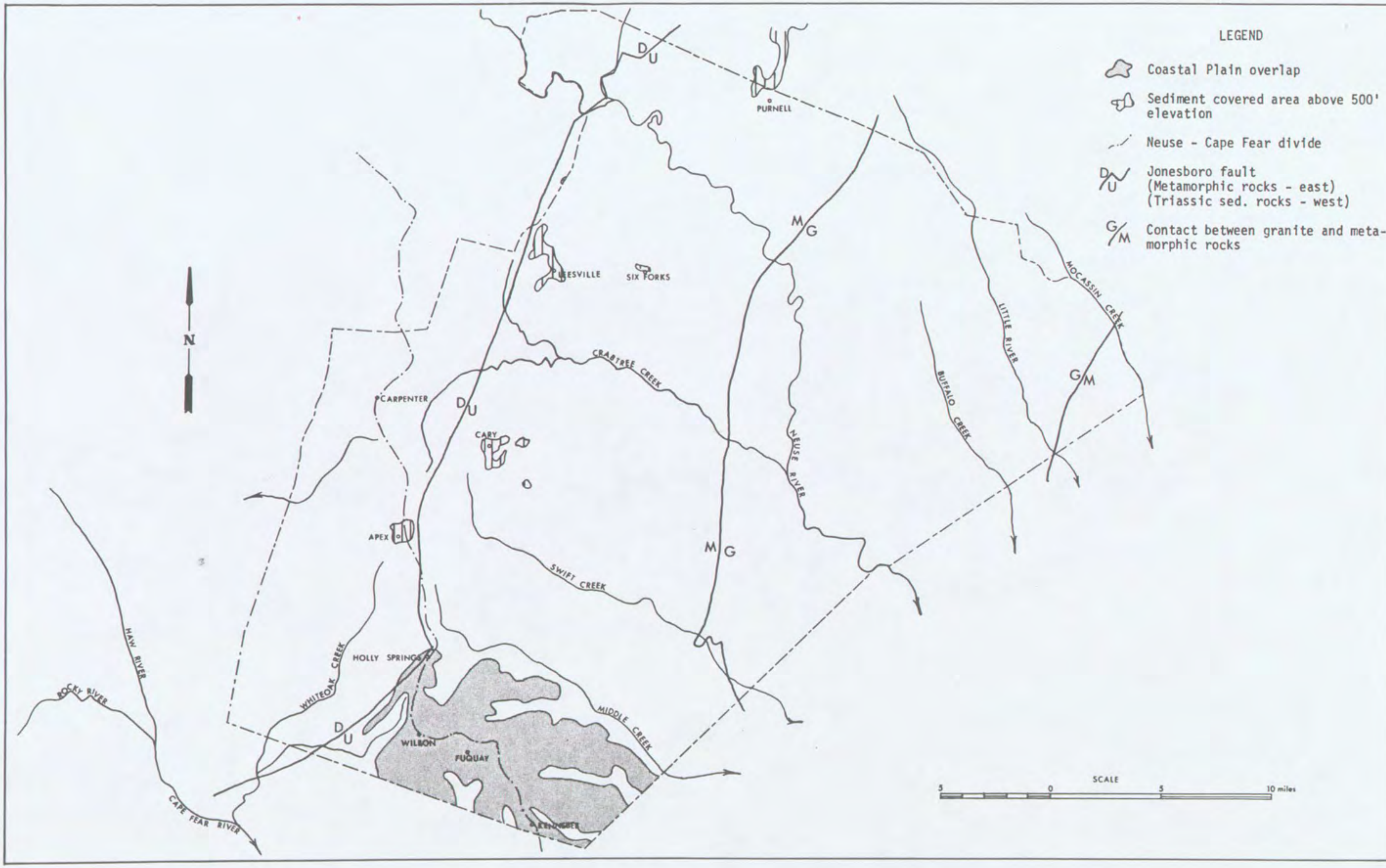


Figure 13. Map of Wake County showing relation of Neuse-Cape Fear Drainage divide to geologic features

ridge, however, at elevation above 470 feet, is brown, well-rounded quartz gravel. On the west slope, 50 to 100 feet lower, wide areas are covered with hard-packed, limonitic, gravelly sediment.

The upland deposits seem clearly to be of fluvial origin. The abrupt variation in composition and texture both vertically and horizontally, the mixture of well-rounded and nearly angular pebbles, and the presence in places of filled channels at the bottom are features identical to the floodplain deposits along existing streams. The poorly sorted character of the deposits and the rather angular quartz fragments suggest the possibility of colluvial origin, that is, that the material accumulated by slow gravity transport or creep of saprolite down slopes. Such material does, in fact, exist along valley sides, but this origin is not possible for the deposits on the highest parts of the land surface, especially since well-rounded pebbles are a nearly universal constituent. The Leesville outlier is particularly convincing on this point.

The upland sediment patches, then, must be a consequence of peneplain erosion. The local variations in elevation of the base - a few tens of feet - is consistent with the shifting positions of streams during erosion of the region to near sea level. Subsequent uplifts have permitted modern drainage to sweep away much of the earlier deposits, reducing them to remnant patches. The thicknesses of these patches also may have been reduced, though the extremely low gradients along many upland ridges suggest that the deposits have been little altered along the ridges though narrowed by flank erosion.

The age of these outliers remains uncertain; perhaps they belong to more than one epoch. They are likely to be basal portions of the "Pinehurst" Formation and hence Pliocene (?), but it is conceivable that some at least are the remains of the "Tuscaloosa" Formation of late Cretaceous age. In the Garner-Auburn area, the upland sediment resting on crystalline rocks is certainly post-Eocene because it contains clasts of Eocene buhrstone. The key to the age problem probably lies in detailed step-by-step correlation of closely spaced drill holes up the drainage divide of the Cape Fear and Neuse Rivers from the Fuquay-Varina area into western Wake County.

Terrace and Floodplain Sediments

Terrace deposits. Many valley sides throughout the county, especially those of the larger streams, are mantled by patches of terrace sediment. These deposits have nearly flat upper surfaces that slope gently toward the valley axis. They rest with abrupt nonconformity on bedrock shelves - seldom exposed - that also slope generally toward the present streams. The terraces (or "second bottoms" as they are sometimes called) consist of irregular patches along the valley sides, interrupted by gullies and small tributary valleys, and are not continuously traceable. They may or may not be matched on the opposite side of the valley by a similar terrace remnant at about the same level. Terraces commonly exist at more than one level in the larger valleys; as many as three may be recognized locally. Along major streams draining southeastward, the southwest (right) sides of the valleys are generally steeper and shorter than the northeast side; terraces are rare on the steeper sides.

The sediment in the terrace deposits is a poorly sorted mixture of coarse and fine gravel, sand, and clay, exactly like that in modern floodplains. The thickness is commonly from a few feet to 10 or 20 feet. The terrace patches are remnants of earlier floodplains formed by the streams at various times when the valley bottoms were at the terrace levels. Recurrent lowering of the base level of erosion, either by lowering of sea level or by uplift of the land, rejuvenated the streams at intervals so that they destroyed most of the old floodplains and established new ones at lower levels.

Along the southeast side of the county, terrace and upland deposits between about 220- and 270-foot elevations presumably belong to the "Brandywine Formation" (Daniels and others, 1966, p. 172-175) of Pliocene or early Pleistocene age. Such deposits extend northward up the Neuse River valley nearly 20 miles. Low terraces some 10 to 20 feet above present drainage levels must be of later Pleistocene age. The terrace sediments have not been mapped for this investigation, in which interest is focused on bedrock geology, and the age relations are not worked out.

Floodplain deposits. The Neuse River and the larger tributary streams in the county have developed floodplains along much of their courses (see pl. 4). These flat bottom lands are underlain by poorly sorted sediment ranging in size from cobbles to clay. The alluvium rests with abrupt nonconformity on eroded bedrock, which in most places is completely concealed. The deposits comprise gravelly sands laid down in channels, over-bank flood sheets of sandy silt, lake sediment ranging from coarse to fine, and clays rich in organic matter accumulated in swampy spots. The thickness ranges from a few feet to 20 feet. Width may be less than 50 feet along small branches or more than 2000 feet in places along the Neuse River. The deposits are discontinuous along the streams, being interrupted where the valleys narrow. Along straighter reaches of the streams, the floodplain deposits lie on both sides but at curves are usually confined to the concave side. These sediments were formed during the Pleistocene and Holocene epochs. They are the youngest sediments in the county and are being intermittently added to during times of flood.

Modern deposits filling a small man-made lake (Lake Boone) in northwest Raleigh have been described in detail by Kautzman and Cavaroc (1973). This lake was destroyed by delta deposits within a 40-year period during urbanization of the drainage basin. The floodplains as topographic features are described later in the section on geomorphology.

GEOMORPHOLOGY

The land forms in Wake County are chiefly those typical of the Piedmont region combined in places with those of the Coastal Plain. The topography is a composite of surfaces formed at various times and in various ways. Most of the land surface is erosional in origin, but part is mainly depositional. The ages of the various land forms range from late Cenozoic (Pliocene ?), or perhaps earlier, to recent times. Variations from place to place result from differing stages reached in landscape evolution, differences in processes at work, differences in underlying materials, and changes in elevation with respect to sea level.

The lowest point in Wake County is about 140 feet altitude where the Neuse River passes into Johnston County, and the highest point is 545 feet on a hilltop 1.5 miles north-northwest of Leesville.

Piedmont Peneplain

The overall character of Wake County's topography derives from its being in a dissected peneplain. As one views the area from a high building, the outstanding feature is a nearly flat, gently undulating plain stretching out on all sides to a nearly level skyline. Carved into this plain and destroying much of its former surface is a network of valleys. This plain coincides with the flat uplands along the drainage divides and it slopes gently eastward. Its elevation is about 300 feet near Zebulon and about 500 feet near Leesville; thus, it has a tilt of about 8 feet per mile. This upland surface bevels across all the old metamorphic and igneous rocks and the Triassic sedimentary rocks. It is a peneplain eroded by streams in two main stages over an immensely long time. Thousands of feet of rock that once extended above the present land were eroded during recurrent uplifts of the region. During late Paleozoic and early Triassic times, a peneplain formed that now exists only where buried by Triassic sediments. In late Triassic time, renewed erosion cut still deeper, and the Triassic basins were filled. During the Jurassic and early Cretaceous, a second peneplain developed that was later buried by Cretaceous sediments. During the Cenozoic era deposition and erosion alternated, so that thin fluvial and marine deposits were spread over the peneplain and then partly removed. Thus, a large area around Fuquay-Varina is a sandy plain of deposition - an extension of the Coastal Plain - seemingly but little altered by subsequent erosion. The uplands of central and western Wake County, on the other hand, retain only thin veneers of sediment or none at all, so that the present upland surface almost coincides with an ancient surface of early Cenozoic, Cretaceous, or possibly even Jurassic age.

The boundary between the relatively flat, sediment-covered Coastal Plain to the east and the rougher Piedmont region of deeply eroded, old crystalline rocks is the Fall Line, so called because rivers crossing this boundary formed rapids or waterfalls as they passed eastward onto more easily eroded sediment. These falls limited navigation and supplied water power, thus localizing early settlements, some of which developed into such cities as Baltimore, Washington, and Richmond. In most of North Carolina and to the south, however, the unconformity beneath the Coastal Plain sediments dips so gently eastward that the Fall Line widens to a zone of 20 miles or more, in which tongues of sediment extend westward along drainage divides, alternating with extensions of crystalline rocks eastward down along the valley bottoms. Raleigh lies in the Fall Zone and has been erroneously designated as a Fall Line city in many authoritative works. In fact, of course, Raleigh is not on a river, though it is near the Neuse River, and its site was chosen by legislative action unrelated to geologic factors.

Stream Valley System

A complex network of stream valleys has been incised into the peneplain, so that more than half of the land surface is made up of valley sides and bottoms. The pattern of this drainage system is dendritic, the tributary streams joining the creeks and rivers like the twigs and branches of a tree. Most of the county drains generally southeastward into the Neuse River, which crosses through the middle of the county, but about a fifth drains southwestward by tributaries of the Cape Fear River. The drainage divide (fig. 13) extends northward from Kennebec and Holland to Fuquay-Varina, then west to Wilbon, north through Holly Springs, Apex, and Upchurch to Carpenter, east to Clegg and again north to Nelson, Bethesda, and Durham in Durham County. The divide thus runs generally northward averaging N. 10° W. but bends sharply for two east-west stretches of 2 and 4 miles. Its elevation is about 360 feet at Kennebec and rises above 480 feet near Wilbon, is 470 feet at Holly Springs, then drops below 400 feet between Holly Springs and Apex, rises to 510 feet in Apex, and then drops to near 400 feet on into Durham County. Most of this primary drainage divide does not follow any geologic boundary. The southern portion lies across the Coastal Plain area, the part from Holly Springs to Apex coincides closely with the Jonesboro fault, and the remainder north of Apex lies within the Triassic basin.

The drainage divide and overall stream pattern in Wake County and the adjacent region are largely independent of the various underlying bedrock subdivisions. This argues that the general positions and directions of the major streams were fixed during the time of peneplain erosion by the regional tilt toward the sea. If the former extent of the Coastal Plain sediments were considerably greater than at present, the drainage pattern may have been acquired on that depositional surface and retained as the sediment was stripped away. It is more likely, however, that present major drainage lines were established during peneplanation, perhaps as long ago as early Cenozoic, and interrupted though little modified by Miocene (Macks) marine transgression. The problem, of course, is beyond the scope of a county investigation.

Valley sides slope gently but not uniformly from the uplands toward the streams. They have numerous sediment-covered terrace patches and are scored by gullies and small tributary valleys. Along the upper reaches of small streams, the lower slopes of opposite valley sides meet one another at the stream channel. Most valley sides, however, end abruptly at the margins of the floodplains. These two kinds of surfaces commonly meet with a distinct angle that is readily apparent in the field. In places, however, the two surfaces have been graded to a curve by slope wash or by deposition of alluvial fans. Locally the toe of the valley side is very steep, with slopes of 30-40 degrees for heights of 20 to 80 feet at points where streams now or in the past have actively eroded their cut-banks on the outsides of curves, thus widening the bottom of the valley. Where the stream no longer flows against an abandoned cut-bank, the steep valley side is scalloped in plan and generally has a swampy spot in the floodplain at the foot.

Floodplains of varying widths lie along all but the smaller tributary valleys. These flat valley bottoms range from a few yards in width to as much as 2000 feet. They lie along parts of the valley where the streams have swung from side to side eroding laterally into less resistant rocks. These flats have been built up by flood waters that exceed the capacity of the normal channels and hence spread alluvium over adjacent low ground. Thus, they are largely depositional features rather than erosional like the other parts of the valleys. They are the most recently formed feature of the landscape and will be modified in the future during major floods. The extent of the larger floodplains is shown on plate 4; they are omitted from plate 1 so as not to obscure bedrock features. Local details of the floodplains are clearly portrayed on the more recent topographic maps (U. S. Geological Survey) by abrupt changes in contour spacing between valley sides and bottoms. Floodways along Crabtree and Walnut Creeks in and near Raleigh have been mapped at large scale (1 inch equals 1000 feet) by the Corps of Engineers (1972). Deposits underlying the floodplains have been described in the section on Cretaceous and Cenozoic sediments.

Most valleys have narrow stretches along which floodplains are nearly or entirely lacking. These constrictions reflect the presence of underlying harder bedrock, though evidence of this is not everywhere apparent. Falls of the Neuse, however, is obviously the consequence of quartzitic felsic gneiss, as are the sites of Lassiter's Mill and Yates Mill. Dozens of such narrow, rocky places have provided sites for small mill dams in the past of which only a few now remain. At such places quartz-rich gneisses or massive granite, as at Milburnie, are present. Water power in the county was briefly described by Swain and others (1899, p. 121-123).

Some larger stream valleys tend to have an asymmetrical cross-section; the right side (looking downstream) is steeper than the left, and the stream lies mainly near the steeper slope. This is most noticeable in such southeast-flowing streams as Middle and Swift Creeks (fig. 14) but is also apparent, though less pronounced and consistent, in Crabtree Creek, Upper and Lower Barton Creeks, and others but not in the Neuse River in Wake County. This asymmetry was noted a century ago by Kerr (1873) and attributed to the earth's rotation (Coriolis effect), whereby moving bodies in the northern hemisphere are deflected to the right. Numerous valleys with steeper left banks and the feebleness of the Coriolis force challenge the explanation. Local variations of dip or lithology seem more likely causes.

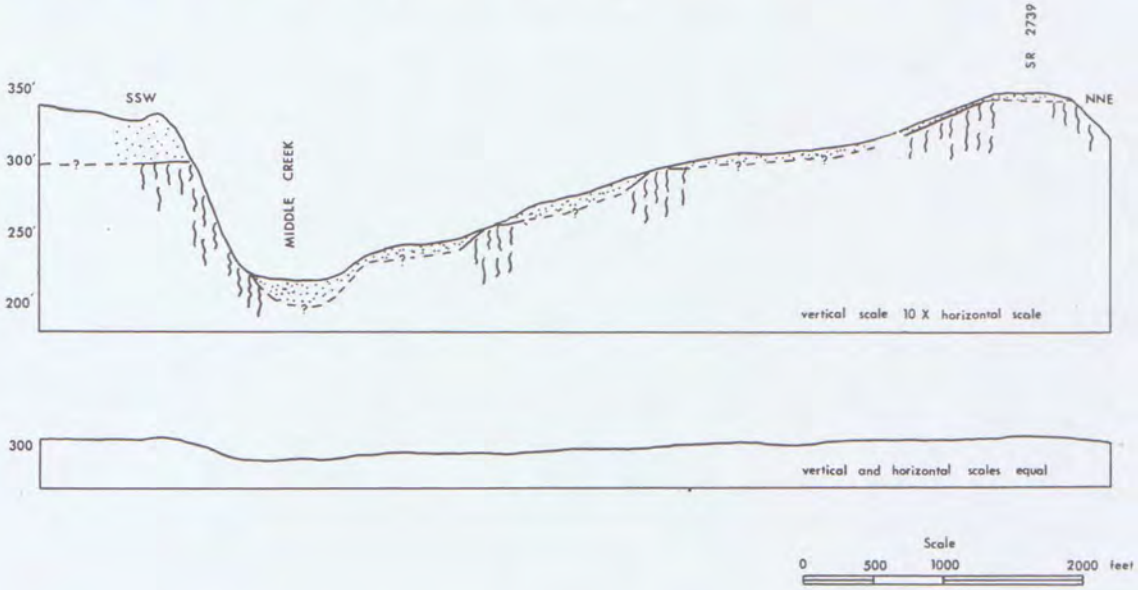


Figure 14. Cross section of Middle Creek valley, southern Wake County, N. C., showing upland, terrace, and floodplain sediments. Drawn along SR 2739 (N. 25 1/2° E.).

Upland Terraces

Ridge crests separating drainages of the larger tributary streams do not descend lengthwise in an even slope or a smooth curve but generally by a series of steps. The ridges are divided by steeper scarps into a series of nearly flat to gently sloping terraces. The scarps are some 20 to 60 feet high, with slopes of about 1/20-40; the terraces are nearly flat for a quarter or half a mile, sloping only about 1/200. Scarps and terraces on nearby divides may or may not correspond in level. These ridge-top terraces are more or less blanketed with upland sediment (described earlier). The scarps may provide exposures of bedrock though they are usually obscured by colluvium. These features are readily apparent on the modern, large-scale (1:24,000) topographic maps but less so on earlier maps (1:62,500). No detailed study of these features has yet been made.

In the Atlantic Coastal Plain farther east than Wake County, a series of extensive terraces separated by scarps has been described (Clarke and others, 1912, p. 266-290; Cooke, 1931). These are regarded by most workers as of marine origin, formed at intervals of high sea level during interglacial intervals in the

Pleistocene epoch. The highest of these terraces is limited on the west by the Coates scarp with toe elevation of about 255 feet (Daniels and others, 1966, p. 178-180). This scarp on the uplands lies east of Wake County though fluvial counterparts extend up the Neuse drainage into the county. The presence of this marine topographic feature so near Wake County raises the possibility that still higher stands of the sea may have been responsible for erosional surfaces and upland sediment across Wake County. Though this concept cannot be rejected, the fluvial origin is favored by the variable elevations and heterogeneous character of the sediment.

A thorough investigation of terraces on upland ridges and valley sides, together with their superficial sediments, is needed to elucidate the erosional and perhaps tectonic history of the region during late Cenozoic time. All these features are aspects of the development of the existing valley system and are remnants of earlier landscape stages having different stream positions. The higher level surfaces are the older, and the formation of lower levels has involved partial destruction and modification of earlier land forms as the shifting drainage cut deeper into the peneplain. Much of this valley shaping occurred during the Pleistocene epoch when stream gradients and base level of erosion varied with sea level fluctuations controlled by waxing and waning of the continental glaciers.

Topographic Divisions

Though the land forms across Wake County seem generally about the same, closer observation shows interesting differences related to the four principal geologic sub-areas. Some of these differences are readily apparent to an observer outdoors, while others require the larger view provided by contour maps. Each area has some distinctive features not shared by the others. These geomorphic divisions generally grade into one another though sharp boundaries are evident locally.

Metamorphic area. The central and northern parts underlain chiefly by metamorphic rocks are a little more hilly than elsewhere. Local relief is commonly as much as 100 feet from upland to adjacent stream, and many slopes are steep. The highest areas in the county are irregular patches veneered with upland fluvial (?) sediment (pl. 4 and fig. 14) rising above 500 feet at Apex, Cary, Leesville, Six Forks, and Purnell. They are situated along the western side of the metamorphic area, Cary and Leesville being just east of the Jonesboro fault and Apex just west. They lie in a belt some five miles wide that trends about N. 35° E. The belt joins the Cape Fear-Neuse divide at Apex (elevation 510 feet), making an angle with it of about 40 degrees. No other areas reaching 500 feet are within 12 to 20 miles westward, on the west side of the Triassic area. The significance of these remnant topographic highs is uncertain.

Some small tributary streams in the metamorphic area tend to flow along north-northeast lines parallel to the foliation of the rocks; examples include much of House Creek and Beaverdam Creek in west Raleigh, Lower Barton Creek, and Richlands Creek west of Wake Forest. Their positions and courses probably are controlled by strongly contrasting resistence to erosion of adjacent rock layers. Larger streams and many smaller ones, however, flow across the foliation direction.

Adam Mountain at Bayleaf is a small monadnock in this belt that results from a partly silicified soapstone body. It is isolated by small creeks on the east, west, and north sides above which it rises over 200 feet to a summit elevation of 478 feet. This height, however, is only about 40 feet above the level of the general upland nearby. Although soapstone is mechanically soft, it is resistant to chemical weathering. This body contains much siliceous rock, thus permitting it to project above more thoroughly decomposed feldspathic gneisses. Iron Mountain back of Stony Hill Church is a similarly steep knob resulting from limonite-rich siliceous rock in an ultramafic body.

Triassic sedimentary area. The Triassic area in western Wake County is not only a structural basin but is also a topographic lowland as was recorded long ago by Mitchell (1842, p. 130). Elevations along the western side of the adjacent metamorphic belt commonly exceed 500 feet, while within the Triassic basin few uplands reach 450 feet, and most of the area lies below 400 feet. The highest points in the Triassic area in Wake County are about 510 feet at Apex and about 500 feet at a point 2 miles north-northwest of Leesville. Both of these points are just west of the Jonesboro fault; the former is also on the Cape Fear-Neuse divide (fig. 14). Elevations of the upland surfaces within the Triassic basin in and near Wake County decrease regularly westward, while those in the metamorphic and granitic areas decrease eastward. This can perhaps be partly accounted for as general slopes toward the major rivers, but the belt of highs north of Apex does not coincide with the drainage divide. These isolated topographic highs may be remnants of a former drainage divide between the areas underlain by metamorphic and Triassic rocks. Their significance, however, remains an enigma whose solution will require regional study.

A sharp topographic break marks in places the Jonesboro fault, the eastern limit of the Triassic rocks. Crabtree Creek has a floodplain half a mile wide northeast of Morrisville in Triassic rocks, but after crossing the Jonesboro fault near I-40, its valley narrows to a rocky gorge in the metamorphic rocks. Likewise, the Neuse River in northern Wake County meanders through a floodplain a mile wide in Triassic rocks but becomes a narrow, steep sided valley in the metamorphic rocks. In this vicinity several streams follow the Jonesboro (or Lick Creek) fault; these include the upper part of Little Beaverdam Creek, the lower part of Beaverdam Creek, the Neuse River at N. C. Highway 50, lower Lick Creek, and lower Laurel Creek. A distinct fault-line scarp exists for 1 1/2 miles north and 2 1/2 miles south of the point where the Neuse River crosses the fault. Small streams that drain westward down this scarp have unusually steep gradients in the crystalline area and extensive outcrops of hard rock. The dam site for the reservoir on Beaverdam Creek extends across the Jonesboro fault just north of the Neuse. This involves contrasting foundation conditions along the northeast and southwest parts of the dam, as well as the remote possibility of earthquake damage.

A fault scarp 2 miles west of Cary was described by Goldston and Stuckey (1930), but this is not confirmed by the writer's recent work. The earlier observations were made without the benefit of a contour base map. The Jonesboro fault in this vicinity cuts N. 20° E. diagonally across Coles Branch, the ridge to the west, and also northward across the unnamed valley north of N. C. Highway 54. No topographic expression of the fault is detected here or elsewhere to the southwest in Wake County except for the probably fortuitous coincidence of the primary drainage divide with the fault between Apex and Holly Springs and the fact that Jim Branch near Burt nearly follows the fault trace.

The significance of the general lower altitude of the Triassic lowland, the abrupt changes in topography along the Neuse River and Crabtree Creek valleys where they cross the Jonesboro fault, and the belt of sediment-covered hilltops above 500 feet elevation near the west side of the crystalline area is presently unclear. The Triassic rocks are commonly regarded as more readily eroded than the crystalline rocks and hence may have been worn to a relatively lower level. The great depth of saprolite on the latter suggests that they also should be readily eroded. Outcrops of hard rock, however, are common along streams in the crystalline areas but essentially absent in the Triassic. A greater rate of erosion in the Triassic should produce a subsequent drainage pattern with streams parallel to the belt. Major tributaries of the Cape Fear River in the basin have this relation. In the wide expanse of lower country between the 500-foot elevations east and west of the basin, at sites 0.5 to 6 miles west of the Jonesboro fault, patches of upland sediment lie on ridge crests at elevations ranging from 330 to 370 feet. Though this might suggest downfaulting of the basin since peneplanation, it may instead indicate it was worn lower during that process. Regional study is required.

Granitic area. The eastern granitic part of the county is somewhat subdued, rolling country. Hilltops tend to be broad, gently sloping, dome or shield shaped. Local relief is commonly less than 100 feet, and steep slopes are rare. Little River, Buffalo Creek, Marks Creek, and Poplar Creek, all in granite, have straight, parallel courses a little east of south. This is the same trend as the persistent diabase dikes in this area. Mapped dikes extend along much of the valleys of Marks Creek and Poplar Creek. An aeromagnetic linear high of the sort caused by diabase coincides with Buffalo Creek for 5 miles. Neither dike nor magnetic high, however, is known along Little River. Other dikes and magnetic linear highs are not associated with valleys, and the widths of the dike outcrops are insignificant compared to valley widths. The parallelism, then, must be coincidental unless both result from some unrecognized cause.

Distinctive of the eastern area are the granite "flatrocks". These wide, gently sloping outcrops of hard granite range from a few square yards up to several acres in extent. They lie mostly on lower and middle slopes and commonly extend down to small streams, but some small ones are on or near hilltops. The surfaces are smooth though undulating. The only one observed outside the granite area is in felsic quartzitic gneiss about two miles south of Falls on both sides of SR 2010 and a quarter of a mile west of SR 2000. The hard rock in such outcrops is little weathered, though similar rock in the vicinity has deep saprolite. White (1945, p. 280) reports that "they pass under residual soils. . .which in some places are capped by a veneer of marine deposits." On the other hand, flat-rocks along U. S. Highway 70 near Auburn at a point 0.4 mile west of SR 2558 at an elevation of 350 feet are overlapped on the uphill side by gravelly sand. Upland sediment has also been observed on several other such outcrops in eastern Wake County. Further investigation of the immediate surroundings of the flat-rocks is needed to demonstrate how they end and what covers them. The writer believes these flat-rocks to be patches of old unconformities once covered with sediment and later laid bare by erosion and that their age may date back to early Pleistocene or Pliocene times. Two readily accessible, good examples of flat-rocks are: (1) beside U. S. Highway 64 just northeast of SR 2339 (0.9 mile west of Franklin County line) and (2) at Mitchell Millpond on Little River just west of N. C. Highway 96, north of SR 2224, and east of SR 2300 (about 4 miles east of Rolesville).

Flat-rock areas commonly have pan-like depressions ranging from a few inches to 20 feet in diameter and up to a foot deep. The bottoms are flat and level and the sides steep to overhanging. They are irregularly circular, and some closely spaced pans seem to have enlarged and coalesced. Most have no outlets in their rims and retain water after rains. These pans seem to have been formed by chemical weathering on originally slightly lower places of the outcrop. Here moisture would persist after the rest of the rock dried, and moss would take hold. Moisture and organic acids would decompose the underlying rock, deepening the depression. Accumulating products of weathering would be occasionally flushed out during heavy rains or blown away during dry periods. The distinctive vegetation of the flat-rock areas in Wake and Franklin Counties has been described by Oosting and Anderson (1939) and by Palmer (1970). The nature and possible origin of flat-rocks in the southern Piedmont, as well as their vegetation, is detailed by McVaugh (1943).

Pedestal rocks and huge boulders are noteworthy in the granitic area. The pedestals are projections of bedrock that are larger at the top than near the ground. Some roughly resemble toadstools in shape. The caps are irregularly rounded and many have a lip where they overhang the sides. The rock is hard on the summits and may have an iron-oxide veneer (White, 1944a). The sides tend to be pitted and are crumbly, forming granitic sand (gruss) around the pedestals. These curious features have been described in Wake County by White (1944a, 1945) and elsewhere in the southern Piedmont by Crickmay (1935) and Petty (1932). They are residuals from weathering of bedrock, presumably formed in rock more resistant than that formerly around it. The overhanging sides are attributed to concentration of rock decay on the partly shaded places which stay moist longer than the top.

Boulders as much as 20 feet in diameter lie on and in the soil and saprolite. They are irregularly rounded and commonly spall off in curved slabs. Road cuts reveal that they are massive and unfractured pieces of bedrock isolated by weathering which proceeded around and beneath them along cracks. Some of them no doubt were once pedestal rocks that were undermined. The character and origin of these residual, exfoliated boulders in eastern Wake County and elsewhere in North Carolina were described by Burbank (1874).

Coastal Plain area. Southern Wake County, in the vicinity of Fuquay-Varina and south of Middle Creek, has flat, sandy land typical of the Coastal Plain. Most of the area lies above 400 feet elevation, and the plain slopes southeastward about 15 feet per mile. The Cape Fear-Neuse drainage divide crosses north and west through it. Wide expanses are nearly flat or gently undulating. Slopes along the uplands are 1 in 300 for distances of half a mile.

This sandy plain is deeply and irregularly indented along its margins by streams draining away from it in all directions. The upland is underlain by flat-lying Coastal Plain sediments ("Tuscaloosa," Macks, and "Pinehurst" Formations), while the marginal stream valleys expose the underlying crystalline rocks.

This upland is presumably a part of the Plain View surface of probable Pliocene age defined by Daniels and others (1966) in the Benson area. They found the maximum relief to be about 2 to 3 feet per 300 feet with an average slope of 0.7 feet per 100 feet (Daniels, Gamble, and Wheeler, 1971, p. 65-66). They present a strong case that the Plain View depositional and erosional surface has not been eroded since it was formed - except for cutting away its margins - and hence the land surface here "can be nearly 10 million years old." (Pliocene is now dated 1.8 to 5 million years.) This conclusion suggests that the sediment-veneered high areas in the adjacent Piedmont may also be of unsuspected antiquity.

The higher divides covered with sediment between Middle and Swift Creeks near Garner and Auburn and around Zebulon are the same as the Fuquay-Varina area, though on a less extensive scale.

Neuse River valley. The Neuse River crosses the county a little north and east of the middle in a generally southeastward course but with many bends and loops. Its direction and character vary with the geomorphic and geologic subdivisions. In the Triassic rocks at the northwest corner where the river forms the boundary with Durham County, it meanders widely through a flat, swampy floodplain up to a mile wide. As it crosses the Jonesboro fault into the crystalline rocks the valley narrows, and the floodplain nearly disappears. For the next 10 miles (straight line distance), the river flows southeastward on the average, crossing the metamorphic rocks. Its course here alternates between short straight stretches and sharp curves. On the outer (convex) sides of the curves, the valley walls are steep and rocky from active stream erosion, while on the inner sides and along straight stretches, narrow floodplains border the channel.

A remarkable entrenched meander of the river occurs in New Light township a mile north of N. C. Highway 98 and 1 1/2 miles east of N. C. Highway 50. The river turns north at right angles and makes a tight hook-shaped, double loop for 3 miles before returning to within 1500 feet of the initial bend, where it resumes its southeast course. Near the middle of this loop, where the river is flowing north, a spectacular cliff and crag (Zeagle's Rock) have been formed (fig. 15). The cliffs extend along the west bank of the river for several hundred feet and the crag overhangs the middle of the river at a height of about 55 feet. The rock here and in the vicinity is garnet-biotite gneiss that dips westward at 25 degrees into the ridge. The crest of the ridge above the crag and within the meander loop at elevations of 300-310 feet is covered with iron-stained quartz gravel, deposited when the river bottom was at upland level and meandered on the then flat peneplain. As uplift of the region rejuvenated the stream, it eroded downward in its existing course and laterally on the outside of its curve, undercutting the west-dipping gneisses. The river's meandering course, then, is ancient and its steep valley sides more recent.

The rapids at Falls result from greater resistance to erosion of the quartzitic felsic gneiss that crosses the river there. The river drops about 15 feet in 1200 feet. The floodplain, some 700 feet wide, extends upstream 2 1/2 miles from Falls and ends abruptly at the rapids. This locality was described by John Lawson in 1701 (Lefler, 1967). It is the dam site for the proposed Neuse River reservoir. Water power at this site was described briefly by Swain and others (1899).

Where the river reaches the granite area at the mouth of Richland Creek, the average course direction changes to nearly south for the next 12 miles (straight line distance). Along this portion straight

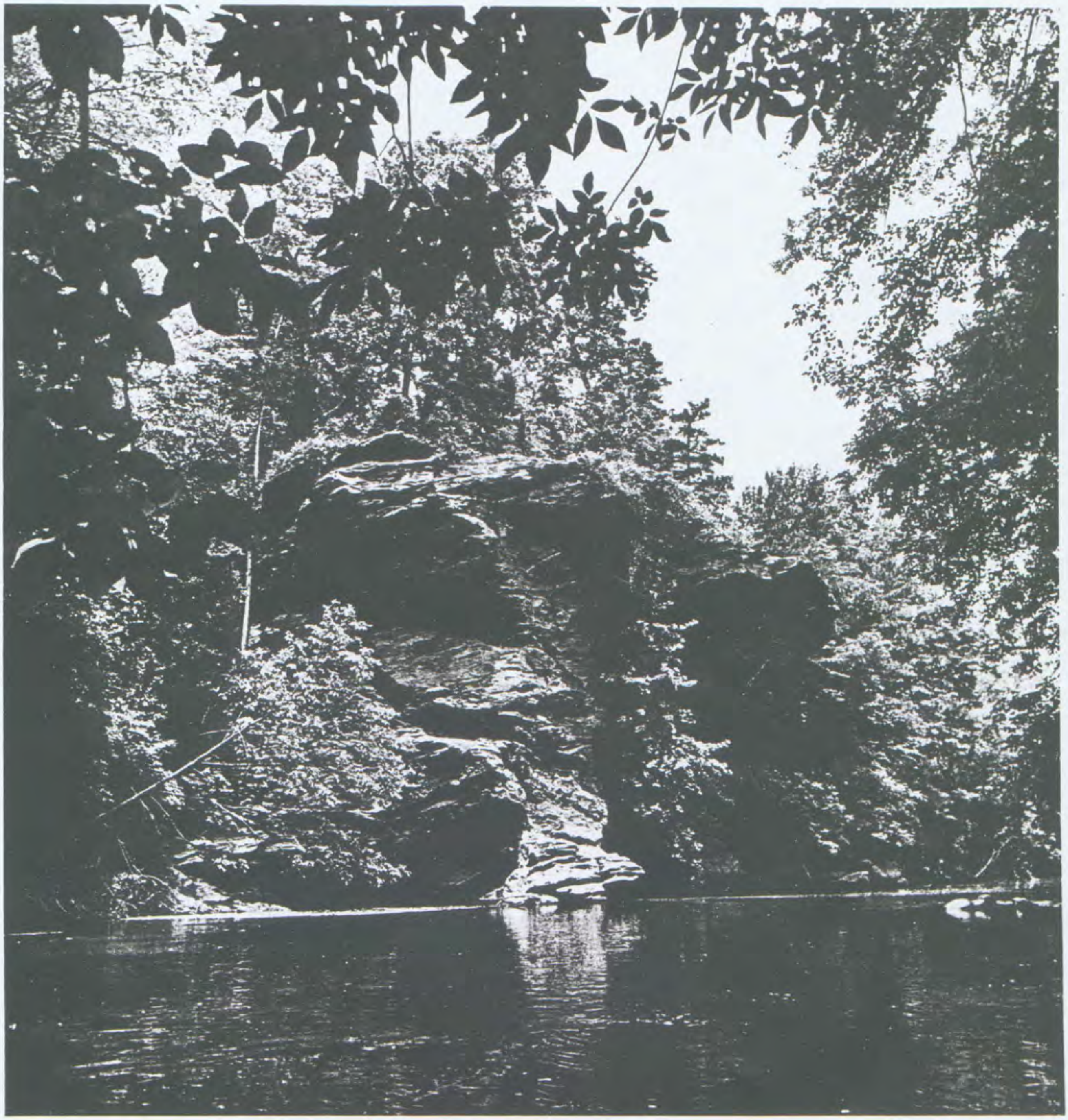


Figure 15. Zeagle's Rock on Neuse River, northern Wake County, N. C.

stretches are longer and sharp bends fewer. No bedrock features adequate to account for these changes are recognized.

A broad S-shaped meander occurs in the vicinity where U. S. Highway 401 crosses the Neuse. A large east-trending diabase dike crosses here just south of the west loop of the meander, but no causative relation has been proven. This meander also is likely to have been inherited from the time of peneplanation.

At Milburnie extensive outcrops in the river of hard granite caused a drop of some 3 feet (Swain and others, 1899) and provided a long-used mill dam site.

The last few miles of the river's course in Wake County are again southeastward but with a series of broad curves. Throughout its lower course in the granite area, the relief is less and the valley sides more gently sloping than in the metamorphic rocks.

The river drops about 90 feet (from 230 to 140 feet elevation) in crossing the county along its 48 mile course; its average gradient is 1.9 feet per mile. The gradient for the upper 10 miles on Traissic sedimentary rock is 1 foot/mile; for the next 15 miles across metamorphic rocks it is 2.1 feet/mile; and for the next 23 miles in granite it is 2 feet/mile. The rapids at Falls, though not spectacular, have had an important effect on the whole river. In the metamorphic rocks above Falls, the gradient is only 1.1 feet/mile, essentially the same as in the Triassic rocks. At Falls in a quarter of a mile, the river falls one-sixth of its total drop in the county or at a rate of 66 feet/mile. The gradient below the rapids is 2 feet/mile, not only across the rest of Wake County, but also for another 15 miles on granite and metamorphic rocks across Johnston County to Selma. The gradient of the river is twice as great below the rapids as it is above.

SOIL AND WEATHERED ROCK

General Features

The natural land surface in Wake County is underlain almost everywhere by soils consisting of various minerals and rocks mixed with organic materials. Hard rock crops out only along some stream beds and banks and is exposed by some excavations. Deep cuts display a gradual transition from agricultural soil at the surface, downward through subsoil into crumbly "rotten" rock, and finally into unaltered solid bedrock. The depth to solid rock varies from about 10 to at least 60 feet.

The mantle of unconsolidated earthy material and softened rock has been developed in underlying parent materials by chemical and physical attack of water, air, and organic substances. The parent materials include the various bedrock types and the different overlying sediments. In some upland areas where sediment cover is only a few feet thick, the parent material in which the soil profile has been developed includes both transported and residual components. Valley slopes are commonly mantled by colluvium, a mixture of residuum and weathering products that has crept downslope by imperceptible mass movement.

The material at intermediate depths in which some mineral alteration has occurred but where original rock texture and structure are still distinguishable is termed saprolite. The saprolite is a composite of original rock-forming minerals and such weathering products as clay and limonite. The latter are most abundant near the land surface in more decomposed rock, which is completely soft. The depth to friable rock ranges from about 2 to 20 feet. Feldspars and mafic minerals are partly decomposed in the upper part and nearly unchanged farther down. Rusty iron stain penetrates deeply along fractures. Phyllites beneath Coastal Plain sediment commonly have rhythmically alternating laminations of lighter and darker buff color that form curved festoons extending at least 10 feet down into the rock. These Liesegang rings or bands consist of an insoluble colloidal precipitate of iron hydroxide released by weathering that diffused through ground water saturating the rock pores.

The soils and subsoils consist chiefly of various combinations of different clay minerals, quartz, mica and vermiculite flakes, partly decomposed feldspar, limonite, and rock fragments. Rounded, exfoliated residual boulders are abundant in and on soils derived from granite and diabase. Iron-manganese (sesquioxide) nodules are important components in soils formed on upland sediment. Angular fragments of quartz are abundant above and down slope from quartz veins. Quartz pebbles and cobbles, many of them iron-stained and crumbly, distinguish soils derived from sediments. Consideration of details of composition and texture of the various soils in the county is beyond the scope of this report. Many of the weathering features in Wake County were described long ago by Emmons (1856, p. 213), Burbank (1874), Kerr (1881), and Russell (1889).

Agricultural Aspects

The soils of Wake County have been mapped in detail by the U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the N. C. Agricultural Experiment Station (Cawthorn, 1970). Thirty-nine soil series are described, and their locations and extents shown on airphoto maps. Physical and chemical properties are given, the suitability of the soils for various purposes considered, and the parent materials from which they were derived are noted. This valuable publication should be consulted in all matters concerning the soils.

The mapped soils are tabulated below (Table 1) according to the parent material from which they were formed. Experience during geologic mapping has shown that some modifications are needed concerning correlations between certain soils and their parent materials. The soils maps have proved to be generally reliable guides in geologic mapping for areas underlain by Triassic sedimentary rocks, Coastal Plain sediments, and alluvium, but relationships in the crystalline areas are more complex.

The most complicating factor is the presence of the innumerable patches of upland sediment west of the main limit of the Coastal Plain. The soils of the Appling, Cecil, and Durham series are stated (ibid.,

Table 1. Soils of Wake County and Their Parent Materials

Parent Materials	Soil Series	Approximate Percent of Area in County
Quartzofeldspathic, micaceous metamorphic and igneous rocks (gneiss, schist, granite & "acidic rocks")	Appling	24
	Cecil	19
	Durham	3
	Louisburg	4
	Madison	*
	Vance	*
	Wake	1 1/2
	Wedowee	3
Metasedimentary and metavolcanic rocks of the Carolina slate belt; both felsic & fairly mafic (phyllite & greenstone)	Georgeville	1
	Herndon	1
Mafic & ultramafic metamorphic & igneous rocks, and mixed "acidic & basic" rocks (hornblende gneiss, gabbro, diabase, soapstone & serpentinite)	Enon	*
	Helena	*
	Lloyd	*
	Wilkes	1
Sedimentary rocks of the Newark group (Triassic) (conglomerate, sandstone, siltstone, shale, mudstone, claystone)	Creedmoor	7
	Granville	*
	Mayodan	3
	Pinkston	*
	White Store	3 1/2
Unconsolidated sandy sediments of the Coastal Plain (Cretaceous & Cenozoic)	Faceville	*
	Goldsboro	*
	Lynchburg	*
	Norfolk	2 1/2
	Orangeburg	*
	Plummer	*
	Rains	*
	Wagram	4
Floodplain alluvium	Buncombe	*
	Chewacla	3
	Congaree	1
	Wehadkee	5
Stream terrace alluvium at low elevations	Altavista	*
	Augusta	*
	Roanoke	*
	Wahee	*
Alluvium and colluvium ("translocated material") in upland depressions	Colfax	1 1/2
	Mantachie	1
	Worsham	2 1/2

* equals less than one percent

Compiled from Cawthorn, 1970, p. 6-64, 110 and table 1.

p. 9, 15, 23) to be derived from granite, gneiss, schist, and other acidic rocks. Though this is correct in the main, many soils on upland areas mapped in these series have been formed in part or altogether from upland sediment. Examples are the divide between Swift and Middle Creeks along SR 1010, the ridge northeast of Burt along SR 1116, the uplands north and northwest of Zebulon, and the high areas north of Leesville. These three soils series underlie about 46 percent of the county (ibid., table 1), a large proportion of which lies along uplands. Areas of limonite rich upland sediment north of Leesville have been mapped as Lloyd loam, a soil attributed to hornblende gneiss. In addition to this correlation, Lloyd has been mapped over diabase near Garner and with Herndon over ultramafic rocks in the Stony Hill Church vicinity in northern Wake County.

Both Georgeville and Herndon series soils are said (ibid., p. 27, 34) to have formed from phyllites of the Carolina slates. The Herndon is probably derived chiefly from greenstone in the Carolina slates and the Georgeville from the metasedimentary phyllites, but this is not established with assurance. These two soils series are also shown west of Cary and northwest of Holly Springs in some areas of Triassic fanglomerate. The abundant fragments of Carolina slate rocks in the fanglomerate dominate the composition of this sedimentary rock. Georgeville and Herndon soils have also been mapped in the Panther Branch amphibolite area.

Engineering Aspects

Use of the land for purposes other than agriculture is also dependent on the properties of the underlying soils and rocks. Sites for buildings, roads, dams and reservoirs, septic tank fields, pipelines, airports, and other uses vary in suitability and necessary construction methods or problems, depending on the physical properties of the underlying materials. The Soil Survey of Wake County (Cawthorn, 1970, p. 87-109) contains a wealth of test data and interpretative evaluations pertinent to engineering uses of the soils. Though not a substitute for on-site observation and testing, this publication can give invaluable guidance and insight into expectable local conditions. Soils having notably unfavorable engineering properties (ibid., table 6) include most of those derived from mafic and ultramafic rocks, from Triassic sedimentary rocks, and from floodplain and alluvial sediment. Most of the soils derived from quartz-rich metamorphic and igneous rocks and the principal Coastal Plain soil types provide favorable though different engineering conditions. The Region J Geology report (Wilson and Carpenter, 1975) also provides much information in useful form.

Several geological aspects of the saprolite and bedrock affect engineering conditions at construction sites. Depth to hard rock ranges from about 10 to more than 60 feet. The change downward from saprolite into hard rock is gradual and no definite surface separates the two materials. Consequently, seismic reflection devices cannot be expected to yield satisfactory results. Furthermore, the depth to hard rock varies abruptly because of varying resistance to weathering of different interlayered rock types. Further, hard residual boulders embedded in saprolite may be underlain by many feet of soft material.

Bedrock, saprolite, and even some subsoil are neither homogeneous nor isotropic. Various rock masses contrast sharply in composition and texture on both small and large scales, and any one type varies in its physical properties with direction. The most pervasive reasons for this are layering, cleavage, and foliation of the metamorphic rocks. Even the granite has weak to strong foliation. These structures dip steeply throughout most of the county and thus impart quite different stabilities to excavation slopes of different orientations. Varying proportions of micaceous minerals in adjacent rock layers, the flakes generally lying parallel to one another, are a paramount cause of anisotropic properties. Carter (1966) carried out compression tests on undisturbed samples of unsaturated residual soil containing large amounts of weathered biotite derived from foliated metamorphic rocks in Wake County. Larger compressions and faster rates of compression occurred when stresses were applied normal to foliation planes than when parallel to them. Consolidation characteristics were not clearly related to soil depth, mineralogy, grain size distribution, natural water content or saturation.

Joints, faults, and fractures in many directions subdivide the rock into discrete blocks, commonly separated by films of weathering products of low frictional values. Such discontinuities severely restrict the validity of interpolations and extrapolations from test sites.

An important danger during excavation results from the black-coated, slickensided fractures (described previously with faults) that occur throughout the metamorphic rocks (Gupton, 1964). Cohesion is extremely low on these surfaces so that overlying masses slide readily into excavations. The danger is greatest in trenches cut for utility lines where workers are closely confined; slides under these circumstances have had fatal results. Slumps along highway cuts are also commonly localized by these surfaces.

Landslides in Wake County are limited to failures along the sides of excavations. Topographic relief and steepness of natural slopes are too limited in the county to be important factors. Rock type and orientation of surfaces of weakness, however, play major roles. A study of landslides in highway cut slopes in North Carolina (Leith and others, 1964) included 24 examples in Wake County. Most of the latter slides occurred in Triassic sedimentary rocks along U. S. Highway 1 southwest of Raleigh. A slide near the Chatham-Wake County line was investigated in detail (ibid., p. 59-71, 98-99); movement totalled 50 inches horizontally and 14.4 inches vertically. The study emphasizes that, for the Piedmont and mountain districts, mica-rich foliated metamorphic rocks are more prone to landslides than all other rock types combined. Surfaces of bedding, foliation, and fracture that dip toward an excavation are especially weak.

SUMMARY OF GEOLOGIC HISTORY

Geologic conditions and events in Wake County evidenced by the rocks now exposed extend back some 600 million years or more into late Precambrian times. The earliest situations are only dimly perceived as yet, while those near our own time can be described more confidently. The full story requires more detailed local studies, particularly radiometric dating of various rocks, and much more understanding of the whole region. The story presently deduced depends partly on analogies with better known areas elsewhere and on correlations with interpretations of adjacent regions. Wake County's geologic history is but a sample of large-scale events occurring throughout eastern North America.

The oldest rocks in the area are the felsic gneisses and schists, some of them graphitic, that are exposed along the axis of the Raleigh anticline in the middle of the county. These rocks are high in quartz content and include numerous layers of quartzite. They constitute a sedimentary sequence at least 8000 feet thick that was deposited under probable continental margin conditions during late Precambrian time.

These rocks were folded along the axis of the present Raleigh anticline and then partially eroded before being unconformably overlain by sediment later transformed into the mica gneisses and schists with interlayered hornblende gneiss, now lying west of the Raleigh anticline. This sequence, totaling some 10,000 feet, consisted originally of interlayered arkose, graywacke, conglomerate, shale, and probably mafic volcanic tuff, a typical eugeosynclinal suite. Thus, the earliest conditions in the county that can be deduced are those of a continental margin and adjacent ocean basin of deposition that deepened progressively to accomodate rapidly accumulating sediment. The relations of this geosyncline to the continents of that time and the place from which the sediment came remain as yet conjectural.

Overlying and probably interfingering with these basal rocks are the mixed volcanic and sedimentary types of the Cary sequence, a part of the slate belt of the southern Piedmont, most of which lies 20 to 50 miles to the west. The narrow strip lying in Wake County, some 4000 feet in thickness, was doubtless derived from eruptions and erosion in lands farther west, presumably an island arc. Accumulation of these materials continued through early Paleozoic time, probably through the Ordovician period, and ended some 450 m.y. ago. Deeper and deeper burial of the older sediments must have gradually transformed them into consolidated rocks.

The sedimentary and volcanic rocks that accumulated during late Precambrian and early Paleozoic time were first metamorphosed at a date tentatively assigned (by analogy to the Taconic orogeny in the northern Appalachians) to the late Ordovician or early Silurian period. The rocks were recrystallized into various metamorphic types having bedding foliation. Deformation as well as higher temperature and pressure from deep burial may have been involved, but folding is thought to have been slight to moderate and the grade of metamorphism probably low. The early mafic dikes (biotite and hornblende-rich) are schistose and may have been intruded before or during this metamorphism; they may, however, be later. The large arcuate Panther Branch amphibolite also has foliation and perhaps was intruded about this time. The other mapped amphibolites and the hornblende gneisses probably belong to the Paleozoic depositional phase.

The Beaverdam Creek gabbro-quartz diorite igneous complex was intruded following the initial metamorphism. It contains numerous biotite and hornblende schist inclusions that closely resemble the greenstone metavolcanic rocks in the walls. The Reedy Creek adamellite and its satellite sills lie along the trend of the Beaverdam Creek complex in lower grade metamorphic rocks, as do the Buckhorn Creek and Sunset Lake plutons. These probably record events during Silurian and early Devonian periods.

The ultramafic bodies seem to have formed during or shortly after deposition of the sediments now constituting the mica gneiss and schist unit. These igneous sheets and lenses are concordant with the enclosing metasediments and have been folded with them. Their chemical affinity to the Beaverdam Creek igneous complex suggests that the two are contemporaneous.

The culmination of basement crustal development was the regional dynamothermal metamorphism that seems to have occurred during the Devonian period, some 400 ± 20 m.y. years ago. This may correspond to the Acadian orogeny of the northern Applachians. East-west compression raised the Wake-Warren anticlinorium and strongly deformed its west flank in central Wake County. The Raleigh anticline and the postulated flanking syncline to the east were refolded, and flowage folds and sub-horizontal lineations were developed through the belt. Coincident with deformation, and probably continuing for a time afterwards, silicic magma was intruded on a large scale, forming the Rolesville batholith with its wide injection aureole of pegmatite and related dikes and sills. The metamorphic rocks in the injected zone were crowded westward during the intrusion and strongly deformed, many of the earlier pegmatites being crumpled into ptygmatic folds. The wall rocks farther west were recrystallized to develop a Barrovian metamorphic facies series concentric with the batholith. Most of the quartz veins were formed late during this metamorphism. Some small quartz veins are still later, a final product of pegmatite injection. This grand episode of crustal deformation, metamorphism, and intrusion doubtless extended over a long time. The Castalia pluton in Franklin County, dated 316 ± 6 m.y. in the Pennsylvanian period, adjoins the Rolesville batholith on the east. The latter itself is composite, and parts of it may have been formed as late as Mississippian or Pennsylvanian time.

The orogeny must have been accompanied and followed by uplift and erosion of the region; deep-seated rocks became exposed at the land surface. As the deeper rocks rose, they cooled and pressure on them decreased. Retrogressive metamorphic mineral changes occurred in various rocks with these recurrent uplifts. By Permian time cooling had stabilized biotite, stopping loss of argon, thus giving rise to the 238 m.y. K/Ar date at the Gresham's Lake quarry (Fullagar, 1971). Jointing of metamorphic and igneous rocks doubtless occurred during these uplifts as the rocks became more brittle. Joints coated with chlorite and epidote are most likely of this date. Others may have formed later.

Peneplanation of the crystalline rocks continued through late Paleozoic time and into the Mesozoic era until the latter half of the Triassic period. A total thickness of up to 70 thousand feet of rock was removed from the region, exposing deep-seated metamorphic and igneous types and bevelling across harder and softer rocks. The site of deposition of the resulting huge volume of sediment is not known. Late Paleozoic sedimentary deposits in the Valley and Ridge and the Allegheny Plateau provinces were supplied from the east, but adequate sources lay much nearer in the Blue Ridge and inner Piedmont areas. Sediment from the eastern Piedmont is likely to have been carried eastward and laid down in unknown basins now deeply buried beneath the Atlantic Coastal Plain and the sea. By middle to late Triassic time a land surface of little relief lying near sea level stretched across the Piedmont. Parts of this surface now coincide with the nonconformity beneath the Triassic sediments.

Late in the Triassic period, about 200 million years ago, the region of the present eastern Piedmont was broken by great, north-trending normal faults. In Wake County the Jonesboro fault was initiated and the land to the west was displaced relatively downward, forming the elongate Durham basin. Recurrent slip along this fault maintained a steep scarp between rugged highlands to the east and the land-locked basin at its foot, which from time to time was deepened and tilted eastward. These movements were a response to the tensional rifting of the earth's crust as the Atlantic Ocean basin began to open.

Erosion of higher lands to both east and west of the Durham basin produced great volumes of clastic sediment that accumulated in the fault trough. Alluvial fans were built out from the scarp into the basin, and alluvium was spread throughout the trough by a shifting river complex as channel and floodplain deposits. Temporary lakes and swamps along the basin axis gave rise to impure limestone-chert deposits and to thin coal and carbonaceous shales. Recurrent faulting maintained the basin for some 20 million years, until several thousand feet of the Newark series sediments had accumulated.

Block faulting of the Triassic sedimentary rocks followed their deposition and probably occurred also during the later stages of their accumulation. Post-depositional slip took place on the Jonesboro fault, and the Newark rocks were tilted more to the east. Numerous normal faults developed thoughout the Durham basin and doubtless in the surrounding areas. The Lick Creek fault and the offsets of the Jonesboro fault must be late results of this tensional tectonic episode which was doubtless of latest Triassic or early Jurassic age, about 180 million years ago. Some of the jointing was contemporaneous.

Intrusion of mafic magma took place during or soon after the faulting and jointing. Dikes and sills of diabase were injected into the fractured rocks throughout the county and region during the late Triassic or early Jurassic periods (195-175 m.y.). Because the diabase varies considerably in composition even within small areas, it is not likely that all was intruded at one time. The period of intrusion is presumed to have been long, but the duration and the sequence of magma types is not known. These intrusions are believed to be peripheral to rifting in the Atlantic basin and the production there of new sea floor crust.

During late Jurassic and early Cretaceous times (175-90 m.y.), the region was deeply eroded. Any local and regional uplifts that resulted from earlier crustal movements were planed down, and the resulting sediment was carried eastward to the new continental edge; these deposits form the lowest, deeply buried part of the Coastal Plain sequence. The region was once again reduced to a peneplain that bevelled across Triassic and all older rocks and which sloped gently toward the sea. This surface is the sub-Cretaceous peneplain, the nonconformity below the Coastal Plain formations.

During the Cretaceous period, as the region became peneplaned, the eastern portion was warped downward so that the sea gradually transgressed the land. The shore line approached Wake County in the latter part of the period so that the "Tuscaloosa" deposits were laid down under estuarine and fluvial conditions. These were covered by the marine Black Creek and Pee Dee Formations, all of which may once have extended across the county. This wide transgression of the sea was ended about 70 million years ago by regional uplift, so that deposition was succeeded by erosion.

The Cenozoic era, extending from some 70 million years ago to the present, brought an alternation of erosion and deposition to the region as its elevation relative to sea level fluctuated. During the Paleocene epoch, erosion removed some of the Cretaceous deposits. During part of the Eocene, the sea again reached into Wake County, and the thin Castle Hayne Limestone accumulated. This was largely destroyed by erosion during the Oligocene epoch, so that it is known now in the county only as fragments in younger deposits. The late Miocene sea resulted in deposition of the Macks Formation, which was buried - probably in the Pliocene epoch - by the fluvial "Pinehurst" Formation. At this date the Wake County area must have been in a flat, sandy coastal plain lying near sea level much like the present easternmost part of the state except that the sediment overlying the Cretaceous peneplain probably was only a hundred feet or so in thickness.

Pleistocene history in Wake County, the last one to two million years, was largely a story of erosion with only minor river deposition. It was controlled by eustatic sea level variations resulting from continental glaciation chiefly in the polar regions. As the ice sheets waxed and waned, sea level fell and rose again, the shore line moved out and in, and rivers were given increased and decreased gradients and erosive power. The series of marine scarps and terraces distinguished in the Coastal Plain resulted from these glacially controlled cycles. The higher terraces are assumed to be the older because any earlier but lower scarps and terraces would have been destroyed by younger transgressions. This succession thus implies a secular or intermittent actual uplift of the land on which glacial eustatic changes were superimposed. The Wake County area, then, may be visualized as gradually rising to higher altitudes while being dissected by streams whose gradients alternately increased and decreased. The larger streams and most of their tributaries are thus regarded as superimposed, their locations being inherited from Pliocene positions on the "Pinehurst" deposits. The Cape Fear and Neuse Rivers, it is conceded, may well be antecedent in courses dating back to Cretaceous peneplanation, or they may have been superimposed from positions on Cretaceous deposits. Erosion during the Pleistocene first stripped away most of the Coastal Plain deposits, leaving only scattered patches to the northwest and larger sheets to the southeast on the higher ground. The streams then deepened and widened their valleys, leaving stepped inter-stream ridges and valley-side terraces as records of varying stream gradients. With higher sea level, streams would tend to meander and widen their floodplains, while during lower sea level, they would trench their floodplains and leave terraces along the valley sides. The Holocene (Recent) situation, with rising sea level during deglaciation, has been one of floodplain construction.

MINERAL RESOURCES

Mineral products in Wake County have been predominantly construction materials. The stone industry has been an important element in the economy since the early 19th century, chiefly dimension stone originally and crushed stone during most of the present century. Sand and minor gravel have been produced on a small scale since about 1915. Manufacture of brick from local raw materials has been carried on intermittently since at least the late 18th century. Graphite was produced on a small scale throughout much of the 19th century. Other minor and potential mineral products include muscovite mica and feldspar, soapstone and talc, chromite, manganese and iron ores, and mineral specimens.

Mineral production data for Wake County are scanty. Information on tonnages and values is usually regarded by producers as confidential and is released to governmental agencies for use only in totals for areas large enough that individual contributions cannot be identified. Thus, figures for counties or industries within a county are rarely published. General sources that have contributed information on the county mineral industry are listed below.

U. S. Census Reports

Mineral Resources of the United States
1882-1923, published by U. S. Geological Survey; 1924-1931, published by the U. S. Bureau of Mines

Minerals Yearbook
1932-1973, published by the U. S. Bureau of Mines; contains some county data since 1952.

Economic Papers, published by the N. C. Geological Survey (1900-1904), N. C. Geological and Economic Survey (1905-1924), and N. C. Division of Mineral Resources (1925-1970); cover separate years or groups of years from 1900 through 1967; contain some county data for first quarter of 20th century.

Publications relating to specific products or localities are cited where appropriate in the following descriptions; these are listed in the bibliography. The Region J Geology report (Wilson and Carpenter, 1975) also provides information.

Stone Industry

Production of stone has been Wake County's earliest and most important mineral industry, a still continuing status that is likely to persist. Dimension stone was the chief product from the early 19th century until about 1920, while crushed stone has greatly predominated since then. Publicly reported production data are too scanty to permit any estimate of the scale of the industry in the county. Despite large production in the past, great reserves of suitable rock are still available, but economical quarry sites are being restricted by competing uses. The absolutely essential nature of crushed stone in construction must be recognized in planning and development in the county. Access to reasonable quarry sites must be assured.

Dimension stone has been quarried at some 15 sites in Wake County, particularly during the 19th century but continuing intermittently on a small scale to the present. Most of the quarries were small, but the former City Quarries were worked for nearly a century. The term "dimension stone" is used not only for rock cut to specified shapes and sizes, but also for rough blocks split into more or less rectangular form and even irregular shapes with one or more flat surface that may be used in masonry construction. Rocks produced as dimension stone in Wake County include injected granitic gneiss, lineated felsic gneiss, granite, soapstone, and sandstone; the first two have been rather loosely referred to as "Raleigh granite" and the second also as "Wakestone." The first three rock types have distinct properties and appearances even though all have commonly been called "granite." The injected granitic gneiss has good planar structures (foliation and layering) so that it splits readily into slabs of rather uniform thickness in a large range of sizes. The two wide surfaces of these slabs appear homogeneous and rather smooth, but the edges of the slabs are streaky or banded. Most blocks are traversed by pegmatite dikes. The lineated felsic gneiss, on the other hand, lacks good planar structure and splits into roughly rectangular prismatic blocks rather than slabs. The four longer surfaces of these blocks have straight, parallel ridges and dark mineral streaks. The two square to rectangular ends of the prismatic blocks appear nearly structureless, that is, without mineral streaks. Finally, granite is relatively massive, splits less readily, and forms blocks that appear almost homogeneous on all surfaces.

Crushed stone production began as a waste by-product from the dimension stone industry, but during the last half century it has almost completely displaced the latter and has become the largest mineral industry in the state as well as in Wake County. The greater speed and adaptability of construction using concrete made of portland cement and crushed stone, coupled with ever expanding road building and increased labor costs, have reduced stone masonry almost to a decorative status. Eight large quarries have been worked chiefly or entirely for crushed stone, one each being in felsic ("quartz disk") gneiss and in injected biotite gneiss and the remainder in granite. Triassic fanglomerate has been tested at one site.

Information on the industry has been obtained from the general sources listed previously and from publications by Councill (1954; 1955), Emmons (1856), Kerr (1875), Lewis (1893), Watson (1904, 1910), and Watson and Laney (1906). These sources are listed among the references and some are cited where appropriate. Reliable information on periods of operation and amounts of production is scanty.

The quarries are described below in two groups: first, quarries whose chief product was dimension stone and, second, those producing mainly crushed stone.

Dimension Stone Quarries

Old Raleigh city quarries. Quarries were opened in southeast Raleigh about 1805 (Tenth Census, p. 185). They were worked systematically from 1833 to 1836 to supply dimension stone for building the State Capital (The Second State House) and were operated at intervals until at least 1903. One opening lay just west of Rock Quarry Road between Davie and Lenoir Streets and opposite the Federal Cemetary on the present grounds of Hunter School. This is reported (Watson and Laney, 1906, p. 31) to have been 850 feet long (north-south), 75 feet wide, and 30 to 35 feet deep. A second opening was between Quarry and Coleman Streets and just south of Lenoir Street. This quarry was 330 feet long (north-south), 75 feet wide, and 25 feet deep. Both openings were later used as dumps and completely back-filled by the mid-1930's; no trace is now apparent.

These sites lie in the belt of injected gneisses and schists. The rock is a gray, layered biotite gneiss with thick sills of granite and numerous thin dikes of pegmatite and aplite. Consequently, the rock produced was variable in character. The gneiss is medium grained and distinctly foliated. The granite, though more massive, also has a distinct foliation. Potash feldspar and sodic plagioclase in about equal amounts make up nearly three-quarters of both rocks, quartz nearly a quarter, and biotite perhaps five percent. Accessory and secondary minerals reported included apatite, zircon, muscovite, epidote, and chlorite. The following chemical analysis made by G. B. Hanna of rock from this quarry was published by Kerr (1875, p. 122, 302).

SiO_2	69.28	FeO	1.22	MgO	0.27
Al_2O_3	17.44	MnO	0.16	K_2O	2.76
Fe_2O_3	1.08	CaO	2.30	Na_2O	3.64

The rock is traversed by numerous dikes of pegmatite and aplite; almost every block quarried contains one or more. These range in thickness from a fraction of an inch to several inches in usable stone. Most of the dikes generally parallel the foliation, but many cut across at various angles and across one another. Though most dikes are tabular, many are irregular in form or have zig-zag (ptygmatic) bends. Both pegmatite and aplite consist chiefly of microcline and quartz with little plagioclase and mica.

Removal of rectangular blocks was facilitated by the steeply dipping foliation and layering (striking about north-south) and by fairly closely spaced, nearly vertical joints almost at right angles. Much stone was used as split out, but a great deal seems to have been sawed or chiseled to specified shapes and sizes.

This stone was used in construction (1833-1840) of the State Capitol for exterior and interior work throughout the building. The original buildings at St. Mary's School (East Rock and West Rock, 1834, 1835) likewise were made of the same stone (Waugh, 1967, p. 53). The trim around doors and windows, the corners, and the buttresses in Christ Church (1848) are of the same stone, as are many foundation walls and steps in the older parts of the city. Much of the stone curbing, paving blocks, and flagging stones in downtown Raleigh must have come from these quarries, though the actual quarry source cannot now be identified. Waste rock was crushed and used as road metal and railroad ballast (Watson and Laney, 1906, p. 31).

Penitentiary quarry. A quarry was opened in 1868 on the grounds of the State Penitentiary (now Central Prison) in Raleigh chiefly to provide stone for building the prison walls. It was located at the southeast corner of the enclosure (see photograph in Waugh, 1967, p. 139). It is reported (Lewis, 1893, p. 78) to have been about 300 feet square and about 60 feet deep. It was abandoned before 1893 and subsequently has been entirely back-filled.

The site is near the western side of the belt of injected gneisses and schists. The rock is hard, fine- to medium-grained, distinctly layered biotite gneiss, ranging in color from light to dark depending on biotite content. Its distinct foliation and layering trends about north and is nearly vertical. Dikes of pegmatite are numerous. Some rock from here was used for curbing and building elsewhere in the city (ibid., p. 78) and for Neuse River improvements.

Unnamed quarries in northeast Raleigh. Two small quarries in injected mica gneiss were formerly worked in the northeastern part of the city. No account of their history was obtained. One quarry is just northwest of the intersection of Brookside Drive and Frank Street across from Emma Conn School and on the east side of a small stream. It is about 90 feet long (north-south), 10 to 30 feet wide, and about 10 feet deep. The rock is layered biotite gneiss with many pegmatites. The quarry seems to have been long abandoned. Probably rough dimension stone was produced.

The other quarry was just north of Six Forks Road and west of Plantation Road in the Crabtree Heights section. It was about 50 by 100 feet in area and apparently some 10 feet deep. The rock was distinctly layered gneiss ranging from coarse and granitic to fine-grained, biotite-rich bands. Microcline-quartz pegmatites were numerous. The quarry was back-filled in the late 1960's. The product probably was rough blocks.

Unnamed quarries in southwest Raleigh. Three small openings in lineated microcline-quartz gneiss were worked many years ago in southwest Raleigh. One near Lake Raleigh is about one hundred yards north of the dam. It is about 50 by 100 feet in area and up to about 8 feet deep. Several large outcrops of gneiss occur nearby on the low ridges.

Two smaller openings were made on the south side of the N. C. State University campus. They are about a hundred feet apart, on the south side of Rocky Branch and 100 yards west of Pullen Road. The rock here is much weathered.

The total production from these quarries seems to have been insignificant. The rock was presumably used locally as rough masonry blocks.

Lewis Place quarries. One of the oldest quarries in the county was opened in northwest Raleigh along a small tributary of the Southeast Prong of Beaverdam Creek just south of the west end of Lewis Circle. At least three irregular openings have been worked to depths of 15 to 20 feet. The rock is gray, fine-grained, lineated, microcline-quartz gneiss. Much of it is quartzitic; mica is minor in amount. Foliation trends N. 10-15° E. and dips 75 degrees east; lineation plunges 5 degrees south-southwest. The strong lineation and weak planar structure permit the rock to be split readily into prismatic blocks rather than tabular slabs. Sparse nearly vertical joints striking N. 80° W. facilitate removal of stone. Lewis (1893, p. 78) reports that trim and sills for Christ Church (built in 1848) was said to have come from here; however, the church walls, not the trim, are of this variety of stone. The quarry was operated at intervals for many years but probably not since the 19th century. Part of this quarry has been transformed into a private rock garden.

Boone's quarry. A quarry in northwest Raleigh was operated by C. R. Boone chiefly during the 1920's but perhaps earlier. It was located southwest of the intersection of Oberlin Road and Glenwood Avenue on the east side of the Southeast Prong of Beaverdam Creek. A series of openings extended about 800 feet north-south along the hillside. They were as much as 100 feet wide and worked to a depth up to 25 feet. The quarry was back-filled during construction of a shopping center, but part of its east wall is visible back of the stores. The rock is gray to buff, strongly lineated microcline-quartz gneiss. The lineation plunges about 5 degrees to S. 15° W. Foliation is poorly developed; it strikes N. 15° E. and dips steeply to both east and west. Steeply dipping joints strike about N. 80° W. Thin quartz veins are numerous. The rock was split into prismatic blocks and used in construction of many residences, walls, and evidently such institutional buildings as Hillyer Memorial Christian Church (1925), United Church (1927), and Needham-Broughton High School (1929).

Sutton quarry. A small quarry in north Raleigh was operated for a few years during the 1950's by D. A. Sutton. It was on the hillside northeast of Crabtree Creek 2000 feet N. 25° W. of Lassiter Mill and just north of Marlowe Road. The opening was about 120 feet long north-south, 40 feet wide and up to 20 feet deep. The rock is typical lineated microcline-quartz gneiss like that in the Boone and Lewis quarries, though much of it is somewhat weathered. Joints trending west-northwest are numerous but veins and dikes are few. Councill (1954, p. 17; 1955, p. 18-19) reports the product was small dimension blocks for schools and churches and for trim and was shipped to many places in North and South Carolina.

Falls quarries. Three small quarries in lineated quartz-microcline gneiss have been worked in northern Wake County near Falls of the Neuse. Two nearby sites are a mile and a half southwest of Falls and a quarter of a mile west of the intersection of SR 2000 (Falls of Neuse Road) with SR 2010. The smaller opening is a hundred yards south of SR 2010 and the larger is 200 yards north of the road. The more southerly quarry was opened in 1956 and worked intermittently for about 3 years. An opening about 30 feet square and 10 feet deep was made at the south end of a large flat outcrop. The larger quarry north of the road was begun in 1961, though a test hole had been made prior to 1954. It has been operated at frequent intervals up to the present. Various operators include Rex Champion, David Sutton, a Mr. Thornton, and others. The quarry extends about 200 feet along the west side of a large flat outcrop and is about 50 feet wide and up to 20 feet deep.

The rock is buff to gray, strongly lineated gneiss that splits into prismatic blocks. The lineation is about horizontal and trends N. 25° E. on the average, though it is commonly twisted adjacent to irregular crosscutting quartz veins. Planar structure is essentially lacking except for rare beds of finer grained rock that range from a few inches to 3 feet in thickness. Steeply dipping joints are fairly numerous. They fall into three sets: N. 5-25° E., N. 40-65° W., and N. 65-75° E. Pegmatite dikes range in thickness from less than an inch to 4 feet. They are so numerous as to cause much waste rock. Thin quartz veins likewise spoil a good deal of stone. Pegmatites clearly cut across some quartz veins that have been fractured and slightly displaced.

The third quarry is 0.5 mile west of Falls, 0.3 mile south of SR 2002 on the west side of a ridge east of Honeycutt Creek. The quarry extends about 200 feet north-northeast along the hillside, is as much as 40 feet wide toward the south end, and reaches a maximum depth of about 12 feet. It was opened on a long outcrop of gneiss by Mr. Munroe Cody of Cary probably about 1960 and was operated intermittently for about a decade. The rock is gray to buff, felsic quartz-microcline gneiss with strong lineation. The lineation is straight and trends N. 20-25° E. nearly horizontally. Planar structure is nearly absent in the rock and consists of scattered streaks of dark minerals. Quartz veins are thin and sparse; most lie nearly parallel to the lineation. Pegmatites are lacking. Joints are comparatively scarce, so that fractures transverse to the lineation tend to be curved and irregular. Rock at the north end of the quarry is somewhat weathered, but most of the rock is hard and sound and seems to have yielded little waste.

The stone from these quarries was used in masonry walls in various buildings in Raleigh. These include the new Parish House of Christ's Church, the retaining wall in front of the Y.M.C.A. on Hillsborough Street, and the former Cameron-Brown building in Cameron Village. Some stone was shipped to nearby cities.

Sycamore Creek quarry. A quarry was opened in William B. Umstead State Park during the 1930's to supply stone for construction of walls, bridges, and buildings in the park. It is on the steep east bank of Sycamore Creek, 1.1 miles south-southwest of Ebenezer Church and about 700 feet west of SR 1647. The quarry is about 250 feet long north-south, 50 feet wide and up to 40 feet deep (Fortson, 1958, p. 35-38). The quarry face slopes west into the opening, parallel to the cleavage which strikes N. 10° E. and dips about 45 degrees west. The rock is gray, medium-grained, quartzose mica gneiss with good cleavage due to parallel arrangement of muscovite and biotite flakes. Small specks of pyrite are fairly common. Indistinct bedding parallels the cleavage. The rock appears to be a metagraywacke. Three sharply discordant quartz veins ranging up to 18 inches thick dip gently eastward. An irregular mass of biotite schist 4 to 8 inches thick cuts obliquely across the cleavage; it is thought to be an early mafic dike. Joints are comparatively sparse. They are short and irregular and are about perpendicular to the cleavage. The rock splits readily into smooth slabs with irregular outlines.

Whitley quarry. A small granite quarry was opened in eastern Wake County a mile and a half east of Knightdale. It lies 1600 feet N. 76° E. of the intersection of SR 2500 and 2501 and about 1000 feet north of the Norfolk Southern Railway in the woods at the head of a small north-draining valley. The quarry is roughly circular with diameter about 150 feet and apparent depth up to about 25 feet. The rock is dark gray, medium-grained biotite granite. It is quite massive and evenly grained. Only a few thin pegmatites cut the rock. Joints and sheeting fractures are rare. Production reported (Pratt, 1914, p. 170; Pratt and Berry, 1919, p. 135) from quarries at Knightdale in 1912 by Granita (sic) Company and in 1917 by Matthews Granite Quarries Company probably was from this site. Councill (1954, p. 20) reports that dimension stone was produced here and that the quarry was last operated for a month in 1950 for crushed stone.

Rolesville quarry. Dimension stone was formerly produced from a shallow quarry at the southern edge of Rolesville about 300 yards back of the high school. A granite flat-rock area here lies at the head of drainage into Harris Creek. Quarrying extended at close intervals for about 200 yards east-west and up to 100 feet north-south to a depth of 1 to 6 feet. The rock is unusually massive and homogeneous, and most is medium grained. Biotite streaks and dikes of pegmatite or aplite are scarce; joints are comparatively wide-spaced. Weak foliation strikes about N. 15° E. Watson and Laney (1906, p. 36-37) give a detailed petrographic description. The rock consists of about equal amounts of potash feldspar and plagioclase with quartz, biotite, and minor amounts of muscovite, apatite, zircon, and magnetite; it would be classified as adamellite. Micrographic and myrmekitic intergrowths were noted.

This quarry seems to have been worked only in the late 19th and early 20th centuries. It may have supplied stone for the lower 30 feet of the old Raleigh Water Tower on Morgan Street, built in 1887 of granite "brought from Rolesville Quarry" (Waugh, 1967, p. 142).

Barham quarry. A small quarry in granite was opened 3.5 miles east of Rolesville in easternmost Wake County. It is 4100 feet S. 49° E. of Barham crossroad in the edge of woods on the west side of a small valley. The quarry is about 250 feet long north-south, ranges from 40 to 150 feet in width, and is up to about 8 feet deep. The rock is gray, medium-grained biotite granite (or adamellite). It is unusually massive and uniform and is essentially free of mica streaks and of pegmatite dikes. Sheeting fractures occur at 1- to 3-foot intervals; joints are scarce. The product seems to have been finished dimension blocks, for which the rock is well suited. The period of operation is reported (R. L. Edwards of Barham, oral communication) to have been in the 1920's, ending about 1932. The quarry is flooded and overgrown with pines.

Wyatt Station quarry. A small quarry in granite was opened about 3.5 miles southwest of Wake Forest near the former flag stop of Wyatt's on the Seaboard Air Line Railway. It is in a small tributary valley on the east side of Richland Creek 0.8 mile N. 27° W. of the U. S. Highway 1 viaduct over the railroad. The quarry is about 25 feet square and up to 10 feet deep. The rock is reddish biotite-muscovite granite with microcline phenocrysts. Thin microcline-quartz pegmatite dikes are numerous. The granite is faintly foliated in N. 35° E. direction. The area was described briefly by Watson and Laney (1906, p. 36) but at that time no quarrying had been done. No information was obtained on operations here. The stone was probably used locally for such purposes as chimneys, house piers, and walls.

Soapstone. Altered ultramafic rocks in north-central Wake County have been used locally on a small scale as dimension stone. This use is described later with other potential mineral products obtainable from these bodies.

Sandstone. Triassic red and brown sandstone has been used locally on a small scale for foundations and chimneys in western Wake County. No systematic quarrying for commercial sale seems to have been undertaken. Watson and Laney (1906, p. 231-232) described two localities northwest of Morrisville, but no quarries have been identified. The sandstone from the Durham basin is friable and inclined to flake off. Bedding is irregular, and the rock is not uniform in its properties. The "brownstone" used in various buildings in Raleigh -- for example, in Holladay Hall at N. C. State University -- was quarried near Sanford southwest of the county. The Wake County sandstone has little or no value as building stone.

Crushed Stone Quarries

Rockton quarry. A large producer of crushed stone was the Rockton quarry opened a mile east of Wendell in eastern Wake County. The quarry is 100 feet southeast of the Norfolk Southern Railway and 0.8 mile northeast of the railroad crossing of SR 2353. It was begun in the early 1920's and abandoned about 1950. This pit quarry eventually became as much as 1000 feet in the northeast dimension and about 800 feet at right angles and was worked to a depth of 125 feet along its northwest side. Operators included Southern Aggregates Company, Bryan-Monroe Company, Inc., and Bryan Rock and Sand Company.

The gray to pink rock is variable in texture and compositon. Most is medium-grained, equigranular granite, but a good deal is porphyritic having plagioclase laths up to an inch long. Councill (1954, p. 20) reports that examination by the U. S. Bureau of Public Roads gave the following range of mineral composition:

Quartz	32 to 42 percent
Orthoclase, microcline, and perthite	37 to 65 percent
Plagioclase	0 to 21 percent
Biotite	0 to 8 percent
Muscovite	0 to 3 percent

Biotite streaks are common in the medium-grained rock. Quartz veins and garnetiferous microcline-quartz pegmatite dikes are numerous. The rock was used as concrete aggregate, road metal, and railroad ballast, mainly in eastern North Carolina.

The floor of the pit on the southeast side was some 80 feet below the level of an adjacent stream, so that water seepage was considerable. After abandonment the pit soon filled with water, and in 1964 it became a reservoir for the Town of Wendell.

Knightdale quarry. In 1963 Superior Stone Company opened a quarry in granite about 1.5 miles northwest of Knightdale in eastern Wake County. It is 0.6 mile north of U. S. Highway 64 and 0.6 mile west of SR 2233. The quarry is in the bed of a west-flowing stream that was diverted around the north side. The pit is roughly rectangular, 400 by 600 feet, and is developed in two levels to a maximum depth of about 40 feet. The biotite granite is medium to coarse grained, and some is porphyritic. Much of it is strongly foliated and even distinctly layered by variations in amount of biotite. This unusually prominent planar structure strikes N. 70-75° E. and dips 30 to 80 degrees southeast. Microcline-quartz pegmatites are common. Production of crushed stone continues at intervals.

Wake Stone quarry near Knightdale. A new quarry was opened in 1970 by the Wake Stone Corporation about 1.5 miles northwest of Knightdale. It is 0.7 mile north of U. S. Highway 64 and 0.75 mile west of SR 2233 about 200 yards west of the Superior Stone Company quarry. The benched pit is some 500 feet square and up to about 75 feet deep. The granite has strong uniform layering dipping about 40 degrees south. Joints parallel to foliation and other irregular fractures are numerous. Two north-trending diabase dikes, each about one foot thick, cross the northeast corner of the quarry. The product is crushed granite.

Garner quarry. A quarry was opened in granite by Superior Stone Company about a mile east of Garner. It is located a few hundred feet north of SR 1004 (old U. S. Highway 70) and 0.55 mile east of SR 2547. It has been operated much of the time since it was begun in 1961. The pit is some 600 feet north-south, nearly 1000 feet at right angles, and about 40 feet deep. The rock is quite variable in texture. Most of it is medium- to coarse-grained biotite granite (adamellite) having distinct foliation that is nearly vertical and strikes a little west of north. Some is darker and fine grained, and some is coarse and porphyritic with microcline phenocrysts. Dikes of microcline-plagioclase-quartz-biotite pegmatite are numerous. The product has been crushed stone.

Lassiter quarry. One of the largest quarries in the state was opened in 1922 about 2 miles southeast of Rolesville in eastern Wake County. It lies just north of SR 2305 and a mile east of SR 1003. The pit is irregularly rectangular in plan and eventually became about 1800 feet east-west and about 1700 feet north-south. The main quarry floor is 60 to 90 feet below the rim, and two large pits were sunk in the eastern and southern areas an additional 20 to 25 feet. The quarry was opened in 1922 (Councill, 1954, p. 18) and until 1929 produced curbing, paving blocks, and crushed stone. Operations were intermittent from 1929 to 1941 but essentially full-time after that until it was closed down about 1965. Operators have included Southern Aggregates Corporation, Bryan-Monroe Company, Inc., Bryan Rock and Sand Company, and Superior Stone Company. A railroad spur of the Atlantic Coast Line Railroad was run in from the east; this has subsequently been dismantled. Shipments of dimension and crushed stone were made to east coast states from Pennsylvania to Florida (ibid., p. 18).

The rock in the Lassiter quarry is quite variable. The two chief varieties are relatively fine-grained and medium-dark, biotite-rich adamellite, and a younger, lighter-colored and usually coarser biotite granite. These two types are intimately mixed in irregularly tabular masses, so that most blocks as thick as 10 feet show both. Each has faint or distinct nearly vertical foliation that trends north-northeast. Dark biotite schist and gneiss masses are a common though minor component. Pegmatite and aplite dikes up to about a foot thick are numerous. Essentially vertical joints trending about N. 80° E., on the average, are closely spaced in much of the quarry. They facilitate quarrying for crushed stone but would handicap production of dimension stone. A few joints have striations and are coated with greenish mica and epidote.

After 1929 crushed stone only was produced and sold for concrete aggregate, road metal, and railroad ballast. The results of 10 Los Angeles Wear Tests are reported (Allen, 1958, Division 5, p. 2) to average 55, 63, and 63 percent losses for A, B, and C gradations. Large amounts of fine quarry sand were an incidental by-product of crushing.

Teer's Raleigh quarry at Wyatt. A large quarry 4 miles southwest of Wake Forest at Wyatt was opened in 1968 by Nello L. Teer Company for production of crushed stone. The site was a large flatrock outcrop lying west of U. S. Highway 1 about a quarter of a mile northwest of the highway viaduct over the Seaboard Coast Line Railroad. This area is in the forked granitic lens lying half a mile west of the Rolesville batholith (pl. 1). Many years previously stone for piers of an old bridge across the Neuse River had been taken from a small quarry on the outcrop (E. G. Macon, oral communication). The locality was described by Watson and Laney (1906, p. 36), but no quarrying had been done at that time.

The bench quarry extends some 200 yards east-west and 100 yards north-south and has a north face 50 or more feet high; it drains southward into the Neuse River. The rock is exceedingly variable. Most abundant is a pinkish, medium- to coarse-grained adamellite consisting chiefly of microcline, plagioclase, quartz, muscovite, biotite, and garnet. This rock is notable for its high muscovite and garnet content. Also abundant in the quarry is dark gray (in part almost black) finer grained rock composed of gray plagioclase and dark quartz with biotite. This rock is probably granodiorite or tonalite. It occurs mainly at the west end but is present throughout the quarry. The adamellite cuts across and encloses fragments of the granodiorite. At the east end is a light gray, medium- to fine-grained adamellite or granodiorite consisting of white feldspar, quartz, and little biotite. Relations with the pink adamellite are uncertain; the pink adamellite in places seems to enclose the light adamellite and elsewhere to grade into it. The light adamellite crosscuts the dark granodiorite. Inclusions of biotite gneiss and of hornblende gneiss are common but not abundant. The various rock types are intimately mixed, forming irregular tabular masses mostly not over 10 feet thick. These slabs dip 10 to 20 degrees southwestward. Pegmatite dikes ranging from an inch to a foot thick are numerous. They consist mainly of pink microcline and quartz with a little white plagioclase. They cut across all the gneissic and granitic rocks. Veins of smoky quartz transect the pegmatites and all other rock types. Joints are fairly numerous. The most prominent set trends about east-west and controls the main quarry face. Fracture surfaces, usually slickensided, commonly are coated with epidote and calcite and in places with fluorite. Pyrite is abundant locally in the shears and disseminated several inches into adjacent rock.

Gresham's Lake quarry. A quarry for producing crushed stone was opened by Nello L. Teer Company about 5 miles northeast of Raleigh city limits near U. S. Highway 1. It is situated in the belt of injected gneisses and schists a little less than a mile west of the Rolesville batholith. It lies just northwest of Greshman's Lake and the Seaboard Coast Line Railroad and 0.4 mile west of SR 2013. Operations began in 1956 and ended in 1970. The quarry is a deep narrow pit extending about 1000 feet east-west, 500 feet north-south, and up to 150 feet deep. Most of the rock is medium- to fine-grained, distinctly layered biotite gneiss. Layers vary considerably in biotite content, and some coarse-grained layers are virtually biotite schist. Kulp and Eckelmann (1961, p. 409) determined the radiometric age by the potassium-argon method on biotite from this quarry to be 238 million years.

Pegmatite dikes and sills are numerous, in places constituting nearly half the quarry face. Most pegmatites consist of pinkish brown microcline, white plagioclase, quartz, and biotite and form irregular dikes 2 to 3 feet thick. Contacts are commonly irregular and gradational though sharp elsewhere. Irregular finer grained, aplitic patches occur in some pegmatites. Less common pegmatites are made up of gray plagioclase, quartz, and muscovite. These are tabular, 5 to 6 inches thick, with distinct contacts. They cut sharply across gneiss and the microcline-bearing pegmatites. The foliation trends generally north and dips about 60 degrees east, though in places it is contorted and faulted. Striated shear fractures are coated with muscovite and epidote.

The results of ten Los Angeles Wear Tests are reported (Allen, 1958, Division 5, p. 1) to average 51, 51, and 52 for A, B, and C gradations. After abandonment the quarry filled with water, and no reclamation of the site has been undertaken.

Crabtree quarry. A large crushed stone quarry has been operated for many years 2 miles west of the Raleigh city limits. It lies on the north bank of Crabtree Creek just west of SR 1664 (Duraleigh Road) and a mile south of U. S. Highway 70 (Councill, 1954, p. 17-18; Fortson, 1958, p. 21-25). The quarry was opened about 1946 or earlier by the N. C. State Highway and Public Works Commission, was closed from 1948 until 1954, and has been continuously active since then. Operators have included Bryan Rock and Sand Co., Superior Stone Co., and Nello L. Teer Co. It began as a bench quarry worked northward into the hillside, but in recent years the western and southern portions have been sunk to a benched pit over 100 feet deep. The quarry extends 1000 feet to both northwest and northeast.

The rock is light gray, felsic gneiss characterized by quartz disks. Quartz makes up nearly half of the rock with roughly equal amounts of microcline and oligoclase forming most of the remainder. Thin films of fine-grained greenish muscovite with a little biotite and scattered tourmaline crystals coat the slightly curved cleavage surfaces. A little calcite is present in pores and cracks. The rock is traversed by a few irregularly tabular masses of biotite schist (early mafic dikes). Quartz veins and pods contain an interesting suite of unusual minerals (described under Quartz Veins). The foliation dips gently southwest. Essentially vertical joints contain thin veinlets of opaline quartz and carbonate.

The rock is crushed and sized and used chiefly as road metal and concrete aggregate. The results of five Los Angeles Wear Tests are reported (Allen, 1958, Division 5, p. 1) to average 23, 24, and 30 percent losses for A, B, and C gradations. The rock does not split suitably for dimension stone. The quarry is in active, large-scale production. An interesting study has been made (Angster and others, 1970, p. 19-36) of alternative dispositions of the site after the quarry is eventually abandoned. The solutions developed are of general application.

Buckhorn Creek quarry. A quarry test site was opened in 1973 on the west bank of Buckhorn Creek in the southwestern corner of Wake County. The site is 0.25 mile north of the Chatham County line and 0.4 mile southeast of SR 1130. The quarry was opened by Nello L. Teer Company for Carolina Power and Light Company for possible use in construction of the Shearon Harris Nuclear Power Plant. The bench quarry, situated on a large natural outcrop of Triassic fanglomerate, has a length of about 100 feet, and the face is up to about 20 feet high. The rock consists mainly of coarse fanglomerate with pebbles and cobbles up to about a foot thick embedded in clayey, silty sand. The cobbles are mainly dark greenstone with poor cleavage but include also lighter phyllite fragments and rounded quartz. Several irregular beds of red silty sandstone up to 2 feet thick are interlayered. The rock is only moderately consolidated, and the pebbles are easily broken. The rock may be suitable for riprap. It had not been used at the time the quarry was examined.

Sand and Gravel

Sand with minor gravel has been a sporadic product for many years. It was formerly produced on a small scale in southwestern Wake County. No production statistics are recorded, but intermittent operations are reported during the period 1913-1923 and in 1926, apparently by the Norfolk Southern Railway. Several abandoned pits lie near the railroad and north of N. C. Highway 42, 3 to 4 miles southwest of Fuquay-Varina. The largest pit is between the railroad and SR 1121 and just west of SR 1101. An area about 500 by 1200 feet has been excavated to a depth of 4 to 7 feet. The gray to buff, medium to fine, loamy sand is chiefly quartz with little mica or dark minerals. Grains are subround to subangular. Pebbles are scarce, and no gravel layers were observed. Almost no iron stain is present. A second narrow pit extends for nearly 1500 feet just southeast of SR 1121 south of the railroad and on both sides of SR 1173. Similar loose sand has been removed to a depth of 5 to 7 feet. The bottom of the pit is hard and limonite-cemented. A third pit lies south of SR 1120 and half a mile east of SR 1119. An area about 400 by 250 feet has been dug 3 to 5 feet deep. Loose pebbles are fairly common here. The pit bottom is hard, limonite-cemented sand. These deposits seem to be in the "Pinehurst" Formation. Gravel is reported (Bryson, 1930, p. 120) extending over several hundred acres northeast of Fuquay-Varina along Terrible Creek near SR 1301.

River sand used mainly for paving has been produced by the N. C. Highway Commission for at least 25 years. It has been obtained near Wake Forest from Smiths Creek just south of SR 2045, from the Neuse River northeast of Auburn and just southeast of SR 2555, and more recently from the Neuse River below Milburnie adjacent to the Southern Railway. Total production has been more than 78,000 tons valued at some $53,000.

Future production of sand on a moderate scale should be possible from many sites in the upland sediment in southern Wake County. It would have to compete, however, with the high value of this land for agriculture. River sand in small quantities will continue to be available along the Neuse River as floods partially replace the sand removed.

Weathered pegmatite has been used on a small scale in place of sand and gravel to surface driveways and farm roads. Two localities formerly worked, the Hill quarry near Wake Forest and the Colonial Heights quarry south of Raleigh, are described later with mica and feldspar deposits.

Brick Clays

Brick-making has been carried on in Wake County since at least the late 18th century. When the City of Raleigh was laid out in 1792, two lots at Hargett and West Streets were reserved for brick-making (Waugh, 1967, p. 4). The State Bank building (built 1813) and the old Governor's Palace (1816) were constructed of brick presumably made locally. About 1830 Dabney Cosby, a local architect, operated a brick yard on Hargett Street (Waugh, 1967, p. 51-52). The 8th U. S. Census (1860) reports five brick concerns in Wake County with an annual product of $16,850. During the late 19th century brick-making was carried on at the State Penitentiary using bottom land clays from southeast of the city (Ries, 1897, p. 130-131). This industry supplied brick for Holladay Hall (built 1889) and Fourth Dormitory (1894) at N. C. College of Agriculture and Mechanic Arts (now N. C. State University) and for the Governor's Mansion in 1891 (Waugh, 1967, p. 145, 149, 152). Apparently the raw material used during the 18th and 19th centuries was entirely alluvial floodplain clay obtained from low ground along Walnut Creek and its tributaries in the Caraleigh section and eastwards. Plastic clay along the Neuse River north of Raleigh is also reported by Ries (1897).

Manufacture of brick and other structural clay products was active during the first quarter of the 20th century. In the period 1901-1917, at least 116 million bricks valued at over $678,000 were produced in Wake County. Alluvial clays were used along Walnut Creek and along Crabtree Creek between U. S. Highways 1 and 64 near the Norfolk Southern Railroad.

Bricks were also made about 3 miles southwest of Apex during the period about 1911-1924. The plant and clay pits were at Friendship between SR 1011 (old U. S. 1) and the railroad opposite the junction of SR 1142.

Five shallow, water-filled pits are scattered over about 2 acres. The raw material was gray to buff sandy clay from the underlying Triassic sediments; it may have included a thin veneer of younger upland sediment.

Brick manufacture in Wake County seems to have ended temporarily about 1924 but was resumed in 1960 with the opening of a modern plant by Triangle Brick Company on N. C. Highway 55 just south of the Durham County line. Triassic silty shale was first mined between the highway and the railroad and later from a pit west of N. C. Highway 55.

Floodplain clays suitable for brick-making are not present in Wake County in deposits of adequate size and uniform quality to support modern manufacturing operations. Triassic shales, on the other hand, exist in enormous quantities. They are interbedded with sandstones, however, and some rock has objectionable amounts of calcium carbonate. Any projected site would require careful and detailed sampling and testing to determine whether material of adequate quantity and suitable quality were present. Recent information on potentially useful shales and clays in Wake County is given in the Region J Geology report (Wilson and Carpenter, 1975, p. 27, 64-65 and pl. 3).

Graphite

Mining of graphite (black lead or plumbago) was an early industry in Wake County. Though intermittently persistent, it seems always to have been of minor importance. Olmstead (1824, p. 4) reported Wake County to have "the largest mine on record." Emmons (1856, p. 221-227) described the industry in some detail, stating it was then in operation and that the vein had been mined to a depth of 70 feet and along a length of 1000 feet. Similarly, Kerr (1875, p. 296) reported the graphite "is wrought to a considerable extent at present." Reported production of graphite is summarized in Table 2. It seems likely that additional production went unrecorded.

Table 2. Recorded production of graphite in Wake County, North Carolina, 1880-1906

Year	Amount (tons)	Value ($)	
1880	200	1800	Heron mine
1881	?		
1882	none		
1883	probably none		
1884	none		
1885	none		
1886	none		
1887	10		Heron mine; for paint
1888	none		
1889	none		
1890	none		
1891	none		
1892	none		
1893	none		
1894	none		
1895	103		
1896	none		
1897	none		
1898	none		
1899	none		
1900	some shipments during past several years		
1901	95	559.25	Crucible and foundry
1902	*830	4300	
1903	50	248	
1904	100	525	
1905	100	475	
1906	100	475	Foundry facings

No later production recorded

*Includes production from McDowell County, N. C.

Mining seems to have been carried on intermittently at three principal locations: (1) Lead Mine Hill (Tucker property) on Mine Creek about 7 miles north of Raleigh, (2) the so-called Old Lead Mines in northwest Raleigh along the ridge between House Creek and present Ridge Road, and (3) at the Goodwin property some 4 miles southwest of Raleigh. Information is too scanty to identify with assurance the owners and operators or to permit allocation of production to specific localities. All mine workings have been partly or wholly obliterated by grading and back-filling.

The most extensive mining appears to have occurred at the Lead Mine Hill or Tucker property on the ridge just west of Lead Mine Road (SR 1820) between its intersection with Lynn Road (SR 1812) and a branch of Mine Creek to the north. The workings (fig. 16) extended northward along the east edge of the ridge for about 800 feet and included at least four shafts and two adits. Mining evidently went down to about the level of the creek at the north end, where water drained out slowly in 1950; the shafts were not flooded. Graphite was mined here from the more westerly zone of the eastern outcrop belt. The workings were largely back filled and graded over in the 1960's.

The House Creek Lead Mines included several small workings opened at intervals along some 2000 feet along the ridges east of House Creek from near present Sandia Drive to Westmoreland Drive. These are likely to include the mine reported in the Tenth Census (1880) (p. 841 and 984) as the Heron mine, operator Carter, Pullen, and Tucker, employing five hands. Pratt (1902, p. 70) referred to these mines as belonging to the Tucker estate (care of Charles H. Belvin). The workings comprised at least five shafts and drift adits which apparently exploited the deposits to depths of perhaps 50 feet. The small size of the dumps indicates the production of graphite was not large. Ten tons sold for paint was reported for the Heron Mine in 1887. This mining also was on the more westerly zone in the eastern outcrop belt.

A little mining was done at the Goodwin property southwest of Raleigh on the ridge just southeast of U. S. Highway 1-64 and west of Jones-Franklin Road (SR 1319) 0.35 mile S. 65° W. of their interchange. This evidently is the site referred to by Pratt (1902, p. 70) as the property owned by E. McK. Goodwin of Morganton. The workings seem to have been little more than a short drift adit into the hillside. The graphite here is in the eastern zone of the western belt, that is, the same unit mined to the northeast but at this point exposed on the west flank of the Raleigh anticline.

Prospecting pits have been identified in the woods about 200 feet south of Avent Ferry Road (SR 1321) at a point 1000 feet S. 83° E. of its intersection with Lake Dam Road (SR 1427). The College View section south of Western Boulevard was also of economic interest years ago. Mineral rights in the area had been alienated from surface ownership (J. L. Stuckey, oral communication). On N. C. State University farmland a mile west of Polk Prison Camp, a short adit was driven long ago into the hillside south of a branch of Richlands Creek. This is the most northerly exposure discovered on the western zone of the western outcrop belt.

Wake County graphite is the amorphous variety which is much less valuable than crystalline graphite. Furthermore, it is mixed with mica, clay, and quartz and hence is impure. Percentages of graphite in the rock are reported to range from a few to as much as 60 percent; better grade for large bodies of rock probably would be about 25 percent.

It is not known whether the graphite was beneficiated in any way or was sold as mined; the latter is more probable. Emmons (1856, p. 225) reports it was used in paint for roofs, stoves, and ships and as lubricant on wagon axles. In 1887 the product was mined for paint; in the period 1901-1906, it was mined for foundry facings and crucibles (Pratt, 1902, p. 70).

Beneficiation by flotation was tested by Ung (1965) using sodium hydroxide and pine oil. Separate tests were made on samples from various locations, on different size fractions, with varying pulp densities, amounts of sodium hydroxide, times of froth removal, and by desliming and by panning. Best recoveries were made in the minus 200-mesh fraction; other variants had little effect. These tentative results, on the whole, were discouraging to further development.

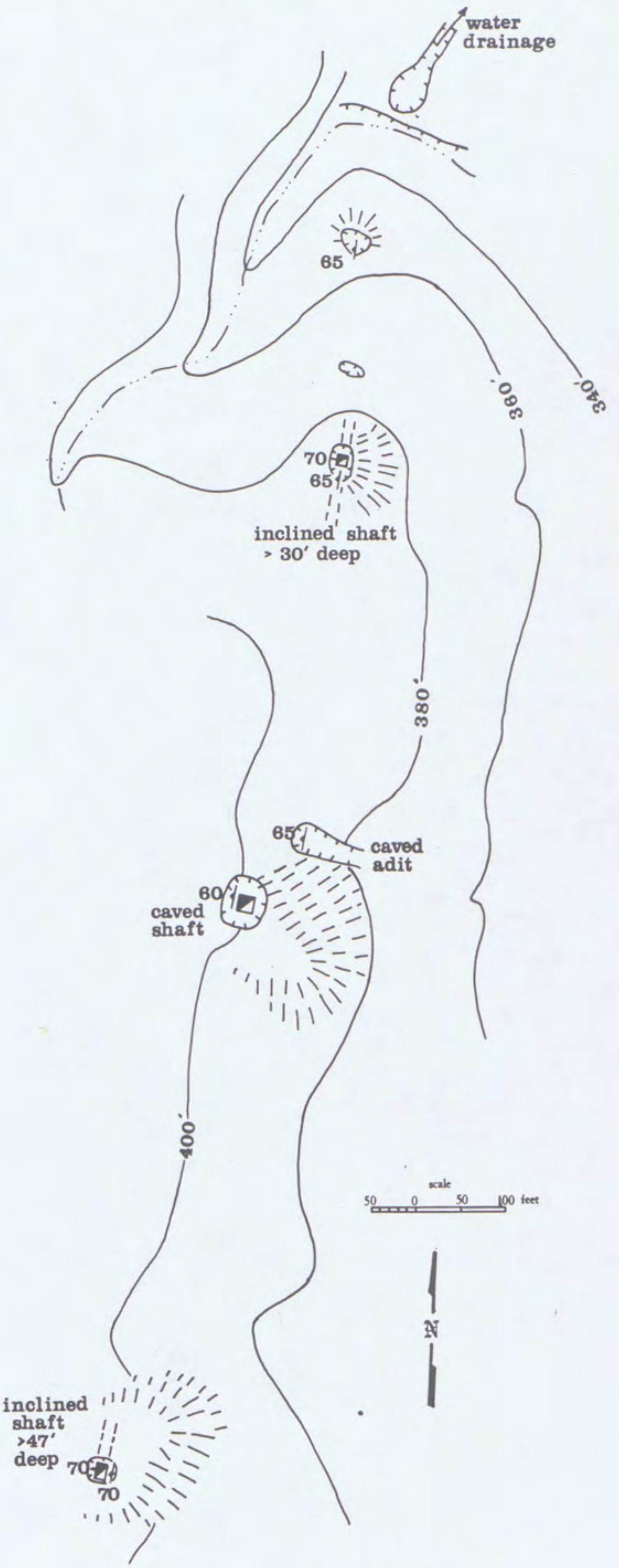


Figure 16. Map of graphite mine workings at Lead Mine Hill, north-central Wake County, N. C.

Mica and Feldspar Deposits

Pegmatites of potential economic value occur in a north-northeast trending belt extending through east Raleigh to Wake Forest. The pegmatites occur in the injected layered gneisses and in the felsic gneisses just to the west. Some of the deposits have been described by Sterrett (1923), Farquhar (1952), Steel (1952), and Griffitts (1953). Potential feldspar resources from pegmatites and other rocks in North Carolina have been evaluated by Neal and others (1973).

Muscovite mica has been produced at intervals over some 60 years. Production figures are not available, but so far as can be learned the total amount has been insignificant. The quality of muscovite from the area is poor, most of it being green, stained, and with A-structure, reeves, and tangle sheet. The maximum size of clear trimmed sheet mica obtainable seems to have been small, probably not over 3 by 3 inches. Though mica books are abundant locally in the pegmatites, their amount and size on the whole have been discouraging. The outlook for sheet mica production, thus, is regarded as poor. The small size of most pegmatites and the low concentration of mica in them provide little potential for production of scrap mica.

Feldspar has not been mined commercially in Wake County, but a good possibility seems to exist for future production. The pegmatites consist chiefly of microcline (much of which is perthitic), and hence they provide a significant resource of potash feldspar. Depletion of potassium feldspar reserves in western North Carolina adds to the potential value of the local deposits. Data now available (Table 3) indicate K_2O content of some samples to be above 12 percent and Na_2O as low as 2 percent. The presence of sodium-rich plagioclase as perthitic intergrowth within microcline, however, disqualifies much feldspar in the district from the potash spar grade in which the ratio of K_2O to Na_2O is about 3/1 or higher. Individual deposits would require careful sampling to determine average chemical grade.

Probably no single pegmatite in the district is large enough to support investment in a feldspar preparation plant, but the district as a whole might. Development of the southern part of the district in and near Raleigh would be hampered or prevented by its being within built-up areas. The pegmatite belt, however, extends northeastward into Franklin County.

Attempts at commercial development of the pegmatites took place in two areas: (1) west and southwest of Wake Forest and (2) south of Raleigh. Other large pegmatites exist between these two areas. The more important localities are described below, in an order generally from north to south. The outlook for feldspar production from rocks other than pegmatites is also considered.

W. J. Kerney mine. The Kerney mine (Steel, 1952, p. 12-13; Wilson, 1962, p. 17) is 2.6 miles N. 80° W. of the center of Wake Forest on the crest of a ridge 0.15 mile east of SR 1923 and 0.5 mile north of Horse Creek. The workings in deeply weathered rock are largely slumped in or caved and overgrown. They included a small inclined shaft and drift with several prospecting trenches. It was operated by William M. Silver during World War II. The pegmatite has a maximum thickness of about 15 feet and is traceable for some 400 feet along strike N. 20° E. The wall rock is steeply dipping mica gneiss striking nearly north-south. The pegmatite consists largely of microcline and quartz with a little plagioclase and biotite. Muscovite is green, has A-structure, and is of poor quality. The largest sheets observed were about 4 inches wide. A little beryl and black tourmaline are associated with pods of smoky quartz. The amount of mica produced is not recorded but doubtless was negligible.

Half a mile east on SR 1927 near the bridge over Horse Creek numerous sharply discordant pegmatites are exposed. They range in thickness from 1 to 20 feet and contain much graphic intergrowth of microcline and quartz.

Thompson mine. The Thompson mine (Steel, 1952, p. 12, and pl. 2 B) is 2.7 miles west of the center of Wake Forest near the lower end of a low ridge on the north side of Horse Creek; it is 0.25 mile N. 43° E. of the bridge on SR 1923. During World War II four shafts ranging from 25 to 40 feet in depth with a drift and small stope were opened by William M. Silver. The deposit was reopened in 1956 and worked intermittently for some months by Robert L. Hammond and others (Crosswell, 1956). Small production reported in 1957 by East Piedmont Mining Company was probably this same operation.

A lenticular open cut about 200 feet long, up to 100 feet wide, and 30 feet deep was made, thus obliterating the earlier shafts. The lenticular pegmatite strikes north-northeast and dips about 45 degrees east; it is generally conformable to the enclosing gneisses. Its thickness ranges from about 6 to 20 feet, with smaller offshoots to the northeast. The wall rock to the east is light-colored, thinly laminated biotite gneiss and on the west is dark-brown biotite and hornblende gneiss. The pegmatite consists chiefly of perthitic microcline with plagioclase and quartz. Coarse graphic texture is common. Muscovite books as large as a foot wide and 32 pounds in weight were obtained in 1956, but total production seems to have been small.

Tharrington prospects. Several prospect pits were opened on the S. H. Tharrington property (Steel, 1952, p. 13) about 3.5 miles west of Wake Forest on the south side of Horse Creek and near SR 1922. Mr. E. A. Hughes dug several pits during World War II, but no mining resulted. The pits have been backfilled. A pegmatite is exposed in the road cut about 0.25 mile south of the creek. It is a sill about 25 feet thick enclosed in garnet-kyanite-mica schist striking N. 10° E. and dipping steeply west. The pegmatite is chiefly microcline with quartz and contains both muscovite and biotite. Quartz-muscovite rock ("burr") composes the eastern foot and a half of the sill.

Hughes mine. This mine, also referred to as the Wakefield prospect (Farquhar, 1952, p. 28-30; Steel, 1952, p. 11-12; Griffitts, 1953, p. 286), is 1.15 miles S. 78° E. of the bridge at Falls on Wakefield Farm on a ridge 0.25 mile northwest of the junction of Richland Creek with the Neuse River. The deposit was prospected rather extensively in 1943 by E. A. Hughes and mined on a small scale though apparently no shipments of feldspar or mica were made. The workings include several shafts and open cuts and many exploratory trenches. All are backfilled or flooded, and the nature and extent of underground workings are unknown. The size of dumps indicates they were small.

The steeply dipping pegmatite sill trends north-northeast, enclosed in hornblende gneiss. It is reported (Steel, 1952, p. 11) to be 50 to 60 feet wide at a maximum and at least 1000 feet long, narrowing toward both ends. It consists chiefly of buff perthitic microcline and quartz; much has graphic texture. Feldspar masses and quartz pods up to a foot thick are common. A few euhedral microcline crystals as large as 5 X 7 inches have been obtained. Some of the pegmatite consists of quartz-muscovite ("burr") rock. Muscovite occurs in small flakes and in wedge-A books up to about 5 inches wide, mainly near the walls of the sill. The mica is light green and commonly distorted, ruled, stained, and with mineral inclusions. The amount of book mica seems to have been considerable, but recoverable trimmed sheet mica must have been small. Biotite occurs mainly along the contacts. Garnet and pyrite are minor components.

This pegmatite might well have potential for production of feldspar with some by-product muscovite, mostly as scrap mica with a little small sized sheet mica. Chemical analyses were made in 1943 (Farquhar, 1952, p. 30) on feldspar samples collected by E. A. Hughes, with the following results.

	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O
Block spar	56.67	23.02	1.04	10.32	8.60
Corduroy spar	70.40	14.22	1.35	9.18	6.32

Additional samples from this pegmatite (Nos. 3927 and 3928) were included in Neal's evaluation (1973) of North Carolina feldspar resources; results are given in Table 3. The samples came from a pile of mined feldspar and are doubtless higher than average grade of the whole pegmatite. On the basis of high recovery and high potassium content, this pegmatite ranked among the best sources investigated.

Hill quarry. The Hill quarry (Farquhar, 1952, p. 20; Steel, 1952, p. 12) is 1.5 miles N. 52° E. of the bridge at Falls on Wakefield Farm near the head of a small valley and 0.4 mile southeast of SR 2000. A shallow open cut was made in 1948, and worked at intervals later, on a pegmatite partly disintegrated by weathering. The material was used without processing to surface farm roads. The cut is about 30 feet wide, 50 feet long, and up to 20 feet deep (Farquhar, 1952, fig. 3 and pls. 1 and 2). The pegmatite exposed in the cut is some 60 feet wide and trends north-northeast. It narrows abruptly and irregularly to north and to south extending many tongues and sills into the surrounding biotite and hornblende gneisses. Inclusions of gneiss in the pegmatite are numerous.

The pegmatite consists chiefly of pink to buff perthitic microcline and white to gray quartz. These are intergrown with unusually fine graphic texture in much of the rock. White, partly kaolinized plagioclase is common. Light-green muscovite occurs as disseminated small flakes; mica books of commercial size are lacking. Biotite occurs sparingly, partly as strips up to 3 inches long. Garnet is a minor component. Hyalite is reported (Steel, 1952, p. 12) as forming yellow-green crusts on feldspar.

Some potential for production of potash spar seems to exist here, though the prevalence of graphic intergrowth ("corduroy spar") lessens the quality. The potassium content and recovery percentage are very good (see #4034 in Table 3). The known form of the pegmatite is so irregular, however, that estimation of reserves would be hazardous without careful exploratory drilling. Mica production seems out of the question.

Phelps prospect. This pegmatite is reported (J. L. Stuckey, oral communication) to be 3 miles south-southwest of Wake Forest, a little east of the Seaboard Coast Line Railroad crossing over SR 2044. The site could not be recognized. This seems to be the prospect mentioned by Sterrett (1923, p. 268); his report is quoted in full.

> A prospect was opened for mica about 3 miles southwest of Wake Forest early in 1916 by J. E. Coggins of Raleigh. When the place was examined in June, 1916, there was a pit about 10 feet across and 5 feet deep. The country rock is granite, slightly gneissic in places. The mass of pegmatite exposed in the walls of the pit is from 1 foot to 3 feet thick, and is very irregular in size and shape. It grades into the surrounding granite by diminishing coarseness of texture.
>
> The pegmatite is composed of partly altered potash feldspar in crystals that reach a thickness of 1 foot, dark, smoky quartz in irregular-shaped masses from less than 1 inch to 18 inches thick, and crystals of mica, some of which are as much as 10 inches across. One crystal of mica taken out is reported to have weighed about 75 pounds. Mica weighing between 400 and 500 pounds was removed from the pit. Part of this is of the A variety, part is tangle sheet, and a little is ruled. Clear sheets 2 by 3 inches, 3 by 3 inches, and probably larger can be cut between A lines of the larger crystals. The mica is clear where free from clay stains and has a smoky, greenish color.

Upper Honeycutt Creek pegmatite. A pegmatite crops out near Honeycutt Creek about 2 miles northeast of Six Forks. It crosses SR 2005 about 0.2 mile south of the intersection with SR 2006. It is exposed at intervals in the road, in the branch to the west, and southwestward up to the ridge crest. Its thickness may be as much as 50 feet in places, and it extends N. 30° E. for at least 1000 feet. The pegmatite is a steeply dipping sill in felsic, lineated biotite gneiss. It consists of microcline, plagioclase, quartz, and muscovite. Mica content is low but feldspar might be of economic interest.

Millbrook pegmatite. An unusually large pegmatite in the Millbrook area was formerly exposed in the branch 0.35 mile west of Falls of Neuse Road and just north of Millbrook Road. This pegmatite is more than 100 feet wide in places and extends at least 1000 feet north-northeast. It is composed largely of perthitic microcline and quartz, part of which has graphic texture. The area has become residential so that mining would no longer be possible.

Colonial Heights quarry. A shallow pit in partly decomposed pegmatite was operated in the 1950's to supply material for surfacing local driveways. It is about 5 miles south of Raleigh on the west side of U. S. Highway 401 and just south of the bridge over the Norfolk Southern Railroad and a creek. Pegmatite is exposed for about 1300 feet along the highway and for about 450 feet to the northwest. The overall form and extent of the pegmatite could not be determined. The rock is variable but seems to be chiefly microcline and quartz. Residential development here has progressed to the point that mining probably would be excluded. Proximity to water and highway and rail transportation, as well as the unusually large size of this pegmatite, give the site economic importance as a source of potash feldspar.

Coburn prospect. A pegmatite is reported by Griffitts (1953, p. 286) on the R. T. Coburn property half a mile east of U. S. Highway 15-A [now U. S. Highway 401] and 5 miles south of Raleigh. This is likely to be in the Colonial Heights area, but the site has not been found. Several prospect pits were sunk prior to 1941 on a pegmatite dike that strikes N. 5° E. and contains flat-A books of spotted, dark-green mica.

Stone quarries. Quarrying of granite and gneiss results in large quantities of sand-size waste from crushing and washing that contains much feldspar. Though much of this is used in construction, some waste might be up-graded to a higher value feldspar product. Neal and others (1973) evaluate tailings from three quarries and two outcrops in Wake County; results are summarized in Table 3. None of these sources is favorable for producing high-potash spar, but material for container glass manufacture might be obtained if market factors favored.

Table 3. Evaluation of selected potential feldspar sources in Wake County, North Carolina

Sample No.	Feldspar recovery (Wt. %)	Chemical analysis of feldspar			Rating number (% feldspar recovered X % K_2O)
		$\%Fe_2O_3$	$\%Na_2O$	$\%K_2O$	
Pegmatites:					
3927	58.4	0.05	1.8	13.8	806
3928	67.2	0.08	2.8	13.7	921
4034	60.3	0.05	2.0	13.9	838
Granites:					
3641	32.9	0.06	3.4	8.9	293
3642	44.5	0.05	4.2	6.7	298
3643	44.4	0.07	4.0	5.7	253
3644	32.3	0.05	3.8	7.1	229
Granite tailings:					
3129A	56.2	0.06	5.8	6.0	337
3129B	47.0	0.06	6.0	5.1	240
3453B	56.9	0.09	5.7	6.3	358
Gneiss tailings:					
3452B	41.8	0.94	7.3	3.9	163

Compiled from Neal and others (1973), which describes procedures and gives additional analytical results.

Locations of samples:

3129A -- Rolesville quarry of Nello L. Teer Company; granite, waste fines, minus 1/8 inch.

3129B -- Rolesville quarry of Nello L. Teer Company; granite, waste fines, minus 1/4 inch.

3452B -- Crabtree quarry of Nello L. Teer Company; quartz disk gneiss, waste fines from pond.

3453B -- Raleigh quarry of Nello L. Teer Company at Wyatt; granite, waste fines from pond.

3641 -- Outcrop about a mile west of Zebulon on U. S. Highway 64-Bypass, east of SR 2370; granite saprolite.

3642 -- Outcrop about a mile west of Zebulon on U. S. Highway 64-Bypass, east of SR 2370; partly decomposed granite.

3643 -- Outcrop about 2 miles east of Knightdale on U. S. Highway 64, east of SR 2236; medium to highly weathered granite.

3644 -- Outcrop about 2 miles east of Knightdale on U. S. Highway 64, east of SR 2236; granite saprolite.

3927 and 3928 -- Hughes prospect on Wakefield farm near Falls; fresh pegmatite.

4034 -- Hill quarry on Wakefield farm near Falls; fresh pegmatite.

Limestone

Limestone in the Triassic rocks in western Wake County and adjacent Durham County was utilized on a small scale in the 19th century. Kerr (1875, p. 187-188) recommended its use for agricultural purposes and reported that lime was burned and used for building during the 1830's and the Civil War. Pratt (1904, p. 57) reported earlier quarrying of the limestone for burning to lime and urged further development. Commercial value under modern conditions is negligible.

Coal

A thin layer of coal is known in the Triassic rocks in eastern Chatham County (Broadhurst, 1955, p. 84); it may extend into Wake County. The coal was exposed about 1947 in a well on the John Goodwin farm on SR 1900 (Chatham County) 1.5 miles west of Wake County and 1 mile south of U. S. Highway 64. The 11-inch thick coal bed was penetrated at a depth of 30 feet. The occurrence of coal here is regarded as of little or no commercial value.

Manganese

Manganese was discovered in 1940 in easternmost Wake County on the Avon Privette property. The deposit is about 3 miles east of Zebulon; it lies 0.3 mile east of N. C. Highway 39 and 0.5 mile north of U. S. Highway 264, on a hill west of Moccasin Creek. Though considerable work was done here, no sign of it has been evident in recent years. Information is derived from reports by Murdock (1941 and 1950), White (1944b), and Thompson (1950). Operators included North Carolina Manganese Corporation and Clough Manganese Company. Crosscut trenches were cut, and a 35-foot shaft sunk on the footwall. The U. S. Bureau of Mines drilled 14 holes between November 1944 and January 1945 with a total length of 2308.5 feet. Details of drilling, mineral dressing, and chemical analyses are given by Thompson (1950). A small experimental plant in Raleigh produced a little manganese sulphate fertilizer from this ore.

The deposit was derived by weathering of a quartz-spessartite (manganiferous garnet) vein complex in fine-grained mica schist or phyllite. The outcrop was a few feet to 20 feet wide and trended N. 20° E. 800 to 1000 feet. The veins were parallel to the cleavage of the phyllite which dips steeply (80 to 90 degrees) eastward. The ore at the surface was hard manganese and iron oxides mixed with quartz and spessartite. At depth where weathering was less complete, the deposit contained actinolite, chlorite, carbonate, and pyrite. Drilling indicated unweathered rock at depths of 50 to 80 feet. The deposit of manganese oxide was low grade and too shallow to afford adequate tonnage for commercial development.

Soapstone, Talc, and Chrome Ore

Soapstone, serpentine, and other altered ultramafic rocks in north-central Wake County have been known since the early 19th century (Olmstead, 1825, p. 112; Mitchell, 1842, p. 30). No commercial production seems to have been undertaken, but residents of the area have used these rocks for foundations and piers, chimneys and hearths, and gravestones. Some rock was used as rough blocks, but much was sawed or carved into rectangular forms. Stone seems to have come from many outcrops. The only definite quarry that has been identified is just south of a tributary to New Light Creek about 800 feet northeast of SR 1918 and 0.9 mile southeast of the junction of SR 1909 and 1918. The opening is about 20 feet wide and 10 feet high.

The soapstone deposits were surveyed during a project of the Works Progress Administration between about 1933 and 1936 (Ward, 1933), but the results do not seem to have been recorded. George (1939, p. 2) reports that numerous trenches, pits, adits, and tunnels were made. Properties that were prospected are listed below:

Evans--100 acres--on Upper Barton Creek just east of N. C. Highway 50.
Harris--60 acres--north of Pleasant Union Church between SR 1847 and Upper Barton Creek.
Davis--60 acres--north of N. C. Highway 98 and east of Neuse River.
Perry--117 acres--north of SR 1919 and west of SR 1918.
Powell--36 acres--northeast of SR 1918 and west of SR 1917.
Woodlief--100 acres--along tributary of upper New Light Creek between SR 1910 and 1911.
O'Neal--90 acres--about quarter of a mile east of Woodlief.

Talc production for various commercial uses was investigated at the Department of Engineering Research of N. C. State College (Dillender and Gower, 1953). A large sample was taken from the ultramafic body north of Pleasant Union Church (on SR 1847) at the end of a ridge just south of Upper Barton Creek. Samples ground to -100 mesh, -200 mesh, and -325 mesh were treated by froth flotation, magnetic separation, and desliming. Reflectance values of the product ranged from 65 to 73, the highest value being that of the smallest particle size. A product deemed suitable for some commercial applications was made, but recoveries ranged only from 60 to 65 percent. The soapstone bodies are so variable in composition that it is probable that the only product possible would be low grade mineral filler.

Chromite in the ultramafic rocks of Wake County seems to have been first reported by Watson and Laney (1906, p. 215). George (1939, p. 19) noted it with serpentine scattered over about an acre 0.25 mile north of Pleasant Union Church and 0.1 mile northwest of SR 1847. The massive chromite rock here includes olivine, tourmaline, veins of cross-fiber talc and chrysotile, with coatings of thulite and fuchsite.

Chromite also occurs on Adam Mountain, half a mile northwest of Bayleaf (Marshall, 1951; Broadhurst, 1955, p. 13; Dickey, 1963, p. 50 and pl. 1; Carpenter, 1976, p. 151-152). The U. S. Bureau of Mines drilled one exploratory diamond drill hole on the south end of Adam Mountain in June 1951. The vertical hole was 156 feet deep and penetrated 20 feet of serpentinized dunite with small specks of chromite between the depths of 66.5 and 86.5 feet; mica schist was penetrated above and below the dunite. Analyses by the Bureau of Mines gave the following results:

Chromite float --	17.6% Cr (sic)
	0.11% Cr
	0.05% Cr
	0.05% Cr
	6 to 26% Fe
Chromite ore from hole	0.99% Cr and 20.3% Fe
	0.37% Cr and 10.1% Fe
	0.85% Cr and 15.6% Fe

Work done in December 1951 at the Minerals Research Laboratory, N. C. State University (E. H. Bentzen, written communication, 1975) on samples from Adam Mountain gave the following results:

Chromite float -- 14% Cr_2O_3; upgraded to 20% Cr_2O_3

Chromite core (?) -- 11.2% Cr_2O_3, upgraded to 28% Cr_2O_3

Bentzen (1970) reported the following analysis of chromite from the diamond drill core from Adam Mountain:

36.0% Cr_2O_3
14.5% FeO (total iron)
6.0% SiO_2
Cr/Fe ratio 2.19
Specific gravity 3.9
Recalculated Cr_2O_3 42% (on silica-free basis)

He emphasized that earlier analyses of North Carolina chromite, including Wake County, were affected by contaminating associated minerals.

Investigations to date have not been thorough enough to evaluate definitively the chromite deposits in Wake County. It appears that chromite of satisfactory composition may be present but that chrome ore of sufficient grade to sustain mining exists only as a potential by-product to other operations. No chromite mining has ever been attempted in the county.

Iron and Titanium Ores

Iron ore in small amounts has long been reported in Wake County but deposits of commercial value are not known. Emmons (1856, p. 126) noted "a bluff of haematite, in the hydrous peroxide of iron" located 7 or 8 miles southwest of Raleigh. This information was repeated by Kerr (1875, p. 221) and Kerr and Hanna (1888, p. 129). The indicated locality would be in the Swift Creek area south-southwest of Macedonia. Upland sediment in this vicinity is cemented locally by limonite and contains limonitic nodules. J. A. Holmes' Geological Map of North Carolina (1887) published by Kerr and Hanna (1888) shows four symbols for iron in Wake County. These are near Macedonia, Apex, Holly Springs, and on the Wake-Johnston County line south of the Neuse River. All of these localities are believed to be based only on limonite in upland sediment.

The aeromagnetic map shows several localities having high values sufficient to suggest the possibility of magnetite iron ore. The outstanding one is the Panther Branch amphibolite near the south end of the county. This reaches a high value of +518 gammas on SR 1006 (Old Federal Road) half a mile north of N. C. Highway 42. Most of this area is buried by Coastal Plain sediment and no magnetite-bearing rock has yet been found.

A second unusual magnetic high is caused by the magnetite-ilmenite quartzite that extends through the northeast corner of Umstead Park. Values here reach +105 gammas with relief above surrounding areas of more than 300 gammas. Though comparatively little is known of this rock since it occurs in a thickly wooded area only as float, it is quite unlikely that a sufficient quantity of iron and titanium ore exists here for commercial development. Furthermore, mining operations would be excluded from state park lands.

A third locality of interest is in northwest Wake County near Perry Pond on and just west of the county line in the triangle between N. C. Highway 98, Durham County SR 1805, and Wake County SR 1831. A peak of +262 gammas is reached with relief of more than 400 gammas to east, north, and west. No rock capable of accounting for this prominent high has as yet been found. This locality lies in the same belt of rocks as the Umstead Park magnetite quartzite, however, and both highs probably have similar sources. The likelihood of commercial iron ore here is slight.

GROUND WATER

Resources of ground or subsurface water depend upon local geologic factors such as rock type and texture, orientation of rock masses, extent of fracturing, thickness of saprolite and soil, and topography as well as upon climatic conditions. Extensive information on this topic is readily available from the publication listed below, so no special attention was given to ground water occurrence during the present study:

> Geology and Ground Water Resources in the Raleigh Area, North Carolina, by V. J. May and J. D. Thomas, Ground Water Bulletin No. 15, North Carolina Department of Water Resources, Division of Ground Water, Raleigh, 1968, 135 p.; prepared cooperatively by the U. S. Geological Survey and the N. C. Department of Water and Air Resources.

The present investigation modifies the information in this publication only in revising the kind and extent of rock present at some localities.

Further information applicable to ground water in Wake County is given by LeGrand (1967), Mundorff (1950), Stuckey (1929), Welby (1968), and Wilson and Carpenter (1975).

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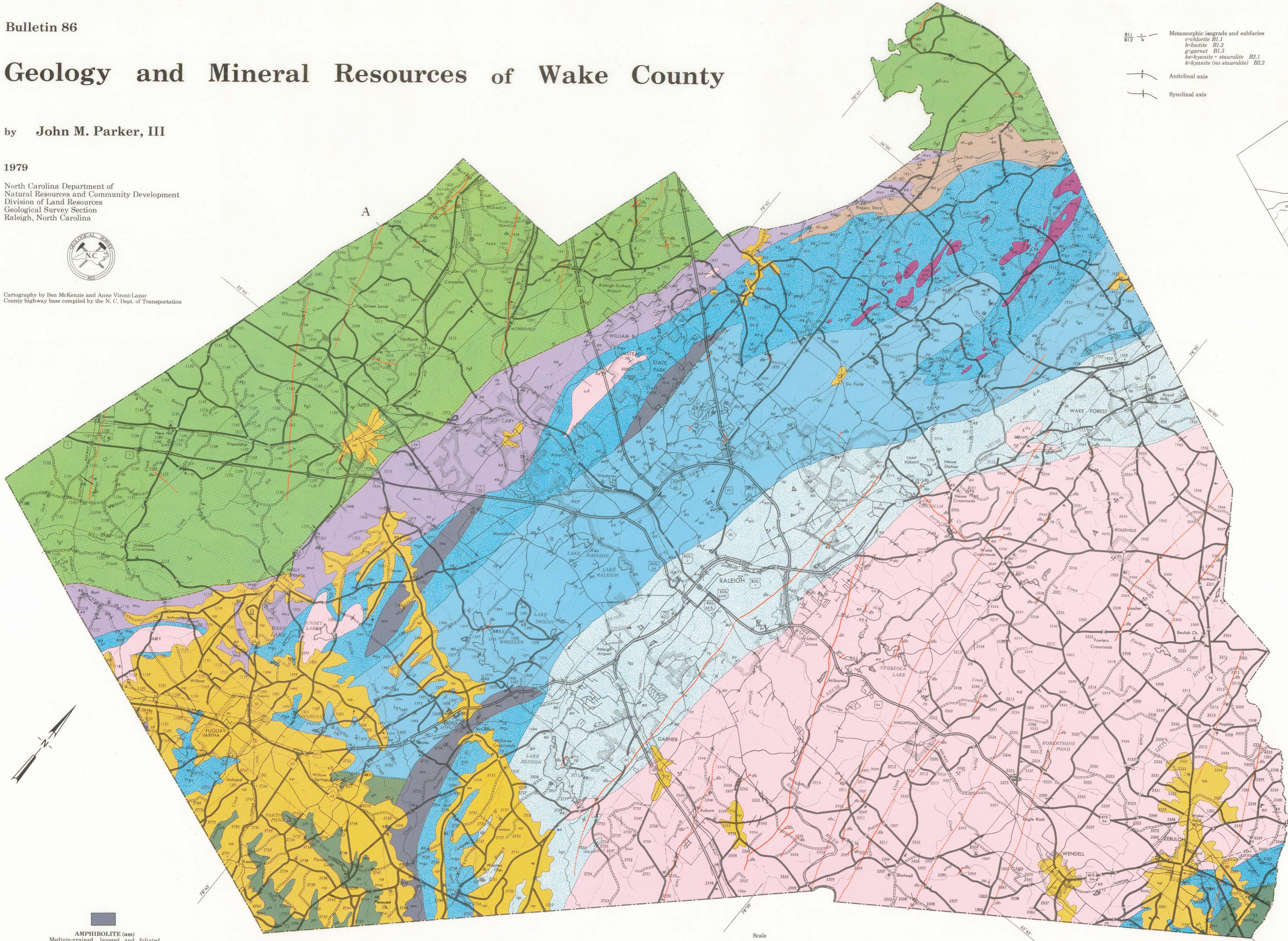
Geology and Mineral Resources of Wake County

by John M. Parker, III

1979

North Carolina Department of
Natural Resources and Community Development
Division of Land Resources
Geological Survey Section
Raleigh, North Carolina

Cartography by Ben McKenzie and Anne Viront-Lazar
County highway base compiled by the N. C. Dept. of Transportation



LEGEND

Contact;
dashed where approximate,
dotted where covered

Contact, gradational

Normal fault; D-downthrow

Strike and dip of bedding

Horizontal bedding

Strike of foliation

Strike and dip of foliation

Strike of vertical foliation

Horizontal foliation

Prospect

Quarry or mine
c=clay *mn=manganese*
cs=crushed stone *p=pegmatite*
ds=dimension stone *s=soapstone*
gt=graphite *sg=sand and gravel*

Cretaceous and Cenozoic

UPLAND SEDIMENT (up)
Unconsolidated and partly cemented gravel, sand, silt, and clay covering uplands. In various places, includes "Tuscaloosa," Macks, and "Pinehurst" formations.

Triassic-Jurassic

DIABASE (db)
Dikes of black, medium-grained rock (dolerite) with subophitic texture, composed chiefly of calcic plagioclase, clinopyroxene, olivine, and opaque minerals.

Triassic

FANGLOMERATE (fgl)
Poorly sorted conglomerate consisting of metamorphic and igneous rock clasts in redbrown clay-silt-sand matrix; interbedded mudstone and clayey sandstone.

SANDSTONE-MUDSTONE (ss-ms)
Irregularly bedded sandstone, siltstone, and mudstone; colors red, buff, and dark grey; partly micaceous and feldspathic.

LIMESTONE AND CHERT (ls-ch)
Red mudstone and calcareous sandstone with thin layers of impure gray limestone and lenses of gray chert or red-brown jasper.

Mid-Paleozoic

QUARTZ VEINS (qz)
White to gray, medium- to coarse-grained quartz; locally containing muscovite, feldspar, tourmaline, ilmenite, carbonate and sulphide minerals, and chalcedony.

ADAMELLITE (ad)
Medium-grained, massive gray granitic rock consisting of subequal amounts of sodic plagioclase and potassium feldspars with quartz, biotite, muscovite, and numerous accessory minerals; locally porphyritic and foliated.

hbdt

DIORITE-GABBRO (di-gb)
Medium- to coarse-grained hornblende gabbro, diorite, and quartz diorite; varying proportions of hornblende, pyroxenes, plagioclase, quartz, and numerous secondary minerals. Belts of coarse-grained hornblendite (hbdt).

ULTRAMAFIC ROCKS (um)
Soapstone, serpentinite, talc-chlorite schist, and actinolite-chlorite rock. Contain chiefly talc, antigorite, actinolite, epidote, chlorite, magnetite, and rarely chromite and corundum. Local siliceous zones (sil).

Late Precambrian and Early Paleozoic

METAVOLCANIC AND METASEDIMENTARY ROCKS (mvs)
Dacitic and andesitic metatuffs and flows with phyllite, metasiltstone, pebbly arkose, and ilmenite-magnetite quartzite. Carolina slate belt types.

MICA AND HORNBLENDE GNEISS AND SCHIST (mgs)
Chiefly quartz-plagioclase-biotite gneiss with mica schist and hornblende gneiss. In part conglomeratic (diamictite?).

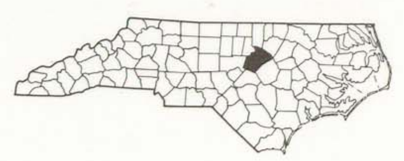
gt

FELSIC GNEISS AND SCHIST (fgs)
Quartz - microcline - muscovite - biotite gneiss, mica schist, micaceous quartzite, and minor hornblende gneiss; includes graphitic zones (gt). Strong mineral lineation common.

INJECTED GNEISS AND SCHIST (igs)
Layered mica gneiss and schist with numerous dikes and sills of granite, pegmatite, and aplite.

AMPHIBOLITE (am)
Medium-grained, layered and foliated hornblende gneiss and coarse-grained, nearly massive hornblende amphibolite; contains hornblende, sodic plagioclase, and/or quartz, with epidote, clinozoisite, and numerous minor minerals.

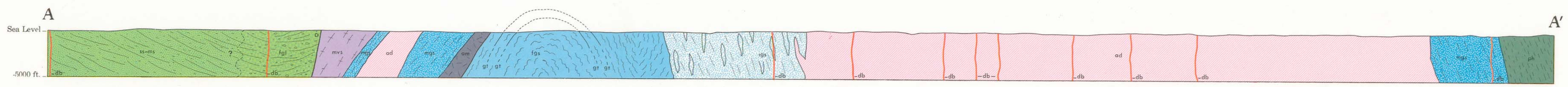
PHYLLITE (ph)
Gray to buff, laminated muscovite-chlorite-quartz-feldspar phyllites; includes graphitic zones (gt).



Scale
1:100,000

1 cm = 1 km   1 in. = approx. 1.58 mi.

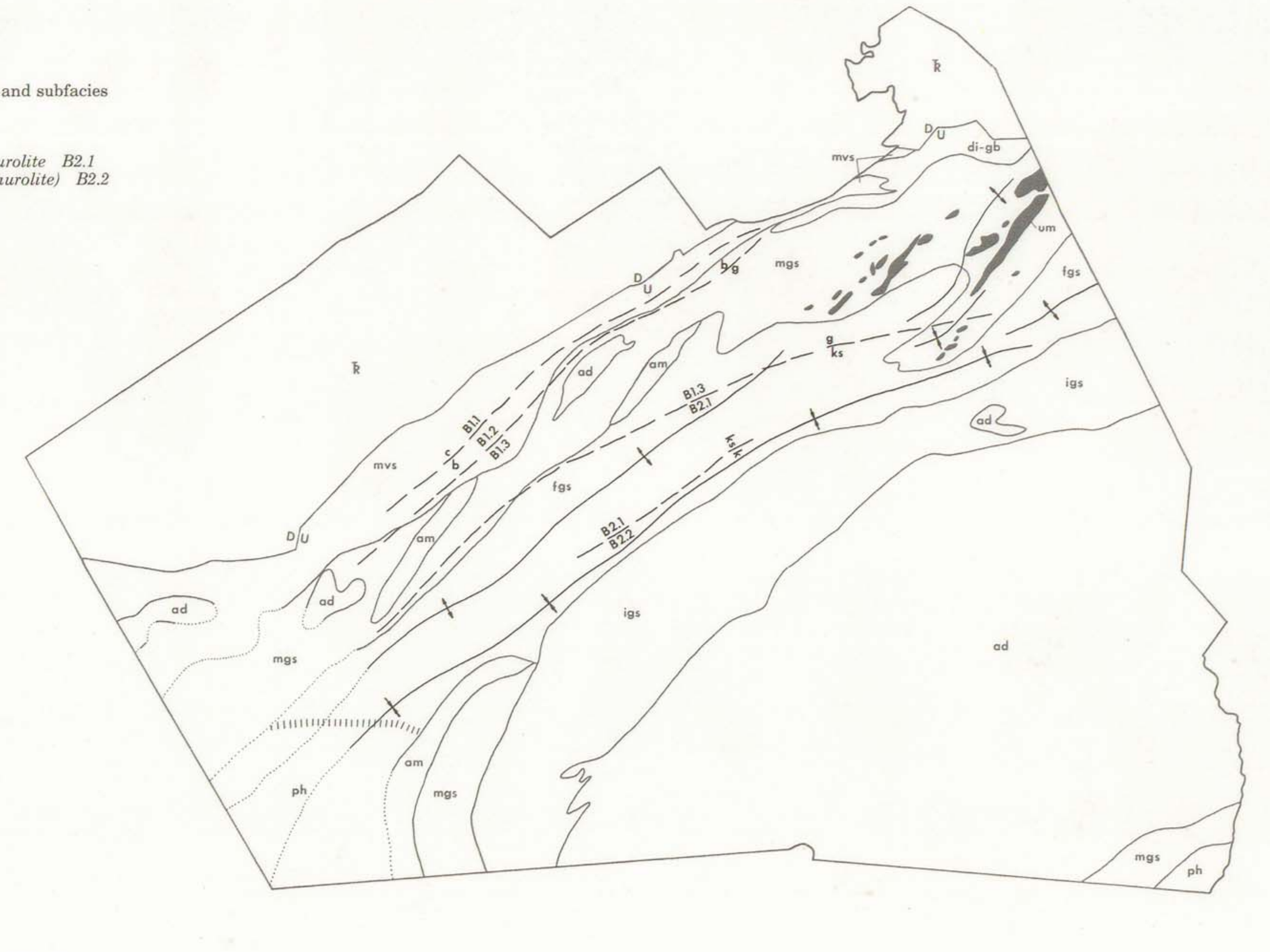
0 — 10 km
0 — 5 mi.

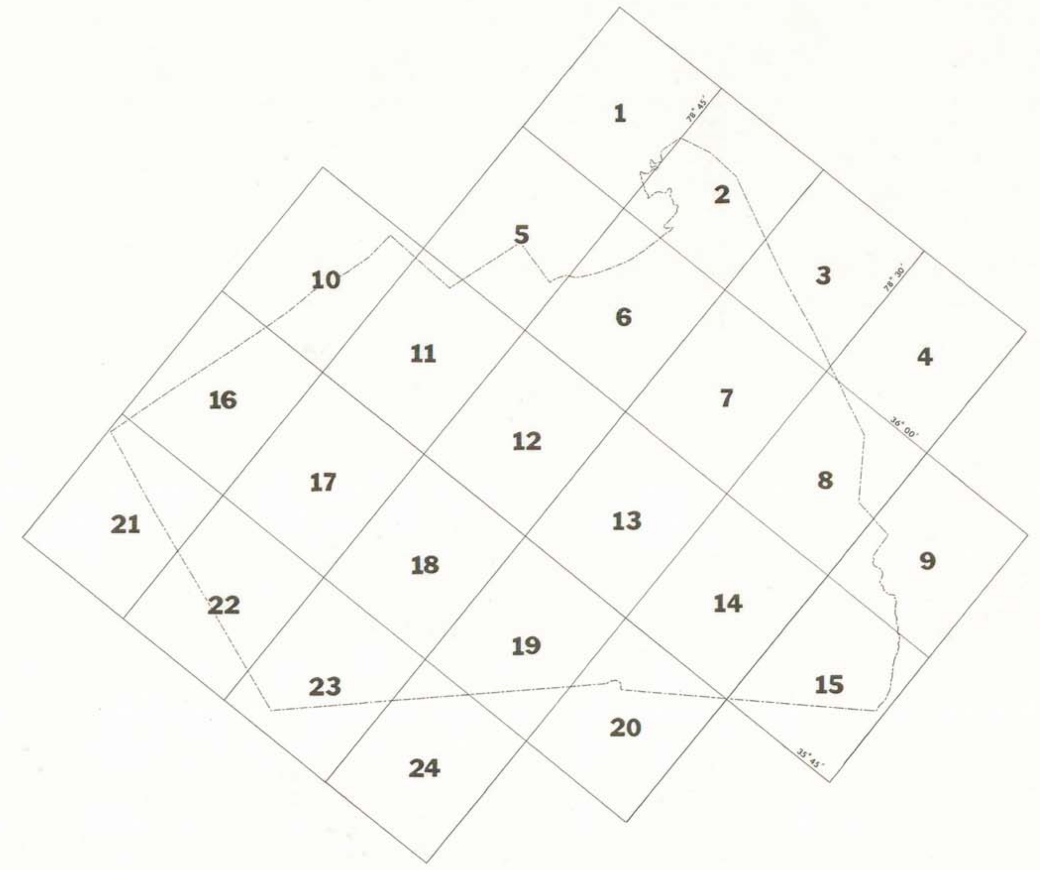


B1.1/B1.2 c/b Metamorphic isograds and subfacies
c=chlorite B1.1
b=biotite B1.2
g=garnet B1.3
ks=kyanite + staurolite B2.1
k=kyanite (no staurolite) B2.2

Anticlinal axis

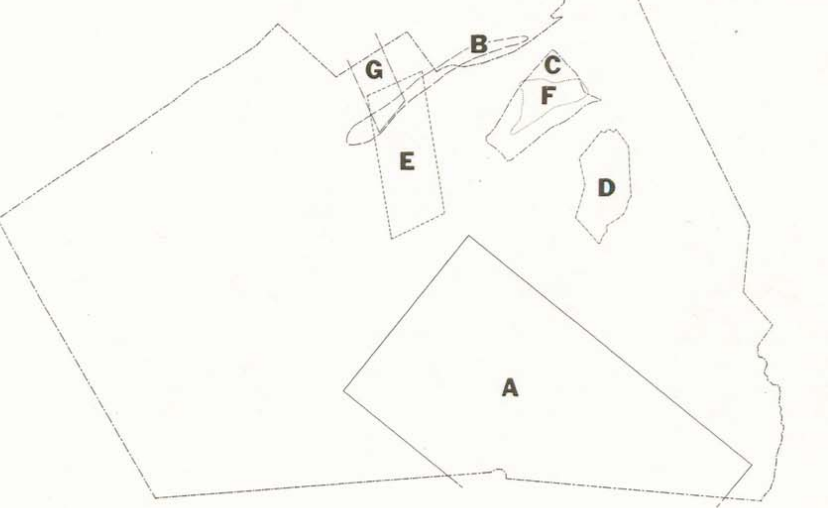
Synclinal axis





INDEX TO TOPOGRAPHIC COVERAGE

1. Northeast Durham
2. Creedmoor
3. Grissom
4. Franklinton
5. Southeast Durham
6. Bayleaf
7. Wake Forest
8. Rolesville
9. Bunn West
10. Green Level
11. Cary
12. Raleigh West
13. Raleigh East
14. Knightdale
15. Zebulon
16. New Hill
17. Apex
18. Lake Wheeler
19. Garner
20. Clayton
21. Cokesbury
22. Fuquay-Varina
23. Angier
24. Edmondson



INDEX TO PREVIOUS GEOLOGIC MAPPING

(A) J. T. Bowman (1969)
(B) H. E. Davenport (1955)
(C) J. B. Dickey (1963)
(D) C. R. Farquhar (1952)
(E) C. W. Fortson, Jr. (1958)
(F) D. R. George (1939)
(G) D. B. Grannell (1960)

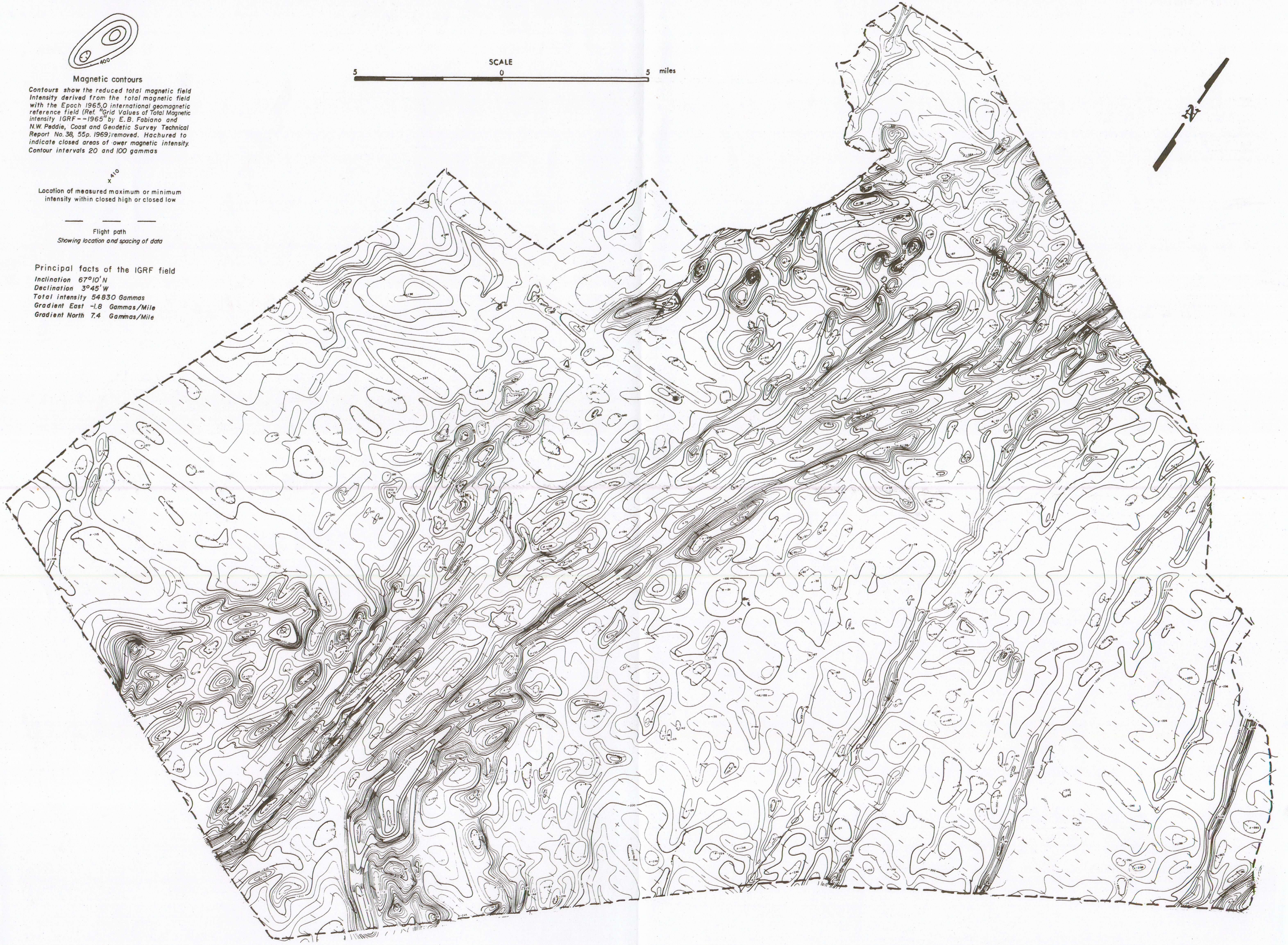
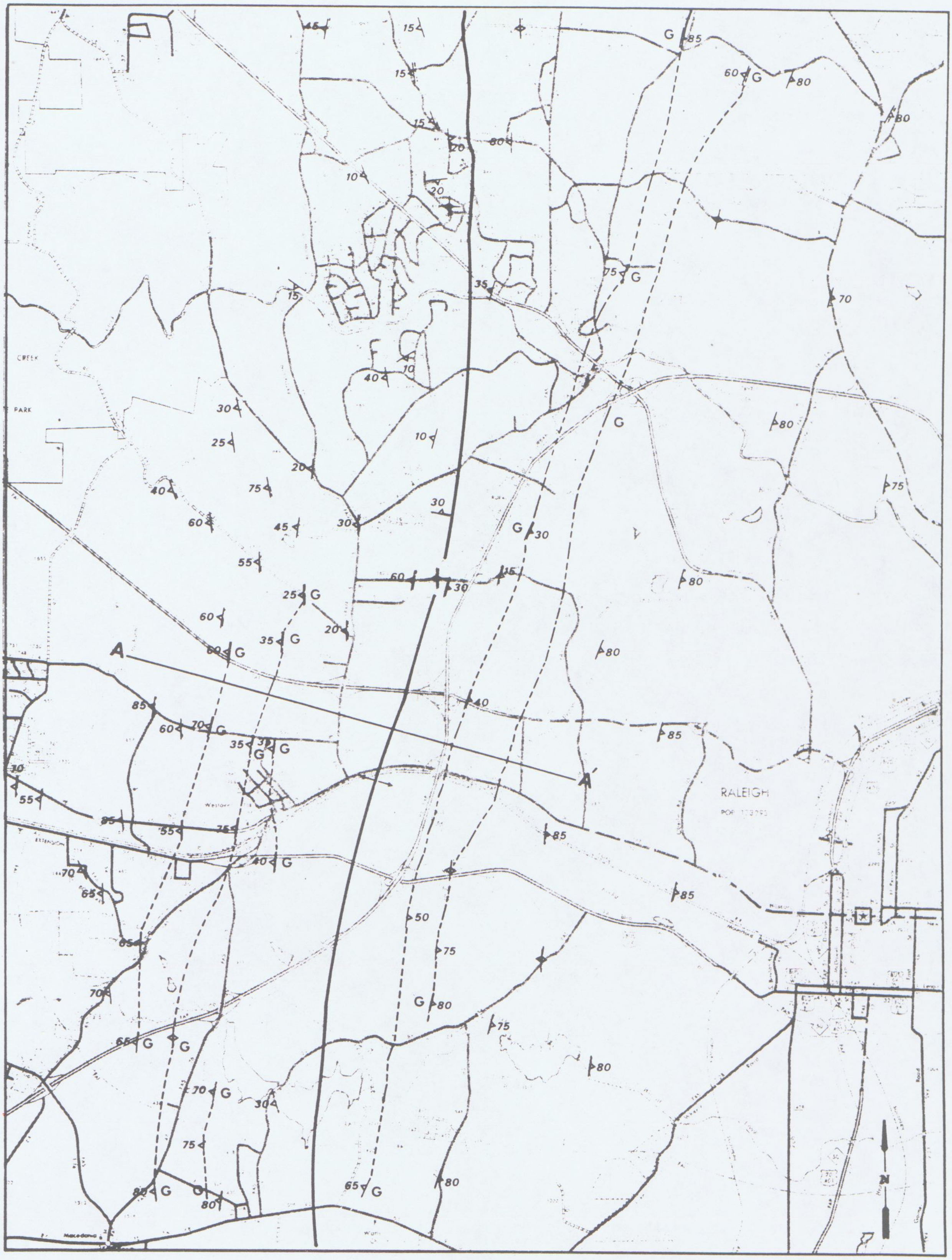
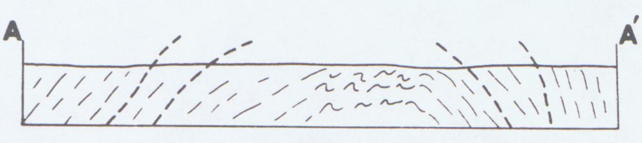
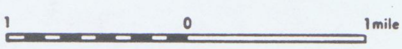


Plate 2. Aeromagnetic map of Wake County and vicinity, N. C. (after U. S. Geological Survey, 1974)

Plate 3. Map and section of graphite belts and Raleigh anticline, west Raleigh, N. C.







LEGEND

- strike of vertical foliation
- G graphite belt
- 55 strike and dip of foliation
- horizontal foliation
- anticlinal axis

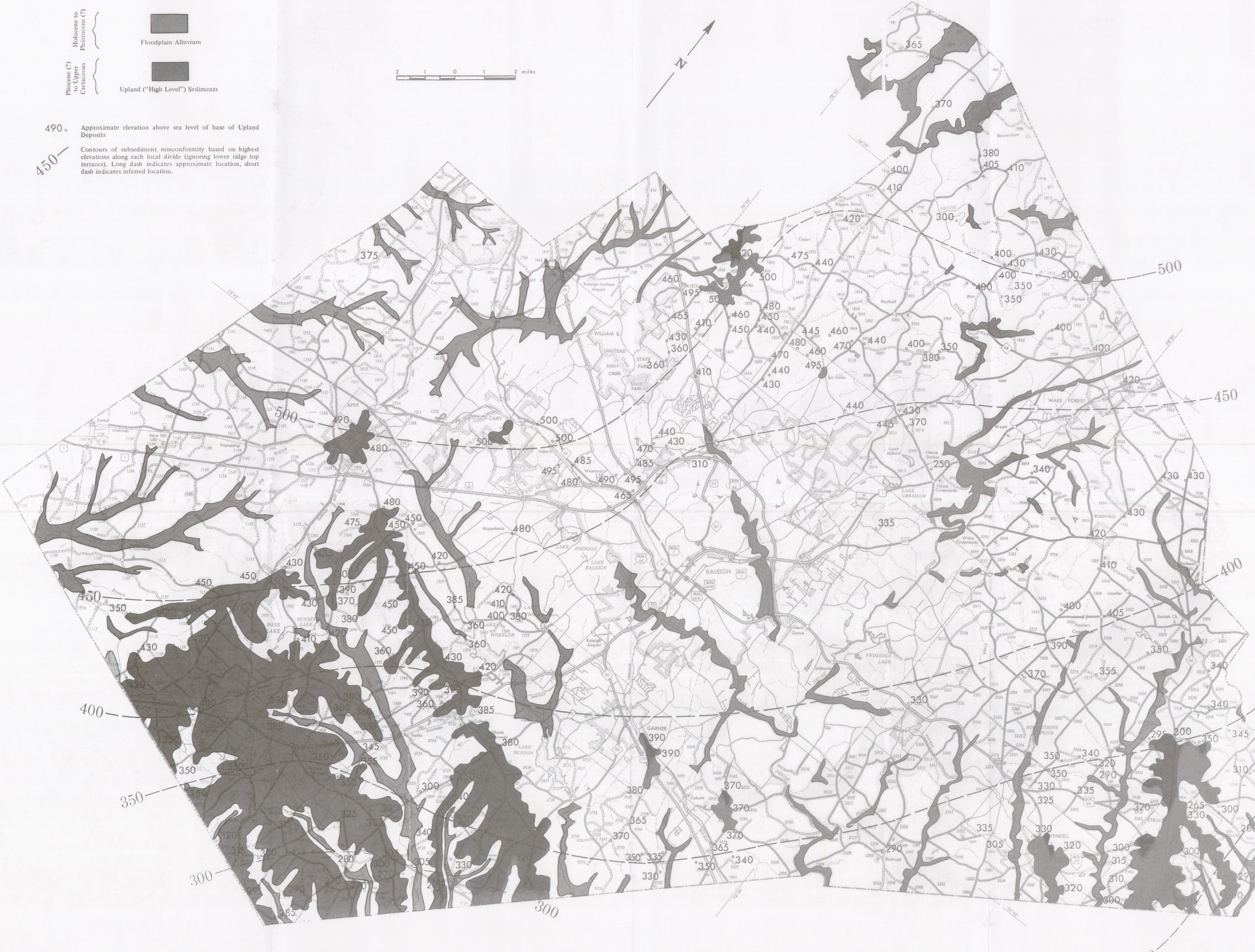


Plate 4. Map showing locations and elevations of Coastal Plain and upland sediments, and extent
of major flood plain deposits, in Wake County, N. C.