NORTH CAROLINA

DEPARTMENT OF CONSERVATION AND DEVELOPMENT

WILLIAM P. SAUNDERS, DIRECTOR

DIVISION OF MINERAL RESOURCES

STEPHEN G. CONRAD, STATE GEOLOGIST

Special Publication 1

GEOLOGY OF THE CHAPEL HILL QUADRANGLE, NORTH CAROLINA

BY

V. I. MANN, T. G. CLARKE, L. D. HAYES, D. S. KIRSTEIN

UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

RALEIGH

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Contents

Introduction

General Statement

In 1954 a project was started to map and study the crystalline rocks in the vicinity of Chapel Hill, North Carolina. The project is far enough along so that a map and a preliminary interpretation may be presented at this time. The present report concerns the Chapel Hill quadrangle only, and not the work which is being done in adjacent quadrangles.

Two U.S. Geological Survey topographic quadrangle maps, the Chapel Hill, and the Farrington, were available as base maps for the study, and the complete investigation is confined to these areas. Because the eastern part of the quadrangles is covered by Triassic sediments, the detailed studies were confined to the crystalline rocks. Where crystalline rocks intruded, or were overlapped by Triassic sediments, such information was only recorded, and the sediments were lumped under general terms.

As envisioned, the larger plan was to map the crystalline rocks as far north and south as could be done with the available topographic sheets, study the intrusive sequences petrographically and publish the completed maps of the two quadrangles. Each of four graduate students was to map one half of a quadrangle. After mapping was completed a petrologist was to decipher the igneous and metamorphic history. As mapping progressed exposures of crystalline rocks decreased so that the southern half of the Farrington quadrangle could not be mapped for this project; it was completed on another project. Although work is continuing in the Farrington area, the petrology has been completed only on the Chapel Hill quadrangle.

Mapping of the northern half of the Chapel Hill quadrangle was done by Dewey S. Kirstein during the summers of 1954 and 1955. The southern half of the quadrangle was mapped by Thomas G. Clarke in 1956 and 1957. Petrography and map revision was completed by Lawrence D. Hayes in 1962. Each presented his portion of the work to the Department of Geology, University of North Carolina at Chapel Hill in partial fulfillment of requirements for the Master's of Science Degree. The entire project was supervised by Virgil I. Mann. The senior author examined and reviewed all data, included more recent findings, and reconciled differences in descriptions, interpretation, and in terminology found in the three papers.

The map presented in this report is essentially that which Hayes compiled from the field maps presented by Kirstein and Clarke. The Hayes' map in turn was modified by Mann. We believe that the rock locations are as accurate as is possible under the present conditions. During the recompilation of data, some of the detail of the original maps was lost, and some of the rock names were changed. The maps used by Kirstein and Clarke were so large that alteration zones they delineated were lost in reduction to the present scale. Further, a petrographic study allowed refinement of some of the more general field terms used in the original maps. Since Hayes' work was completed further petrographic data has become available, and modifications of his terminology have been made. No doubt in the future, even more detailed studies of this area will add more sophisticated refinements to terminology as well as to understanding this rock series. In this highly weathered terrain the field men found locating rock boundaries difficult; however, under the circumstances, we feel that until trenching, road building, or drilling is used to more accurately establish the contacts, these boundaries as seen on the map will remain unchanged.

Thus, the basic geologic map of the Chapel Hill quadrangle presented here is the combined effort of four people; Kirstein and Clarke mapping, Hayes studying the rock types petrographically, and Mann supervising and modifying interpretations as new data became available. Each junior author has his own report on file in the library of the University of North Carolina at Chapel Hill. The reader who is interested in more detail than is available in this paper, should examine the original papers.

Location

The Chapel Hill quadrangle is located in the eastern Piedmont province of North Carolina, almost entirely within Orange County. The 7 1/2 minute quadrangle lies between Latitudes 35° 52' 30", and 36° 00' North, and between Longitudes 79° 00' and 79° 07' 30" west. Two villages, Chapel Hill and Carrboro, lie within the limits of the quadrangle which represents an area of about 64 square miles.

General Geology

Many kinds of igneous, metamorphic, and sedimentary rocks are found within the boundaries of the quadrangle. In the northern and western portions of the area are many varieties of the Carolina Slate Series, or Slate Belt rocks, into which have been intruded igneous rocks. Although the southern and central portion of the quadrangle contains some members of the Slate Belt, there are a far larger proportion of igneous intrusives there. The eastern portion of the area is overlaid by Triassic sediments into which were intruded basic dikes.

The Slate Series contains the oldest known rocks in the area. Joseph St. Jean (1964) has identified Cambrian Trilobites in rocks of this series in Stanly County. This general age has been suspected by geologists, for Stose (1946), identified these rocks on the Geologic Map of North America as Paleozoic, and Stuckey and Conrad (1958), listed them on the North Carolina State Geologic Map as "Precambrian or lower Paleozoic". Except for the one specimen mentioned above most of the formations of the Slate Belt are still to be dated.

Much work is being done in the Slate Belt by Butler (1963, 1964), Conley (1962, 1962a), Sundelius (1963), Bell (1960), Stromquist (1959), and others attached to the U.S. Geological Survey and North Carolina Department of Conservation and Development. The rock sequence has been found to consist of midly metamorphosed volcano-sediments; with many varieties of felsic and mafic volcanics as well as argillites, and conglomerates. Kulp and Eckelmann (1961) established an age of 296 million years for a Slate sample obtained near Columbia, South Carolina, which means only that the micas they used were formed by metamorphism during Pennsylvanian time. Much more study will have to be done before a full understanding of the Slate Belt is available.

Intruding the Slates along a northeastward trend are a series of igneous rocks. Granodiorites, adamellites and diorites predominate; however, more basic varieties such as gabbro and ultrabasics are present. The latest intrusives of this sequence are lamprophyres and aplites. These intrusions are a part of the sequence of igneous rocks which extend through the Piedmont from Virginia to Georgia. They are listed as Carboniferous by Stose (1946), but Overstreet (1961) reported an age of 245 to 270, $\pm$

30 million years for similar intrusives in South Carolina. The present report is concerned mainly with this group of crystalline rocks as they are found in the Chapel Hill quadrangle.

Triassic sediments seen along the eastern border of the map are separated from the crystalline sequence by a resequent faultline scarp. These younger sediments occupy a faulted and filled graben (Mann & Zablocki, 1961), which extends northeastward through the State. The Triassic sediments were not investigated in detail for this study. The interested reader is referred to Harrington (1951) for a general description of the rocks and of the structures associated with them. In general they consist of red and yellow sands, arkoses, shales, and conglomerates which locally have been intruded and thermally metamorphosed by basaltic diabases. These Triassic rocks are readily distinguished in the field from the crystalline sequence under investigation.

Carolina Slates

General Statement

Combined volcanic and sedimentary processes long have been postulated for the origin of rocks of the Carolina Slate Belt. (Stose, 1946; King, 1955, p. 343; Stuckey & Conrad, 1958, p. 51). Recent mapping by Butler (1963), in Orange County has confirmed the presence of such major rock units as argillite, slate, phyllite, greenstone, lithic-crystal tuff, devitrified glassy rocks, breccia, and volcanic conglomerates. All are slightly metamorphosed to the chlorite zone, and many have a well developed cleavage which is nearly vertical and has a northeast strike. Some of the rocks are apparently former flows, tuffs, and other devitrified rocks of igneous extrusive origin. Still others are clearly sedimentary, and many contain relatively unaltered fragments of the igneous extrusive sequence.

Although most of the above rock varieties are probably to be found as small outcrops in the quadrangle, the original field map could not include such a subdivision of the Slates. Instead the Slate Series was divided into recognizable and easily mappable sediments and flows; detailed classification was left to a later study. The mappable units include meta-arkose, metagraywacke, and slates into which are lumped non-bedded tuffs, greenstones, phyllites and rhyolites. A detailed subdivision of the Slate Series is underway under the direction of Butler (1964).

Sedimentary Varieties

At least two varieties of sedimentary rocks, arkose and graywacke, have been assigned to the Slate Series in the quadrangle. Deeply weathered light colored sandy members are more abundant in the northern half of the quadrangle, whereas a dark colored highly siliceous variety is more prevalent in the southern half. The light colored Slates are exposed abundantly in a broad zone extending northeastward from the west central margin to the northeast corner of the quadrangle. Graywacke crops out in innumerable places throughout the quadrangle.

The light colored arkosic varieties are white to light gray, and are mostly fine grained. A well developed schistosity is apparent, and quartz is usually recognizable in discrete grains. Parker (King, 1955, p. 344), described rocks of this type as quartz-sericite phyllites. These rocks commonly weather to a friable schist consisting of sand and clay which is stained with hematite.

These arkoses consist of 50 percent to 75 percent angular to subrounded quartz grains in a matrix of finer grained sericite. Quartz ranging in size from .04 to 1.0 mm. rarely shows any evidence of strain. In zones of moderate stress, the sericite is bent around the grains of quartz, and strung out in thin parallel plates, establishing, or paralleling the cleavage. In a few places where the entire rock has been crushed, a shear zone was outlined. The great abundance of sericite locally in clusters, and granular quartz, suggest that this rock was derived from siliceous, and arkosic sediments. A further more detailed study will be necessary for positive identification of the origin of this rock.

The dark varieties of slates undoubtedly have many origins; however one typical graywacke sediment has been identified and mapped over a wide area. It consists of 30 percent angular feldspar fragments and numerous quartz grains in a matrix of extremely fine quartz, sericite, and biotite. Quartz is partly replaced by sericite, and often is oriented in the direction of schistosity. Alkali feldspars and a recognizable sodic plagioclase, (An_8), is almost entirely sericitized, whereas more calcic plagioclase is altered to epidote and zoisite. Biotite, although present, is subordinate in quantity to a pale green chlorite. Often when bedding is recognized it is graded. This rock was named graywacke, according to Pettijohn's classification (1957, p. 303-305).

The Wacke conglomerate identified in the district south of Chapel Hill contains much the same mineralogy as that of the graywacke; however in this large grained pebble conglomerate there are abundant rhyolite fragments. The rock contains subrounded pebble sized fragments of quartz, plagioclase, and microcline, cemented in part by finer grained epidote, chlorite and magnetite. Sorting is very poor, and in places the rock consists of 95 percent rhyolite fragments. Quartz always has a wavy extinction, the feldspars are subrounded, and epidote is mostly yellowish. The rock was distinctive enough to be mapped as a separate unit, even though it is far less abundant than the remainder of the Slate sequence.

Extrusives

Minor amounts of pyroclastics were recognized during the course of mapping, but they were either not of sufficient extent, not easily traced, or of questionable origin; hence they were not recorded as a separate unit on the present map. Chemical and petrographic work will have to be done on this unit to allow the authors to be certain of future subdivisions; at present it was placed in the broad "Slate" category.

A rhyolite extrusive was mapped because it had sufficient extent and was readily identified in the field. This rock appeared to be related directly to the Slate sequence, for Clarke was able to map rhyolite porphory interbedded with slate just east of the junction of Neville and Phils creeks. Three such areas of rhyolite were mapped; one in the northwest, one in the west central and one in the southwest portion of the quadrangle. The largest exposure just west of University Lake is greater than one mile square.

On a fresh break this rock has a dark color, however, after weathering it has a white surface. Flow banding is emphasized by parallel alignment of light and dark bands. Feldspars aligned parallel to the band, and very fine grained quartz are the only two minerals recognizable in hand specimen. The banding consists of layers of quartz alternating with layers rich in sericite, epidote, and iron oxides.

Oligoclase (An_{27}) partly altered to epidote and sericite seldom reaches .9 mm. in size, whereas matrix minerals are .03 mm. Quartz rich layers consist of crystalline and cryptocrystalline forms. Other grains identified include magnetite, ilmenite, pyrite, and biotite. All of these are distributed randomly throughout the rock.

This Slate sequence is undergoing detailed examination and interpretation. The igneous rocks, and subsequently derived sedimentary rocks of this series are older than, and were intruded by the igneous sequence which was the major concern of this study. Further information concerning the Slate sequence will be forthcoming.

Igneous Rocks

General Statement

Intrusive into the Slate Belt sequence are a series of rocks grading from ultramafics to tonolites. Because of lack of exposure in the boundary areas, the full knowledge of the age relationships between these rock types is not yet available. An attempt to evaluate this is presently underway. Even so the rock types may be described at this time, and a preliminary interpretation presented.

The rock types which can be delineated include: two ultramafics, gabbro, adamellites, granodiorites, diorites, tonolites, aplites, lamprophyres, diabases, and various altered forms of this sequence. All except the diabase appear to be related to one generation of intrusion. The diabase is placed in the sequence as Triassic (?) in age.

Ultramafic

A small outcrop of ultramafic rock occurs just east of Iron

Mine hill. The outcrop is elliptical in shape, with the long axis approximately 800 feet in a north-south direction, and the short axis about 250 feet in an east-west direction. The rock consists of large subhedral plates of brown hornblende, which poikilitically include other minerals. In some cases serpentine pseudomorphs after olivine make up approximately 50 percent of the rock, and in other cases talc after pyroxene and olivine is the abundant inclusion. Magnetite makes up approximately 3 percent of the rock.

Hornblende occurs in two forms; one in large plates up to 7 mm. in length, and subhedral crystals interstitial to the larger grains, averaging .8 mm. in length. The hornblende is pleochroic from reddish brown to pale green with a large optic angle of approximately 85°. Portions of the hornblende crystals have been altered to a chlorite, identified as penninite, whose crystal planes are outlined by magnetite. Pseudomorphs of serpentine and talc average 17 mm., are rounded, and are intimately associated with magnetite stringers. In some places no evidence of earlier olivine could be found, but instead talc, pseudomorphous after pyroxene was readily distinguished. These phases have been classified as amphibolites, and/or pyroxenites, whereas the ones containing olivine are named courtlandite, or hornblende peridotite.

Exposures are so poor that an application of Bowen's (1956, p. 167), concepts of emplacement of a rock of this type cannot be established here. An evaluation of the factors critical to the interpretation of a rock of this type (Turner & Verhoogen, 1960, p. 312-316), were not completed. Nothing in the exposures would refute the concept of intrusion of this material as a crystal mush into the surrounding rock;

on the other hand, there is no contact zone so as to permit identification of this rock as an intrusion.

Gabbro

Two small bodies of gabbro were mapped by Kirstein in the northwest and extreme northeast portion of the quadrangle. The gabbro consists of labrodorite in euhedral to subhedral crystals, and relatively large anhedral grains of augite in an approximate 2:1 ratio. Other minerals present in relatively minor amounts include hornblende, chlorite, magnetite, and pyrite. Augite is commonly replaced by hornblende which in turn is altered to chlorite and magnetite.

Plagioclase occurs in zoned crystals which reach An_{53} at the core and An_{31} at the margins. This feldspar, called labradorite, shows slightly patchy alteration to sericite and in places to saussurite. It appears less altered than the feldspars in diorites and granodiorites.

Augite grains are as large as 3 mm. The crystalline masses are nearly equidimensional, and anhedral; often the grains are fringed with uralite and in places completely replaced by hornblende, chlorite and magnetite. In rare cases the pyroxene is altered to talc. Augite, always interstitial to plagioclase, sometimes includes labradorite.

Diorites and Tonolites

Calc-alkalic rocks in the northern half of the quadrangle show zones feldspars of intermediate anorthite composition. These are classed by the authors as diorites or as tonolites respectively depending upon the absence or presence of quartz. These are in contrast with the diorites exposed in the southern half of the quadrangle where the sodic plagioclase borders intermediate plagioclases. This latter rock sequence will be considered in the section called "Altered Rocks".

Diorites and tonolites are the most widespread plutonic rocks in the Chapel Hill quadrangle making up almost 50 percent of the total surface exposure of igneous intrusive rocks. Both Kirstein and Clarke presented considerable evidence that this rock sequence was intrusive into and incorporated much of the Slate Belt rocks. They were able to show this in the lateral gradation from diorites into slates, and by partly digested fragments of the Slate sequence along the borders of the diorites.

Fresh diorite is a fresh greenish-gray, medium grained equigranular aggregate of plagioclase, orthoclase, and hornblende, plus or minus quartz. Occasionally fine grained magnetite and pyrite grains are present in the rock. This rock is characterized by a hypautomorphic granular texture.

Light green plagioclase crystals making up 50 percent of the rock are subhedral to anhedral. Subhedral to anhedral dark green hornblende makes up as much as 35 percent of the rock. Quartz, occurring as a minor constituent, varies in its percentage but is interstitial to plagioclase and hornblende. Potash feldspar when observed is in pink anhedral grains interstitial to the plagioclase. This potash feldspar more often is microcline or microcline perthite. Magnetite and ilmenite are common accessories along with alteration products which include chlorite, epidote, zoisite, and sericite. Epidote occurs more as an alteration product of hornblende and plagioclase and is found in veinlets cutting all the minerals. Pyrite, sphene, and apatite were observed in some places. No biotite was found in the normal diorites or tonolites.

The plagioclase is usually on the order of 2 1/2 mm. in length, and varies in composition from An_{47} in the core to An_{30} in the margins. Such zoning is emphasized in part by concentrations of saussurite and sericite near the cores. Albite twins where recognized were used in the identification of the anorthite content. Although andesine includes fine magnetite grains, this feldspar may be observed as an inclusion in hornblende, quartz, and even potash feldspar.

Common green hornblende occurring as elongated to stubby prisms scattered throughout the rock makes up as much as 30 percent of the diorites. The crystals usually are a millimeter in length, have a large optic angle, and a pleochroism of emerald green to yellowish brown. Commonly this mineral is altered to chlorite and very rarely to biotite. The reddish brown hornblende found in the ultramafic was observed also at the contact of the hornblende peridotite and the diorite.

When present, quartz is interstitial to the feldspar and hornblende mesh. It incloses all minerals except the potash feldspars. In many of the tonolites, it is intergrown with the potash feldspars in a microperthitic pattern.

Although potash feldspars are nearly absent from the diorite, they do make up at least 10 percent of some samples. Commonly the potash feldspar is interstitial to plagioclase and hornblende, and thus is quite angular.

Magnetite is most commonly associated with chlorite replacing hornblende, which suggest that its origin was a result of the alteration. In places, leucoxene is present, which suggests that some of this "magnetite" was actually ilmenite. Such is more common in the northwestern portion of the quadrangle where the diorites are in contact with the gabbros.

In some of the diorites, pyrite was a minor accessory. These grains are anhedral, and are interstitial to plagioclase and hornblende. Most are bordered by hematite and are partly replaced by this oxide.

Epidote occurring as an alteration product of andesine and hornblende is found in random patches in the rock. Commonly epidote developed at a time after the rock had crystallized, and is found in veinlets which transect all other minerals. This could have been generated as a result of hydrothermal solutions, or possibly from deuteric activity. Low rank metamorphism might possibly have been the cause of the developmemt of epidote. (See discussion by Dietrich, 1964).

Small crystals of sphene and apatite are scattered throughout the rock; they are seldom more than a grain or two.

This rock sequence is identified as diorite and tonolite. The rock group contains an intermediate plagioclase in excess of 2/3 of the total feldspar. When quartz exceeds 10 percent of the volume, the rock was called a tonolite. When quartz varied from 0 to 10 percent, the rock was named a quartz diorite.

Adamellites and Granodiorites

In a large area of the exposed intrusive rocks, the potash feldspar exceeds 10 percent of the total feldspar, but is less than 2/3 of the total feldspar. Because the rocks are so intimately mixed, these variations have been lumped in the field under the general terms of adamellites and granodiorite.

In the northern half of the quadrangle these rocks types crop out as small bodies within the larger diorite masses. The concentration of this rock group occurs in the south central portion of the northern half of the quadrangle.

This rock pair is separated from the tonolites by the greater amount of potash feldspar which gives the rock a faint pink color. Texture, grain size, and presence of quartz are not distinguishing features.

Subhedral plagioclase (An_{27}) averaging 2.5 mm. in length is the abundant mineral. Locally it makes up 45 percent of the rock. Orthoclase comprises 30 percent of the total rock; and a common green hornblende similar to that described in the diorites is present up to 15 percent of the rock. Quartz, interstitial to the other minerals, varies in abundance up to 20 percent. Biotite occurs in ragged books in some of the more alkalic members. Micropegmatite intergrowths have been recognized to be 35 percent of the total volume in some of these more alkalic varieties. Epidote, zoisite and magnetite are minor constituents.

Plagioclase crystals are altered to sericite, sausserite, and chlorite. The potash feldspar, often microcline, is usually interstitial to earlier formed plagioclase crystals; in some cases larger grains of orthoclase include grains of plagioclase poikilitically. Orthoclase generally is clouded by a mixture of sericite and kaolinite. In some of the rock specimens, microcline perthite was identified.

Micrographic intergrowths of quartz and orthoclase are not uncommon, and can be identified in some varieties as making up as much as 35 percent of the rock. When it is independent of the feldspar, quartz is anhedral.

Yellow green hornblende is altered in part to pale green chlorite along irregular margins. In some places epidote is an associate of the chlorite.

A brown biotite, not observed in the diorites, reaches three to five percent in the adamellites. Sphene was noted in a few of the specimens.

Albite Granodiorite

The largest granitic body in the southern half of the Chapel Hill quadrangle is an albite granodiorite. When this was mapped in the field it was given the name "granite". After detailed petrographic studies were completed, the rock was found to contain an excess of plagioclase over orthoclase, quartz, and a considerable amount of very sodic plagioclase. (An_8).

The albite granodiorite consists of gray to pink, medium grained, aggregates of feldspar, quartz, and hornblende. Veinlets of epidote and of sagenitic quartz cut these rocks. Partly altered hornblende makes up from 1 to 15 percent of the rock. Phenocrysts of white to green plagioclase in this rock contrast with the more equidimentional forms found in the diorite. Potash feldspar is generally pink and along with quartz is interstitial to the larger plagioclase grains.

When examined in detail, these albite granodiorites are found to be coarse grained hypidiomorphic aggregates of plagioclase feldspar and quartz, with minor hornblende, potassium feldspar, chlorite, biotite, epidote, sphene, zircon, and magnetite-ilmenite. The sodic plagioclase, found as large as 4 mm. in length is subhedral to anhedral and makes up as much as 70 percent of the rock. Microcline and orthoclase occur as mottled subhedral to anhedral grains, and as micrographic intergrowths with quartz, are rarely more abundant than 10 percent of the volume. The dark minerals rarely exceed 15 percent. The sodic plagioclase (An_8), is twinned according to the albite law and in "chessboard" fashion. Locally thick overgrowths of albite are found around polysynthetically twinned anhedral plagioclase crystals. In other places, intergrowths of quartz and albite, and quartz and orthoclase, are found at the contact of the albite crystals and adjoining grains. Most of the albite, and vaguely zoned albite plagioclase is clouded by a mixture of sericite and zoisite. Often large feldspars mottled by a chessboard structure are altered in part to sericite and clinozoisite, and, in part, to iron oxides. Inclusions in the albite are hornblende, magnetite-ilmenite, chlorite, epidote and even patches of calcite.

There appears then to be two plagioclase feldspars, a chessboard form and a mottled form. Chessboard forms are the large polysynthetically twinned crystal mesh; whereas the mottled varieties are smaller, anhedral, and interstitial to the large feldspars.

Quartz, usually anhedral and interstitial to the feldspar, varies in grain size from .5 mm. to 1.5 mm. One is led to a conclusion that quartz has replaced parts of the feldspars because vestiges of fine laminar structure in quartz grains include fragments of plagioclase.

Hornblende, a slightly pleochroic greenish yellow variety, is altered in part to a green chlorite, (penninite), epidote, and magnetite. In other slides there are reddish yellow biotite, chlorite, epidote and iron oxides in patterns suggesting the former presence of hornblende.

Accessory magnetite, ilmenite, epidote, sphene, and zircon are found in both plagioclase and quartz grains. Most of the magnetite and ilmenite are coated with thin rims of leucoxene. Collectively these accessory minerals make up no more than 3 percent of the rock.

This rock group, the albite granodiorite, apparently was intruded into all of the other sequences, for it includes xenoliths of all the other rock types.

Altered Rocks

General Statement

Included in the group of altered rocks are three varieties. These are altered diorites, altered slates, and cataclastically altered rocks. It is likely that there is a relationship between the altered diorites and the altered slates; however, because of their immediate locations, they are considered separately in this report.

Altered Diorites

A group of tonolites in the southern part of the quadrangle near the contact with the albite granodiorites, show features which deserve special consideration. In hand specimen these are indistinguishable from the diorites described earlier, however textural variations are apparent when they are examined under a microscope. These rocks contain rims of sodic plagioclase around cores of sericitized and saussuritized intermediate plagioclase crystals.

The rocks have a hypidiomorphic granular texture, containing euhedral to subhedral plagioclase crystals, and subhedral hornblende crystals, separated by interstitial quartz and potash feldspars. Euhedral plagioclase cores are altered to saussurite and sericite and the entire crystal is often rimmed by clear sodic plagioclase. Scattered throughout the rock are the accessories, biotite, chlorite, epidote, magnetite, ilmenite, pyrite, sphene, and apatite. Plagioclase crystals making up in excess of 65 percent of the rock, range in size from .5 mm. to 4 mm. in length. Uniformly saussuritized and sericitized cores are bounded by clear plagioclase which may conform to the euhedral outline of the core, or have a ragged edge. In the rims the plagioclase is oligoclase (An_{22}), whereas the center of the core ranges from An_{35} to An_{43}. Often polysynthetic twinning in the core ceases abruptly at the border of the rim, although when twins do extend into the rim they are hazy and lack sharp outlines. Occasionally euhedral plagioclase crystals in this rock type are surrounded by myrmekite. In some cases the arrangement is a highly altered core of plagioclase, a fringe of oligoclase which in turn is bordered by a vermicular intergrowth of quartz with soda or potash feldspar. Oligoclase in the rims is continuous optically with the adjacent myrmekite, and tongues of the oligoclase can be traced into the rims of the bordering myrmekite. Potash feldspar is also found in tiny spots of microcline associated with the plagioclase, and even with quartz. Quartz, more abundant in the southern diorites than in the northern exposures of this rock, sometimes reaches 20 percent of the rock. Because of its intergrowth and general location in the slides, quartz could possibly have replaced part of the pre-existing minerals.

Hornblende occurring as subhedral to anhedral grains is pleochroic in green and brown, and has been altered to a brown biotite, plus some chlorite, epidote, and iron oxide.

This apparent late movement of alkalies so as to rim pre-existing minerals, and to result in myrmekite as well as possibly replacement textures, leads the authors to the conclusion that this rock has undergone deuteric alteration. A discussion of the overall origin is reserved for a later part of the paper.

Altered Slates

During the mapping and petrographic study igneous plutonic rocks were never found in direct contact with members of the Carolina Slate Belt; instead the two appear to be separated by a zone of transition rocks. Depending upon the direction from which the mapper approached this area in the field, these rocks were sometimes called igneous and sometimes classified as metamorphic. Rocks in the zone are characterized by a porphoroblastic feldspar, and they appear to the senior author to be a metamorphic slate generated in part by thermal process, plus some metasomatic alteration.

These altered slates, or transition rocks, consist generally of two varieties; one is a light pink and the other dark gray. Porphyroblasts of feldspars are present in both. The present authors suggest that there is a relationship between the resultant altered zone and the original rock. Light pink varieties came from arkoses and dark gray forms from graywackes, both of which were part of the Slate Belt.

One feature common to these rocks is a matrix of heterogeneously oriented fine intergrowths of quartz and feldspar. Albite is the only persistent porphyroblast in the rock. Biotite occurs in some as shredded books and as porphyroblastic plates in other varieties. Light green hornblende was noted in two samples. Anhedral magnetite, biotite, epidote, and chlorite are found in dark rocks; pyrite and hematite are found in all varieties.

Albite, occurring as large porphyroblastic forms is 50 to 75 percent of the volume of these rocks. The porphyroblasts reach 4 mm. in length, usually are equidimensional, and range in anorthite content from 5 to 13. Boundaries of the crystals are seldom sharp, even though the prismatic form is generally identifiable.

Fractures in the plagioclase are often filled with quartz and the borders are rimmed with quartz. Albite is never zones, and only occasionally twinned polysynthetically. In the northern part of the quadrangle the slate contains sericitized plagioclase; where adjacent to diorite, the zones contain sericitized and saussuritized feldspars. Feldspars in the altered slates in contact with the albite granodiorite show all the replacement criteria noted in the intrusive rock, including clouded and mottled feldspars, clear plagioclase rims around the plagioclase crystals and chessboard structures. Quite often the texture could be identified as decussite, a term used for thermally metamorphosed rocks.

Quartz, usually second in abundance to plagioclase, making up from 10 to 35 percent of the rocks, may reach 1.5 mm. in diameter and include fine crystals and fragments of feldspar.

Hornblende, the same yellow-green variety found in the albite granodiorite is minor in amount. Biotite is even more subordinate.

Potash feldspars occur as fine subhedral grains intermixed with quartz and plagioclase in the matrix of this rock. A perthitic texture often results from the fine albite stringers exsolved from the orthoclase. Epidote occurs in scattered grains and veinlets cutting all other minerals, as well as in patches. Magnetite and chlorite, along with pyrite and sphene are found only occasionally.

Position and gross textures of the altered slates indicate they are metamorphic portions of the Carolina Slate Belt.

Cataclastic Rocks

A group of intrusive rocks generally conforming to the northeast-southwest line across the northcentral portion of the quadrangle show cataclastic textures. The textures vary from a granulation in the quartz of tonolites to a development of a fine grained, banded cataclastic gneiss.

In the least altered rocks, the evidence of former stress is found in strained quartz and highly twinned plagioclase feldspars. The orthoclase becomes perthitic.

Near the center of the quadrangle along State Highway 86, the shear zone exhibits a cataclastic "mortar structure" with large rounded feldspar relicts in a fine groundmass of granulated quartz, microcline, microperthite, plagioclase, hornblende, and biotite. Minerals in the rock are badly crushed, and the rock possesses a poorly developed foliation. In some of the more intensely sheared rocks, fragments are strung out in the direction of cleavage, and hornblende is reduced to chlorite, and magnetite.

Just east of Iron Mine Hill is a mylonite. Minerals are so badly crushed they can be identified only with difficulty as quartz, plagioclase, microcline, and some pyrite. The rock is granulated, and small books of biotite and chlorite are sprinkled throughout the rock.

These rocks apparently originated as a result of dynamic metamorphism with only a slight elevation of temperature. It is possible that when more detailed studies can be made of this rock, this might well be determined to be a tectonic feature related to late, even Triassic activity. For details of this rock type, the interested reader is referred to the original papers by Kirstein and Hayes.

Dike Rocks

General Statement

Throughout the quadrangle fine grained dikes classified as aplites, and dark colored varieties called lamprophyres cut the intrusive sequence. A third variety, an olivine diabase which is extremely fresh in appearance and apparently related to the Triassic sequence, is found as an even later crosscutting intrusive. It does not appear to be associated with the other two intrusives in time or in space.

Aplites

Aplites in the quadrangle are light colored sugar textured fine grained aggregates of quartz and feldspar. Commonly they exhibit a faint violet color upon freshly broken surface. Very few dark minerals are present in the rock.

This rock type exhibits a microporphyritic texture with suhedral plagioclase crystals set in a fine grained groundmass of anhedral quartz, plagioclase, and microcline. The plagioclase comprises 30 percent of the rock, and quartz grains are 50 percent of the groundmass. The remainder of the groundmass is plagioclase and microcline with extremely minor quantities of magnetite, biotite, and apatite. Apatite, chlorite, biotite, and magnetite collectively do not exceed 3 percent of the rock. Epidote veinlets may be observed cutting the aplites.

The porphyritic plagioclase is oligoclase (An_{10} to An_{12}), which is partly altered to sericite. Albite and Carlsbad twins are common.

The rock has a quartz, microcline, and albite groundmass which averages .2 mm. in diameter per grain; the minerals appear fresh and unstrained. Quartz is anhedral and includes earlier formed plagioclase. Microcline is usually slightly larger in size than quartz. In some specimens it is the dominant feldspar in the rock; in other the microcline is subordinate to the low An oligoclase.

Albite stringers are visible in about one third of the microcline grains, and possibly are the result of exsolution. Quartz is included poikilitically in some of the microcline, and in other places the two are intergrown in myrmekitic textures.

This dike rock, with such a group of minerals having a sugar texture, has been classified as an aplite. The character of the plagioclase feldspar is such that it could be interpreted as a late magmatic rock. Even though the amount of plagioclase at times exceeds that of orthoclase, the highest anorthite content recognized in the plagioclase was An_{12}.

Lamprophyre

The dark rocks, called lamprophyres, which may be observed in the bypass around the south side of Chapel Hill are completely destroyed by weathering. Although boundaries of these dike rocks are visible, and photographs may be taken of them, there remains nothing more than a powdery clay fraction. There is no way to identify the rock, for no minerals of the original rock are preserved. Even so, the age may be determined by the fact that some of the aplites cut the lamprophyres, and some of the lamprophyres cut the aplites. They appear to have been developed at the same time.

Olivine Diabases

The diabase dikes cut the Slates and igneous rocks as well as the neighboring Triassic sediments. In view of the early work done by Steel (1949) in the Durham-Triassic basin on dikes of this type, only one dike sample was studied for this paper. It was taken from a dike which intruded diorite in the southern portion of the Chapel Hill quadrangle. The interested reader is referred to the early works by Steel, and the more recent studies on these rocks by Fleisher, (1963), and Singh (1963), and Hermes (1963).

The rocks are a dark greenish gray medium grained aggregate of augite, plagioclase (An_{56}), and olivine. Well-formed plagioclase laths are inclosed in dark colored augite giving rise to an ophitic texture. Olivine is scattered throughout the rock. When weathered, this rock yields rounded boulders and a yellow clay.

The labradorite laths comprise 45 percent of the rock, whereas augite and olivine collectively make up the remainder. Plagioclase crystals are subhedral to euhedral and are inclosed in the augite. Augite is anhedral and interstitial to olivine and plagioclase. Olivine is partly altered to yellow-green antigorite along irregular fractures in the grains. A small amount of magnetite interstitial to all other minerals is associated with the antigorite.

These rocks are so commonly related to the Triassic sediments, that whenever a fresh olivine diabase is found, the field man immediately lists it as a diabasic dike of Triassic age. As these dikes have been traced from the Triassic sedimentary sequence into the igneous sequence, and the specimens studied come from such a dike, the rock is classified as Triassic olivine diabase dike.

Geologic History and Interpretation

The lower Paleozoic Carolina Slate Series consisting of volcanic and volcano-sedimentary rocks was intruded by a series of plutons which consisted of gabbro, diorite, granodiorite, and adamellites. It is possible these could have been differentiates of the same rock or could have been the result of solutions from a common magma. Field evidence indicates that the gabbro-diorite rock was the first igneous rock formed. This was later intruded by a granodiorite-adamellite sequence, although there is evidence that the diorite and adamellite could have been approximately of the same age. These earlier rocks were in turn intruded and altered in part by an albite granodiorite. Alteration included thermal effects, and an apparent introduction of silica and alkali rich fluids. The albite granodiorite in turn was modified by late fluids which may have been deuteric; the most pronounced effect was an albitization of earlier feldspars. Slates in contact with these igneous intrusives were metamorphosed and altered in part to igneous-appearing rocks containing plagioclase and quartz porphyroblasts.

Dynamic metamorphism, possibly associated with Triassic faulting has given rise to an apparent fault zone, but most certainly cataclastically altered igneous and metamorphic rocks.

At least two important dilemmas remain unsolved; they are: (1). the origin of the small ultramafic body in the central part of the quadrangle, and (2). the relationship between the gabbro and diorite rocks in the northwest corner of the quadrangle. A temporary origin has been assigned to the hornblende peridotite; the authors assume that this is an early segregation of the gabbroic magma emplaced in a manner such as described by Bowen (1956). The full knowledge of which was the intrusive in the northwest corner, the diorite or the gabbro, will have to be established before the apparent anomalous intrusive relationship may be determined. If the diorite has intruded the gabbro, no anomaly exists; however, if the gabbro has intruded the diorite, then a more mafic material is surrounded by a more siliceous intrusive. This would have to be explained in a manner similar to that used by Camsell (1913), and more recently by Rice, (1947), for Olivine Mountain in British Columbia.

All of the igneous rocks are cut by aplites and lamprophyres. Triassic diabases penetrate the intrusive area in only a few places. Epidote veinlets cut the aplite rocks, and these are probably the result of late deuteric action.

Field and microscope evidence reveals a genetic relationship between the gabbro, diorite, granodiorite, and adamellites. Gradations from dark, augite-rich gabbro to the lighter colored rocks in which hornblende is a major mafic constituent may be traced in the field. Plagioclases are similar in form and manner of progressive zoning in the rock varieties, but hornblende is far more abundant in the diorite than in the gabbro.

The diorites in turn grade locally into granodiorites and into adamellites with an increase in amount of potash feldspar and quartz at the same time as there is a decrease in plagioclase and hornblende. Along a traverse from the top to the base of Blackwood Mountain on its east flank, one may observe the transition from granodiorite to tonolites. The granodiorite differs here from the tonolite primarily by possession of more micropegmatite. Free quartz and orthoclase are slightly more abundant in the granodiorite while plagioclase and hornblende decrease correspondingly. Crystallization in this gabbro-diorite-granodiorite series conforms satisfactorily to the reaction principles proposed by Bowen (1956, p. 54-62). Fractional crystallization of a basaltic magma could very readily result in this sequence with or without late quartz, and potash feldspar. The difficulty in applying the reaction series to this rock sequence is in the special relationship.

Assuming fractional crystallization of a basaltic magma cooling from the borders inward, one would expect an increase in alkali content from the margins towards the core of the igneous mass. However, in the Chapel Hill quadrangle, the rocks grade from adamellite at the outer extremities to gabbro at the core. The field men explained this phenomena by attributing the changes in composition to assimilation of the intruded slates in the outer portion of the intrusive. Whereas this might be affected by assimilation of an arkosic variety of slate, the senior author doubts that assimilation of a graywacke would have such a pronounced effect on the differentiation of a magma. A possible explanation is that the body crystallized from the center outward, according to the procedure suggested by Kennedy (1955, p. 496), when he proposed that water vapor migrating to the margins of the magma because of lower pressures and temperatures there would affect a reverse crystallization, such as that recognized in the Chapel Hill quadrangle. A geological example of reversed zoning of a basic stock was examined in British Columbia near Princeton, B.C., at Olivine Mountain, and at Union Bay, Alaska, by the senior author. Camsell in 1913, and Rice (1947) described differentiation of this type of peridotite through progressive zones of pyroxenite, augite syenite, and finally granite; Ruckmick and Noble, (1959, p. 1005) discussed reverse zoning found in many places in the world. A thorough examination of literature for other examples has not been made for this study, because other examples such as the reversed zoning has been observed by the senior author in many other places in British Columbia and Alaska.

For this reason, the senior author believes that either or both the mechanisms suggested, fluid migration or rock assimilation during fractional crystallization, would suffice to explain the rock sequence grading from gabbro through adamellite and granodiorite in the Chapel Hill quadrangle. As yet there is not enough data available to choose which of the two possibilities was most important.

The origins of the altered diorite and the albite-granodiorite apparently are intertwined. Both of these rocks contain a preponderance of plagioclase although the feldspar is a very sodic variety. Hayes (1962, p. 41-42), found considerable evidence for a replacement origin for these rocks; he (1962, p. 38-39), reviewed papers by Anderson (1937), Gilluly (1933), and Read (1947), and applied factors determined by them as important in the identification of rocks which had been replaced. He recognized mottled feldspars which suggested replacement of potash feldspars by albite; and chessboard structures in plagioclase which indicate the same process, clouding of feldspars by non-supergene iron as evidence for metasomatism, development of myrmekite which he felt represented a replacement of plagioclase by quartz in these two rock types, and finally pointed to rims of sodic plagioclase around intermediate plagioclase in the diorites and albite-granodiorite as evidence for albitization. Lastly, Hayes pointed to the widespread occurrence of epidote and chlorite in the albite-granodiorite, with a corresponding decrease in normal pyrogenic mafic minerals, as indicative of very late magmatic fluid activity, or even hydrothermal activity. Assuming the replacement theory to be correct, the source of albitizing fluids is available in three places: (1) intruded Carolina Slates, (2). solutions from buried rocks or even other intrusives, or (3). local rest magma or solutions derived from crystallizing magma. Chemical analyses show that the Slate Series is richer in soda than in potash. It is conceivable that portions of the granodiorite and the altered diorites may have received contributions of alkali and silica through endomorphic reactions with the Slates. One would expect that a wide scale application of this theory would also include replacement features in the diorite throughout the entire rock sequence in the quadrangle. As of now they cannot be found in the northern part of the quadrangle; however this may be because of lack of critical exposures.

Ichors from an unknown source have been suggested as the source of fluids which could convert rocks into igneous appearing rocks (Read, 1947, p. 10). Although this is possible, such would be indeed difficult to recognize in this rock sequence, and in the environment of the sequence.

The late rest magma where there is a concentration of alkalies and silica has long been recognized (Gilluly, 1933, p. 18-19) as a potential source for non-acid solutions. These deuteric reactions have been recognized in many places, and could possibly explain the phenomena observed in the altered diorites, and albite-granodiorites; however the senior author believes that the mineral and rock sequences found here most readily are explained by a deuteric concept. Further this concept would assist in explaining the contact aureole observed around each intrusive as it is in contact with the Slates. Although the Slates were heated by the intruding masses, solutions apparently high in both soda and silica have entered the Slates, to form porphyroblasts of albite and quartz. That potassium migrated at least slightly, either from earlier material or perhaps was added from outside the rock, is shown by the increasing size of potash feldspar as the intrusive is approached. Biotite, rarely observed in these igneous rocks, is a rather common component of the altered Slates.

Thus, although there is some suggestion of potassium having migrated, there is more suggestion that soda and silica moved either from within the original rock, or into the metamorphosing environment.

The entire sequence is cut by the late dike rocks which have been classified as aplite and lamprophyre varieties. The aplites are high in alkalies and the lamprophyres appear to have been so; the aplites are also high in silica. All are cut by deuterically related epidote stringers, and blue quartz. The latest igneous activity occurred sometime considerably later with the emplacement of Triassic igneous dikes.

Summary and Conclusions

The Paleozoic Slate Series was intruded by a later Paleozoic igneous sequence consisting of gabbro, diorite, granodiorite, adamellite, and ultramafic. The intrusives altered the Slates and in turn were altered by later intrusives in the same sequence. All were modified to some degree by late solutions high in alkalies and silica. One zone of dynamic metamorphism was recognized in the intrusive belt, although the edge of the intrusive is bounded by a resequent fault line scarp of Triassic age. All the rocks are cut by aplite and lamprophyre dikes, as well as a much later series of Triassic dikes. Epidote and sagenite veins, probably related to the intrusives, cut all but the Triassic dikes.

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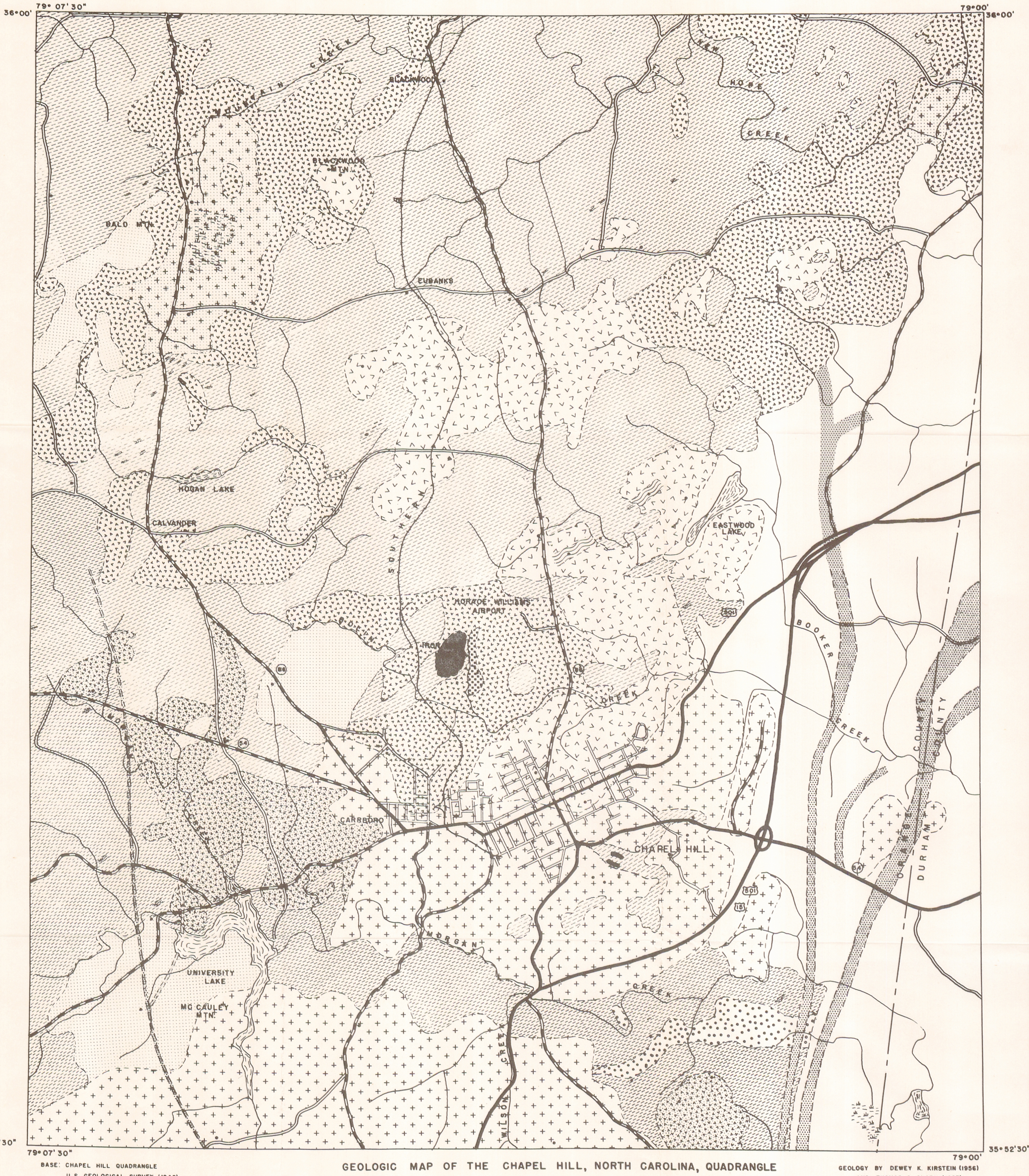

BASE: CHAPEL HILL QUADRANGLE
U.S. GEOLOGICAL SURVEY (1946)

NORTH CAROLINA STATE HIGHWAY
PLANNING SURVEY COUNTY MAP NO. 68
(1955)

GEOLOGIC MAP OF THE CHAPEL HILL, NORTH CAROLINA, QUADRANGLE

GEOLOGY BY DEWEY K. KIRSTEIN (1956)
AND THOMAS G. CLARK (1957)

PETROGRAPHY BY LAWRENCE D. HAYES (1962)

MODIFIED BY V. I. MANN (1964)

LEGEND

ROCK SYMBOLS

ALBITE GRANODIORITE

GRANODIORITE AND ADAMELLITE

DIORITE AND TONOLITE

RHYOLITE

ALTERED DIORITE

GABBRO

ULTRAMAFIC

CATACLASTIC ROCKS

SLATES

WACKE CONGLOMERATE

TRIASSIC SEDIMENTS

TRIASSIC DIABASE DIKES

IRON DEPOSIT

SPECIAL SYMBOLS

ACTUAL AND PROBABLE CONTACTS

SHEAR ZONES

SAMPLE LOCALITIES

APPROXIMATE MEAN DECLINATION (1946)

3½°

MAGNETIC NORTH

TRUE NORTH

SCALE

1 ½ 0 1 MILE

1000 0 1000 3000 5000 7000 FEET