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GEOLOGY OF THE CHAPEL HILL QUADRANGLE, NORTH CAROLINA

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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 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.

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 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, 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 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

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 tion 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.

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.

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 under-

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.

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.

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, 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.

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 quence.

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

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