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THE METAMORPHIC HISTORY OF THE SPRUCE PINE DISTRICT*

J. LAURENCE KULP and ARIE POLDERVAART

ABSTRACT. The Spruce Pine District is located on the Blue Ridge Plateau in western North Carolina. The rocks of the area consist of mica and hornblende gneisses and schists, quartzofeldspathic gneisses, ultramafic rocks, pegmatite and alaskite, granite, metadiabase and metagabbro, and younger, unmetamorphosed diabase. Field relations indicate two distinct periods of regional metamorphism. The first was Precambrian and was attended by plastic deformation, producing the Cranberry-Henderson and the Carolina-Roan gneisses from the original sedimentary sequence. Ultramafics were intruded into the Carolina-Roan gneiss along the keel of the geosyncline during the early stages of this period of metamorphism. Small granite intrusions in the Cranberry gneiss may have resulted from mobilization of lower parts of the Cranberry rocks.

Apparently the first metamorphic phase was followed by a period of local crustal tension, during which the country rocks were essentially rigid. Local subsequent brecciation of the metamorphic rocks was followed by the emplacement of the Bakersville-Roan Mountain basaltic dike swarm with northeasterly trend. The second metamorphic cycle followed the emplacement of this basaltic magma. In the Bakersville-Roan Mountain area this cycle caused recrystallization of the diabase, gabbro, and the cementing material of the breccias to mineral assemblages of high metamorphic grade, but left the Cranberry gneiss virtually unaffected. Pegmatites and alaskites were intruded toward the end of this second cycle at 330 ± 10 million years ago.

Finally, there was another phase of crustal tension and diabase dike intrusion which may be Triassic.

INTRODUCTION

The Spruce Pine District has been studied and mapped on a scale of 1:125,000 by Keith (1903, 1905, 1907), but more recently general geologic mapping at scales of 1:12,000 and 1:24,000 has been carried on by the U. S. Geological Survey in cooperation with the North Carolina Department of Conservation and Development (Olsen, 1944; Parker, 1953; Brobst and Kulp, in press). This paper briefly reviews the geology of the district and attempts to synthesize the geologic history. Mafic intrusive rocks are the chief clues to the sequence of events in this complex metamorphic terrane. Field evidence indicates that the area has undergone two periods of regional metamorphism.

The area described in this paper occupies parts of Mitchell, Avery, and Yancey counties on the Blue Ridge plateau in western North Carolina, and a small part of eastern Tennessee along the northern slope of Roan Mountain. An index map (see fig. 1 of F. D. Eckelmann and Kulp, 1956) shows the regional setting of the Spruce Pine District.

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GENERAL GEOLOGY

Regional Setting

The Spruce Pine District lies west of the axis of the Appalachian geosyncline (King, 1950). The area (fig. 1) consists predominantly of intricately folded gneisses and schists. At the beginning of this century, Keith (1903, 1905, 1907) distinguished four main formations: the Carolina gneiss (mainly mica gneiss and schist), the Roan gneiss (mainly hornblende gneiss and schist), the Cranberry and Henderson granites (mainly quartzofeldspathic gneisses). More recent work by Brobst and Kulp (reports in press) has shown on structural, stratigraphic, and petrographic grounds that the Roan and Carolina are probably best considered facies of one formation, i.e., the Carolina-Roan. F. D. Eckelmann and Kulp (1956) have shown that the Cranberry and Henderson rocks are metasedimentary in origin and are stratigraphically equivalent. The Carolina-Roan formation and the underlying Cranberry-Henderson gneiss appear to represent an original sedimentary sequence, although some pyroclastic material may contribute to the Roan facies.

In the Spruce Pine District, these rocks form a broad synclinorium which plunges toward the southwest (fig. 1). Foliation and schistosity are parallel to the bedding planes of the original sediments. Garnet, kyanite, and staurolite have been found in the metamorphic rocks, but these minerals could not be used as indicators to map zones of different metamorphic grade. Numerous intrusive bodies of ultramafic rocks, pegmatite, alaskite, granite, and both metamorphosed and unmetamorphosed basaltic rocks penetrate the synclinorium.

Rock Types

Brief descriptions of the various rock types are given below, but more detailed descriptions will appear elsewhere (Brobst and Kulp, in press; F. D. Eckelmann and Kulp, 1956; Wilcox and Poldervaart, in preparation).

Cranberry-Henderson Gneiss.—Leucocratic, quartzofeldspathic gneisses of granitic composition with minor schists, consisting chiefly of quartz, microcline, plagioclase (albite-oligoclase), with little biotite, muscovite, epidote, and chlorite, accessory black opaque ore, apatite, sphene, calcite, allanite, and zircon, and occasional garnet and hornblende.

Carolina-Roan gneiss.—A. Roan facies. Various hornblende gneisses and schists of cafemic affinity, mainly composed of hornblende, actinolite, plagioclase (oligoclase-andesine), quartz, epidote, zoisite, biotite, garnet, diopside, and chlorite. Accessories include black opaque ore, sulphides, sphene, rutile, apatite, zircon, allanite, calcite, and sericite. Microcline may or may not be present. The schists are generally darker colored than the gneisses which contain more quartz and feldspar.

Layering is conspicuous throughout (pl. 3 of F. D. Eckelmann and Kulp, 1956) with dark schist bands alternating with paler-colored gneissose layers. The width of the layers is highly variable with a maximum of 3-4 feet and minimum measured in a few tenths of inches. The average thickness of individual bands is about 1 foot, and the schist bands appear to have approxi-

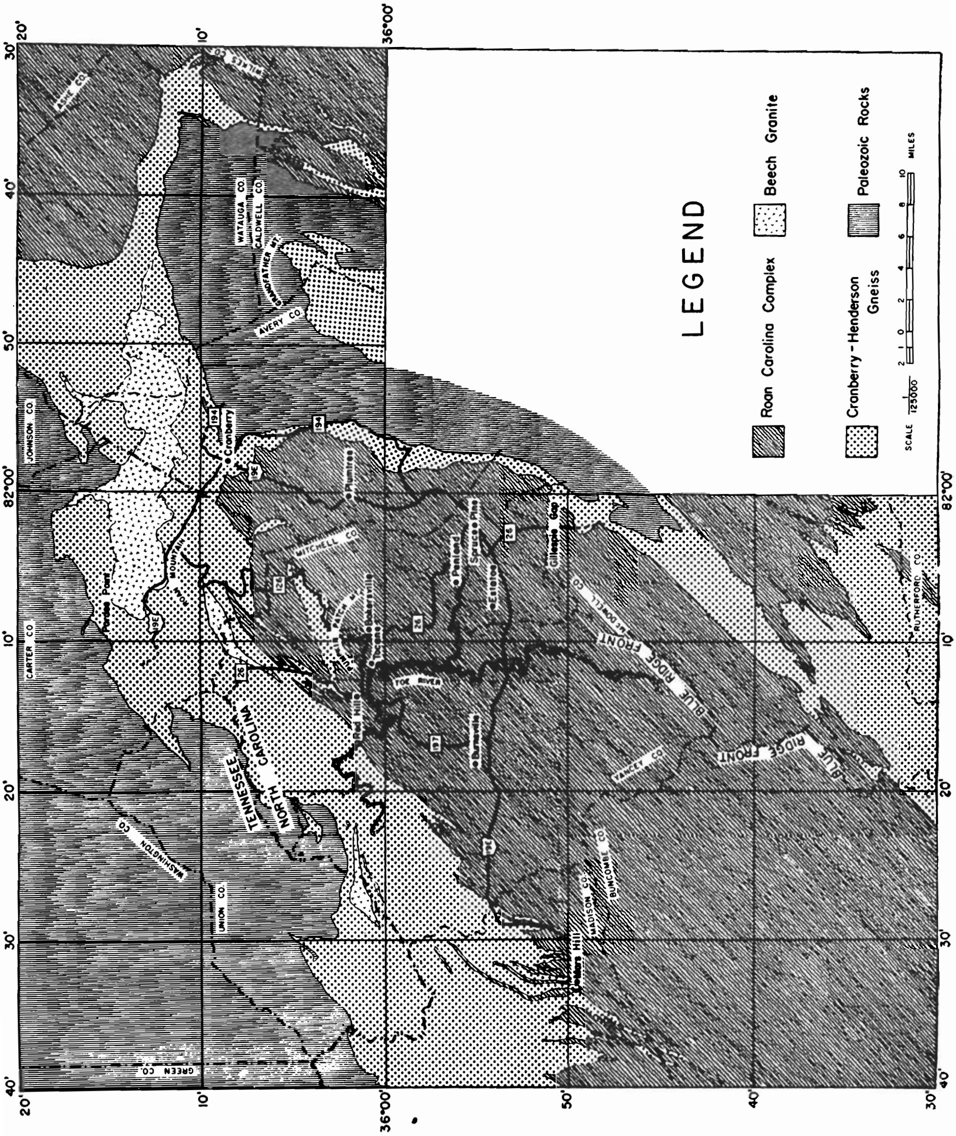


Fig. 1

mately the same width as the gneissose layers. The grain size is extremely variable, not only from one band to another but also within each layer.

B. Carolina facies. Various micaceous gneisses and schists of pelitic affinity consist of quartz, oligoclase, biotite, and muscovite. Accessory minerals are black opaque ore, epidote, apatite, allanite, zircon, sphene, rutile, chlorite, sulphides, and calcite. Chemical analyses show traces of carbon. Microcline may be absent or may occur in minor quantities in the schist, but is more prominent in the gneisses and may even exceed the amount of oligoclase. The schists generally contain more muscovite than biotite, but in the gneisses this relationship is frequently reversed. With the appearance of hornblende and actinolite in increasing amounts, transitional phases between Carolina (mica gneisses and schists) and Roan (hornblende gneisses and schists) facies are produced. Garnet, kyanite, and staurolite may become prominent in certain layers, especially in the more schistose rocks. The Carolina facies is generally less well layered than the Roan facies. Alternating bands of mica schist and gneiss of varying width are found in places, but it is more usual to find one locality consisting predominantly of mica schists, while in another mica gneisses are more abundant.

Ultramafic rocks.—The ultramafic bodies consist of more or less altered dunite with olivine and disseminated chromite in minor amounts as the only primary minerals. Antigorite, enstatite, talc, anthophyllite, chlorite, serpentine, and magnetite may be found as secondary minerals. All transitions between slightly serpentinized dunite and soapstone bodies consisting largely of talc and serpentine are found.

Granite, pegmatite and alaskite.—The pegmatite and alaskite of the Spruce Pine District are closely allied; both are leucocratic, extremely variable in grain size, and the predominant alkali is sodium. The alaskite forms large unzoned bodies, has a granitic texture, and is coarse grained, but pegmatitic patches and schlieren are abundant. The pegmatites form smaller bodies some of which are zoned and of lenticular shape. The grain size is extremely variable but generally coarser than that of the alaskite, whereas the texture is pegmatitic. Both rock types consist mainly of oligoclase-albite, perthitic microcline, quartz and muscovite. Accessories are garnet, zoisite, biotite, zircon, apatite, columbite, uraninite, samarskite, beryl, tourmaline, black opaque ore, and sulphides.

Small patches of granite are found in the Cranberry in this area. This granite has the same mineral composition as the Cranberry rocks described above.

Metadiabase and metagabbro.—The rocks show textural and mineralogical variations which correspond to various phases in the recrystallization of basaltic to metabasaltic rocks (Poldervaart, 1953). Textures vary from subophitic to granoblastic. Palimpsest plagioclase and pyroxene may be heavily clouded and surrounded by newly formed metamorphic minerals including sodic plagioclase, green hornblende, almandine garnet, rhombic pyroxene, biotite, quartz, and black opaque ore. The minerals are typical of assemblages formed in the presence of low water concentrations. All the metabasaltic rocks are garnetiferous and the mineral assemblages are those of the amphibolite facies. Especially near the contacts, the rocks may show faintly to well developed foliation which usually parallels the contacts.

Diabase dikes.—Thin, unmetamorphosed diabase dikes occur in the area. These rocks consist of pagioclase (An_{50}), augite, and olivine which may be altered in part to serpentine. Textures are aphanitic to porphyritic and diabasic. Veins of calcite, zeolites and sulfides are associated with the dikes.

Geological Relationships

Cranberry and Carolina-Roan gneisses.—The Cranberry-Henderson gneiss is a typical metamorphic product of an arkosic series low in iron. The Carolina facies of the Carolina-Roan gneiss is the result of metamorphism of argillaceous sediments. The Roan rocks are probably the metamorphic equivalents of impure dolomitic limestones with intercalated arenaceous and argillaceous sediments. The intricate interlayering of the Roan and Carolina facies and the similar interlaying of the Roan-Carolina with the Cranberry-Henderson at their contact preclude an appreciable fraction of the Roan's having been volcanic flows. Further, the trace element composition of these rocks is not consistent with an origin from pure mafic volcanic materials (Brobst and Kulp, in press). The possibility that the Roan consists, at least in part, of intercalated reworked tuffs cannot be ruled out. An analogous unmetamorphosed sequence might be the tuff-sediment series in Puerto Rico.

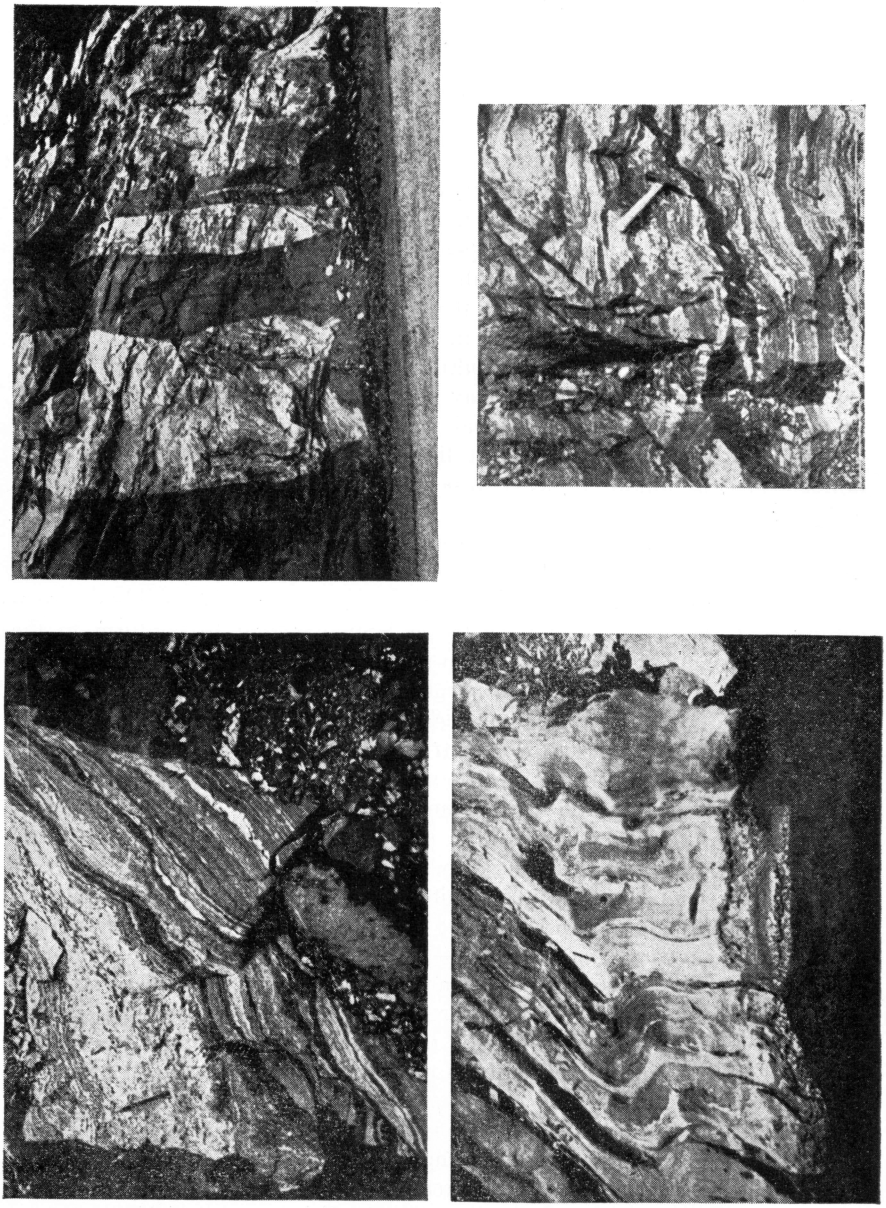
The ultramafic rocks.—All of the dunite-peridotite bodies maintain the regional trend of the Alpine-type ultramafics of the Appalachians (Benson, 1926). Alteration of the dunite may be synchronous with its emplacement, or the result of subsequent regional metamorphism, or finally, due to emplacement of pegmatites which cut the ultramafic bodies. Alteration zones developed in the dunite adjacent to pegmatites have been described by Kulp and Brobst (1954).

In the Spruce Pine District, each ultramafic body shows a relatively unaltered dunite core surrounded by alteration zones of varying width. The contacts of these bodies with the country rocks may be conformable or cross-cutting, but the majority appear to be lenticular and to conform to the regional strike. It is believed that the ultramafics were emplaced during the initial stages of the regional metamorphism which produced the main plastic deformation of the Carolina-Roan rocks. During subsequent metamorphism and plastic deformation of the country rocks the intrusives were squeezed into new positions and probably both modified in shape and reduced in size, as has been observed in the Coast Ranges of California (Taliaferro, 1943). This process is thought to have been effected by marginal alteration of the dunite to various hydrous minerals with sheet structures, which effectively "greased" the contacts, while the dunite cores remained essentially unaltered (c.f., Turner and Verhoogen, 1951).

Granite, pegmatite and alaskite.—Small, irregular intrusions of granite are found in the Cranberry-Henderson unit. Contacts with country rocks are usually gradational, and it was at first believed that these slightly or non-foliated rocks were formed in situ by more thorough metamorphic recrystallization. Field evidence in this case is not determinative, and on the basis of field observations it could be argued with equal justification that the rocks were formed in place, or that they are igneous rocks with granitized marginal zones. However, the non-foliated granites contain sharply euhedral zircon crystals of characteristic habit, whereas the Cranberry-Henderson gneisses show only a few, well rounded zircons (F. D. Eckelmann and Kulp, 1956). This is regarded as evidence that the granites are true igneous rocks and

PLATE 1

B D



A C

were not formed in place (Poldervaart, 1950). They may not have traveled far and may still have been produced from fusion of the lower Cranberry-Henderson.

Pegmatite and alaskite of the Spruce Pine District are concentrated along the eastern and northeastern part of the synclinorium. They intrude the Carolina-Roan gneiss but do not appear to extend to the Cranberry-Henderson.

The pegmatite and alaskite are believed to have been emplaced during the later phases of the second regional metamorphism of the Carolina-Roan gneiss since there is no evidence of deformation or metamorphism of these rocks. Near the contacts, however, exposures may show faint to distinct foliation which parallels the foliation of the country rocks.

Metadiabase and metagabbro.—In the northwestern part of the area there are many parallel dikes of metadiabase, varying in width from 1/2 inch to 50 feet or more. The dikes cut across the foliation of the country rocks with sharp, clean contacts. Excellent exposures may be found along N. C. State Route 261 north from Bakersville and Tennessee State Route 143 on Roan Mountain. Here there are also local developments of breccia, in which angular fragments of foliated gneissic rocks are enveloped by a dark matrix which itself has been metamorphosed during the second metamorphic cycle (pl. 1-A).

Metagabbro of variable grain size is found as a large composite mass at Pumpkin Patch Mountain, northwest of Bakersville. Marginally the intrusive contains numerous inclusions of country rocks which have been mobilized in many cases by the gabbroic magma. Mobilization has resulted in modifications of the original outlines of the metasedimentary inclusions, and their foliation has been partly or wholly destroyed by thorough recrystallization. Xenoliths which have not been mobilized are angular to subangular in outline, and foliated in the same manner as the country rocks (pl. 2-A).

There can be no doubt that the basaltic rocks were emplaced after the first metamorphism of the Cranberry rocks, i.e., when these rocks were already tightly folded and plastically deformed. The local development of breccias, and the occurrence of the well defined dike swarm at Roan Mountain further indicates that the region was under tension. The fact that some of the Roan Mountain dikes are amygdaloidal is evidence that they were emplaced fairly near the surface and thus the environment was relatively cool. Finally, the fact that both basaltic rocks and breccias are themselves metamorphosed proves the existence of two distinct metamorphic cycles, separated by the intrusive phase of basaltic magma (pl. 1-B).

Two outcrops strongly suggest that the Bakersville gabbro was intruded into the Carolina-Roan prior to the final metamorphism which culminated in

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A. Sharp contacts of layered granitized Cranberry in metadiabase matrix near top of Roan Mountain.

B. View from Roan Mountain road on Tennessee side showing three dikes cutting the foliation of the light-colored Cranberry rocks.

C. Excellent layering showing asymmetric folding along Crabtree Creek. Dark layers are hornblende gneiss, light layers are mica gneiss or schist.

D. Hammer point is at sharp contact of thin metadiabase dike and granitized Cranberry.

the pegmatite-alaskite invasion. One is along the Toe River on the West bank about 0.1 mile south of Toecane. Here a diabase-gabbro dike in the Carolina Roan has been metamorphosed to an amphibolite gneiss. The other is a sill of the porphyritic gabbro in the Carolina-Roan along the new roadcut on Route 197 two miles south of Red Hill. This sill has been completely recrystallized.

Shear zones.—A small number of major shear zones are found in the area. The most prominent of these dips at low angles and has a sinuous outcrop extending through Estato north to Penland and south toward the Gillespie Gap. This shear zone contains blocks of hydrothermally altered gneisses and schists, set in a matrix of schistose chlorite and actinolite with disseminated iron and copper sulphides. It is certain that those shear zones were initiated subsequent to the plastic deformation of the Carolina-Roan rocks and probably subsequent to pegmatite intrusion of the area. Mineralization and hydrothermal alteration occurred along these fracture zones apparently at relatively low temperature.

Diabase dikes.—A few thin dikes of unmetamorphosed diabase cut metasediments and pegmatites. Similar dikes occur throughout the Appalachians from Nova Scotia to Alabama. They are generally believed to be Triassic in age.

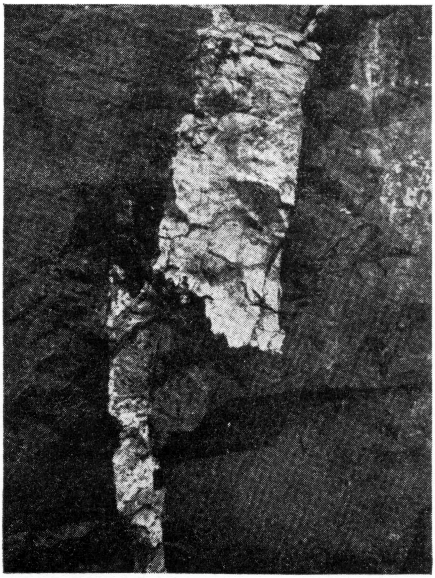
QUANTITATIVE AGE MEASUREMENTS

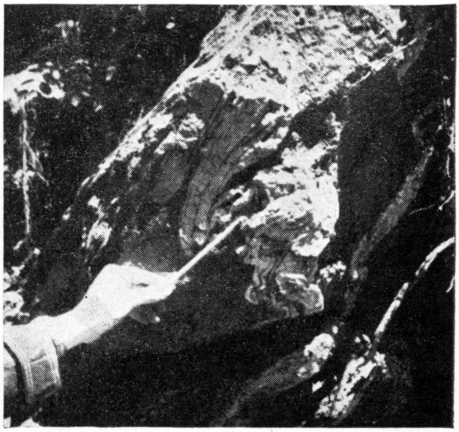
Recent complete isotopic and chemical studies on a number of radioactive minerals from the Spruce Pine pegmatites (W. R. Eckelmann and Kulp, 1956) show that these pegmatites, and therefore also the alaskite were emplaced 340 $\pm$ 20 million years ago. The completeness of this study and the concurrence of the ages obtained from the isotopic ratios makes the Spruce Pine District one of the well dated localities in North America. The earlier age estimates based only on chemical data range from 310-370 m.y. with exception of the Mars Hill monazite. This was shown to have been incorrectly dated at about 600 m.y. since it contains some common lead. When the proper common lead correction is made the age of the Mars Hill sample lies in the 300 m.y. age range also.

This date of 340 $\pm$ 20 m.y. indicates that the final major regional metamorphism climaxed at about the Ordovician-Silurian boundary. This may be correlated with the Taconic orogeny in New England. It is significant that stratigraphic evidence for the existence of a Taconian orogeny in the southern Appalachians has been accumulating rapidly for several years (Rodgers, 1952).

Recently Carr and Kulp (in press) have reported some potassium-argon ages for a number of Southern Appalachian localities. The inherent errors in this method are larger than in the uranium-lead method but do not exceed 20 percent. The perthite from Spruce Pine pegmatites indicates a date of origin around 300-350 m.y. ago consistent with the uranium-lead ages for these pegmatites. A sample of the Beech granite which is intrusive into the Cranberry gneiss just northwest of Roan Mountain and probably dates the culmination of the plastic deformation of the Cranberry-Henderson rocks gave an apparent age of about 700 m.y. Cranberry and Carolina gneiss also gave ages in the same range. This proves that the first metamorphic cycle was Precambrian.

PLATE 2





A. Xenolith of Cranberry-Roan rock in metadiabase matrix on Roan Mountain road.
B. Typical folds found in the gneisses of the Spruce Pine District.

GEOLOGIC HISTORY

From the data given above the following geologic history can be constructed for the Spruce Pine District. The key position of the mafic intrusives in this interpretation will appear.

1. Deposition of a thick sedimentary sequence in the Appalachian geosyncline, now represented by the Carolina-Roan gneiss and the underlying Cranberry-Henderson gneiss. The Carolina facies becomes dominant over the Roan going up stratigraphically. This sedimentation occurred in the Precambrian (800-1000 m.y. ago) and possibly was contemporaneous with the deposition of the Talledega series in northern Alabama as suggested by King (1950).

2. Regional metamorphism occurred which plastically deformed the Cranberry-Henderson and Carolina-Roan gneisses. This probably occurred about 700 m.y. ago. Where the Cranberry rocks are in contact with lower Cambrian quartzites and phyllites such as around Grandfather Mountain and at Pardee Point there is an extreme contrast in degree of metamorphism. It is not certain, however, that this contact is a depositional one or is a thrust plane. Local pods of granite (Beech and Max Patch) were probably intruded into the Cranberry during the maximum of regional metamorphic cycle. Ultramafic bodies were emplaced during this first metamorphic cycle.

3. The first metamorphic cycle was succeeded by relative crustal tension during which the rocks were essentially rigid. Local brecciation of the metasedimentary rocks was followed by the intrusion of basaltic magma as a dike swarm with northeasterly trend in the Bakersville-Roan Mountain area. Some of these dikes extended south into the Carolina-Roan complex.

4. A second cycle of thermal metamorphism caused recrystallization of the basaltic rocks and the breccia matrix in the vicinity of Roan Mountain. The temperature was apparently greatest along the keel of the major syncline, causing local melting at depth with consequent pegmatite-alaskite intrusion into the Carolina-Roan rocks.

The ultramafic bodies which were intruded in the first regional metamorphism were altered peripherally and along joint planes. This second regional metamorphism ended at about the beginning of the Silurian (330 m.y. ago).

5. The development of shear zones after the region had cooled and was again under compression might reasonably be related to the Appalachian folding to the northwest at the end of the Paleozoic.

There is no certainty as to the age of the younger unmetamorphosed diabase dikes, but geomorphological evidence suggests that they are probably pre-Cretaceous, because younger sedimentary deposits are uninvaded. They are correlated tentatively with the Triassic intrusions found all along the eastern seaboard of North America.

GENERAL CONSIDERATIONS

The intense folding in the Cranberry-Henderson rocks which accompanied the first metamorphic cycle contrasts sharply with the lack of folding during the second. This may be related to the temperature and water distribution since even in regional metamorphism the surfaces of equal degree of metamorphism may dip rather steeply. Both cycles emphasize the complex problem of the spatial distribution of regional metamorphism. In the Spruce Pine District two distinct metamorphic periods can be recognized, and it is therefore of interest to inquire into the environmental conditions of these two cycles.

In the first metamorphic cycle a thick sequence of sediments was brought from its original state to one of essentially high-grade metamorphism, at least in the Cranberry and the Roan Mountain areas and presumably in the entire Blue Ridge of western North Carolina. During this process the rocks were tightly folded while in a plastic condition. The fold pattern of the area differs from place to place, and symmetrical folds are common in some localities, while others show highly asymmetrical folds which vary even from layer to layer (pl. 1-C and 2-B).

After cooling, tension, and intrusion of the gabbroic dikes, another thermal rise occurred which caused pegmatite formation in the vicinity of Spruce Pine-Plumtree-Bakersville but merely recrystallized the dikes on Roan Mountain. Along the Toe River at the two localities mentioned earlier, however, a gabbroic dike and sill may have been slightly deformed in addition to being thoroughly recrystallized.

On Roan Mountain the thinnest metadiabase dikes are perfectly clean-cut and undeformed (pl. 1-D). The dikes also cut sharply across the foliation of the country rocks (pl. 1-B), and there is no evidence of "streaming" of foliation planes in the immediate vicinity of the igneous contacts, as would be expected with continued folding. Therefore, it is concluded that the second cycle did not have the same high temperature or water content in the Roan Mountain area as the first cycle. The first cycle metamorphosed sedimentary rocks throughout the area but the second obviously affected only the unmetamorphosed basaltic rocks in the Roan Mountain area. However, both energy level and water concentrations at Roan Mountain were sufficiently high to effect metamorphic changes in the breccia matrix, diabase, and gabbro—rocks which had not been metamorphosed previously. The lack of plastic deformation in these rocks or the adjacent Cranberry gneiss may have been due only to low water concentration. With low water concentrations, rates of reaction would be much lower and the number of mineral transformations proceeding at any particular instant would be less, with the result that the rocks would remain essentially rigid at the prevailing temperatures and pressures.

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Lamont Geological Observatory
Palisades, New York