Monazite in the Granitic Rocks of the Southeastern Atlantic States—an Example of the Use of Heavy Minerals in Geologic Exploration

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By JOHN B. MERTIE, JR.

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Concentrates panned from saprolite used to interpret origin of granite

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MONAZITE IN THE GRANITIC ROCKS OF THE SOUTHEASTERN ATLANTIC STATES—AN EXAMPLE OF THE USE OF HEAVY MINERALS IN GEOLOGIC EXPLORATION

By John B. Mertie, Jr.

ABSTRACT

Monazite was discovered in North Carolina in 1849, and placer deposits were worked from 1887 to 1911 and sporadically from 1915 to 1917. During this early mining, monazite was found in North Carolina and South Carolina within a belt, now called the western Piedmont monazite belt, that trends to the northeast for 160 miles. The present investigation, conducted from 1948–57 through studies of heavy minerals panned from weathered rock, has extended this belt northeastward into Virginia and southwestward across Georgia into Alabama for a total distance of 620 miles. In addition, two previously unrecognized subparallel belts have been discovered, of which one, called the eastern Piedmont monazite belt, has been traced for 420 miles across Virginia, North Carolina, and South Carolina. The other, called the mountain monazite belt, has been followed intermittently for 610 miles across Virginia, North Carolina, and Georgia.

Owing to deep weathering in the Southeastern States, exposures of unaltered rock are uncommon; therefore, the distribution of monazite was traced regionally largely by means of accessory minerals panned from saprolite. Locally the material panned was the rock powder that accumulates under jaw crushers at quarries; in some places lacking saprolite, the unweathered rock was crushed and milled for panning. The accuracy of appraising the amount of heavy minerals by panning is shown to be such that tenors of 0.00003 percent may readily be determined, and by taking large samples still smaller tenors in heavy minerals may be measured.

Field methods are described for separating magnetically the recovered concentrates into four fractions, and instructions are given for the recognition of monazite and xenotime by use of a hand spectroscope.

Many granitic rocks have been analyzed in the Southeastern States but as of 1957 when this work was finished, only 18 of these proved to be monazite bearing. Most of these 18 rocks are adamellites, but 5 of them are monzotonalites (granodiorites), and none of these monazite-bearing granitic rocks is especially different from other granitic rocks that lack monazite.

The accessory minerals panned from the granitic rocks are shown to have genetic significance. Seven criteria are formulated for the recognition of the metasedimentary or migmatitic origin of granitic rocks on the basis of their accessory minerals, of which the heterogeneity, quantities, and ratios of the quantities of accessory minerals are most useful:

1. Preservation of inherited characteristics in one or more accessory minerals.
2. Variations in the color, size, crystalline habit, degree of rounding and other physical properties of any one accessory mineral in a single sample.
3. Unusually high or low tenors for all accessory minerals.
4. Unusually high or low tenors for one or two accessory minerals in a single sample, with the possible exclusion of others.
5. Anomalous composition of the iron ores, the predominance of ilemite over magnetite, the alteration of ilmenite to leucoxene, or the absence of all iron ores.
6. Marked variations in the amount and character of one or more accessory minerals in multiple samples taken either along or across the regional trend of a granitic formation.
7. The presence of minerals such as corundum that are not ordinarily found in granitic rocks.

The mean tenors of total accessory minerals and of five of these minerals in bedrock and in concentrates for the monazite-bearing rocks are shown in the table below.

Mineral	Bedrock (percent)	Concentrates (percent)
Total accessory minerals	0.072	Not applicable
Magnetite	.017	12.9
Ilmenite	.029	29.1
Monazite	.0047	21.9
Zircon	.0022	11.3
Rutile	.0008	1.7

The principal part of this report is a discussion of the three monazite belts and the descriptions of the panned concentrates that justify their delineation, details that constitute an example of the use of heavy minerals in regional geologic exploration. The tenors of accessory minerals in rocks from the monazite belts in Virginia, North Carolina, South Carolina, Georgia, and Alabama are listed, and where possible these mineralogical data are translated into genetic interpretations.

The origin of the monazite belts is discussed in the light of the mineralogical data, from which it is concluded that the beltlike distribution of monazite is analogous to a petrographic province. The localization of monazite is variable along the belts and is thought to have existed first in the granitic crust of the earth and to have been perpetuated by various geological processes, of which the dominant ones were erosion, sedimentation, and reconstitution of the sediments into rocks, operating at repeated intervals in Precambrian time. Melting of some of these metasedimentary rocks is thought to have produced small magmatic intrusive bodies at some localities, and migmatized rocks at others. Monazite is variably present in all types of granitic rocks within the belts, or it may be absent locally therein, but monazite is typically absent from the same or similar rocks outside the belts. Hence, neither petrographic character nor degree of metamorphism is believed to be a principal determinative factor in the localization of these belts. It is thought that these belts mark the sites of Precambrian valleys that were sinking basins of sedimentation produced by lateral compression or faulting. Subsequent to deposition the sediments were metamorphosed and parts of them were melted. Three sinking basins are thus predicated, one for each belt, but it is inferred that they were noncontemporaneous and may have been separated by long intervals of time.

INTRODUCTION

EARLY WORK

The existence of monazite in the Southeastern States has been known since 1849 when the mineral was found in North Carolina (Shephard, 1849). Between 1887 and 1911, and sporadically from 1915 to 1917, placer deposits of monazite were mined in North Carolina and South Carolina. The early literature on monazite in this region is extensive. The principal geologists and mineralogists who contributed to the literature before and during the period of monazite mining, named alphabetically and chronologically in the order of their publications, are: Dana (1882), Derby (1889, 1891a, 1891b), Fontaine (1883), Genth (1862, 1891), Genth and Kerr (1881, 1885), Hidden (1881a, 1881b, 1886, 1888, 1893), Hidden and Washington (1887), Hintze (1922a, 1922b), Kithil (1915), König (1882), Nitze, 1895a, 1895b), Pratt (1902, 1904a, 1904b, 1905, 1906, 1916), Pratt and Sterrett (1910), Schaller (1917, 1919, 1920, 1933), Scharizer (1887), Sloan (1907, 1908), Smith (1854), Sterrett (1907, 1908a, 1908b, 1909, 1911a, 1911b, 1912), Taber (1913), and Watson (1907). A review of these papers is available (Overstreet, 1967); hence, their contributions are not presented here. After the decline of placer mining, there was a general lack of interest in monazite in the Southeastern States until the present investigation was started.

PRESENT INVESTIGATION

The early mining operations in North and South Carolina had disclosed the existence of a monazite belt 160 miles long, having a northeasterly trend. Examination of the fluvial placers therein by the writer in 1945 brought under scrutiny the bedrock sources of the monazite and associated minerals. The results of this work led in 1947 to a general study of the accessory minerals in the granitic rocks of the Southeastern States, the fieldwork for which was terminated in 1957 (Mertie, 1953, 1954, 1955, 1956, 1957 and 1958). This investigation has extended the original belt, now called the western Piedmont monazite belt, northeastward into Virginia and southwestward into Alabama for a total distance of 620 miles. Two belts of monazite-bearing granitic rocks were also discovered and their general limits defined: an eastern Piedmont monazite belt extending 420 miles across Virginia, North Carolina, and South Carolina; and a mountain monazite belt exposed intermittently for 610 miles across Virginia, North Carolina, and Georgia. These three belts (pl. 1) also delimit the areas in the Piedmont and Blue Ridge provinces where fluvial placers of monazite may occur.

PURPOSE OF STUDY

The purpose of the present study was to demonstrate the use of resistate heavy minerals for geologic exploration in areas of deeply weathered crystalline rocks. The geologic features discovered as the result of this work in the Southeastern Atlantic States are the heretofore unknown distribution of three belts of monazite-bearing rocks and the relations of the heavy minerals to the origins of their source rocks. The aggregate length of the belts exceeds 1,600 miles. Interpretation of the significance of these belts is evidently one that touches fundamental aspects of the regional geology of the southern Appalachians. Mineralogical study of the concentrates affords clues to the probable mode of origin of some of the granitic rocks. Interest necessarily attaches to the criteria so established where geologic interpretations of syngenetic ore deposits are to be evaluated, and where methods are to be developed for geochemical exploration in regions of deeply weathered rocks.

The period following the completion of the writer's investigation has been one of increased geologic research by other scientists in the region covered here, and a number of new reports have been published on the region and adjacent areas. The fieldwork of the present investigation was done before these recent advances in knowledge of the stratigraphy and tectonics in the Piedmont and Blue Ridge provinces; thus, the geologic maps and stratigraphic nomenclature used during the fieldwork have since been superseded by more advanced syntheses of the geology. The recent maps certainly will change the interpretations applied to some of these data, but the overall concept of monazite belts related to pre-existing rock units appears to remain valid.

Formation names of rocks represented in the collection of concentrates were assigned on a basis of the distribution of the units on State geologic maps or other publications. No detailed geologic mapping was done to support the assignments because the work was necessarily of a reconnaissance character. For this reason, many samples are not given a formation name; they are merely described by the lithologic character of the saprolite at the site.

Distances were recorded from the odometer of the field vehicle in traverses by road. Route numbers are those in use at the time of fieldwork and were taken from the county road maps issued by the several State Highway Departments from 1945–1956. Active programs for highway construction in these States since that time have resulted in new roads or segments of roads. The reader is therefore referred to the road maps of the late 1940's and early 1950's of the appropriate State Highway Departments for these locations, which are described in detail in a separate report (Mertie, 1978). Inasmuch as only the major geographic names in the region are shown on the sample locality maps, the reader is again referred to the appropriate State Highway Department maps for detailed locations of other place names.

The numbers used in this text and on these figures for the samples are the writer's original field numbers. They appear also in a tabular listing of descriptions of the field localities (Mertie, 1978). The scheme followed in assigning field numbers, for example 50 Mt 222, is that the first number shows the sample was taken in 1950; the letters show the sample was collected by Mertie; and the last number shows that the sample was the 222d collected by the writer in 1950.

ACKNOWLEDGMENT

The work described in this report was done by the writer alone, without the help of any field or office assistants, except for some laboratory work by personnel of the U.S. Geological Survey, acknowledged elsewhere. However, the writer was accompanied on all field trips from 1945 to 1957, inclusive, by his wife, who as an unpaid worker rendered material assistance in driving, recording traverses, aiding in the collection of samples, and in performing many of the necessary chores associated with the project and conventionally undertaken by field assistants. The crushing and milling of hardrock samples was done in Asheville, N.C., at the Minerals Research Laboratory of North Carolina State College. The writer takes this opportunity to thank Dr. Jasper L. Stuckey, then State Geologist and director of this laboratory, for his helpful cooperation in this work.

FIELD CONDITIONS AND METHODS

SAPROLITE

The granitic and related rocks that farther north show little or no surficial alteration are in the Southern States deeply weathered. In the southeastern Piedmont province and on the plateau that forms the northwestern slope of the Blue Ridge province, bedrock is weathered to a depth of 20–100 feet. Most of this weathering is believed by the writer to have taken place under wetter and warmer climatic conditions than those of the present time, possibly in the interglacial stages, and particularly during the last interglacial stage. Under present climatic conditions, residually weathered products are believed to be accumulating very slowly, and at some sites are being removed as fast as they form. Along the southeastern slope of the Blue Ridge, active erosion is a deterrent to deep weathering, and streams having high gradients remove weathered debris very rapidly.

Most outcrops in the Southeastern States consist principally of decomposed, coherent, and untransported bedrock which Becker (1895, p. 289–290) named saprolite. This term is not equivalent to grus (gruss, grush), geest, arkose, or laterite, as it applies neither to the mechanical disintegration of rocks nor to the final stages of chemical weathering present in the tropics. Saprolite connotes chemical alteration in place, as opposed to mechanical disintegration, slumping, or the accumulation of residual debris. Saprolite is produced mainly by the chemical weathering of feldspars, though the mafic minerals are also altered. Saprolite characteristically retains to a large degree the structure and fabric of the original unweathered rock; thus, structural observations may be made. Moreover, as this material can be cut in any desired plane, the trigonometric transformation of structural measurements can be avoided.

Tracts as large as many acres have in places been so eroded as to remove the overlying saprolite and expose the underlying unweathered rock. Such sites have been designated by the writer as pavements. Observations on pavements at quarries show that the relation of saprolite to unweathered rock is variable. Saprolite may lie directly upon unaltered or little altered rock, or saprolite may be separated from the unweathered rock by a transitional zone 5–20 feet thick. This transitional material is too soft to be usable as crushed stone and too hard to be easily removed by power shovels. Some quarrymen apply respectively the names sap and sap-rock to the saprolite and the partly decomposed rock of the transitional zone. A mantle resembling saprolite may lie directly upon unweathered rock, as at quarries east of Salisbury, N.C., but panning of the mantle will generally reveal the presence of a few pebbles, indicating that this material is not in place. Collections of heavy minerals recovered from such material are obviously of little interpretative value. Fortunately, mantles of this kind may generally be recognized by the presence of reddish, greenish, or yellowish streaks that are not present in true saprolite, and by the pebbles revealed by panning.

USE OF ACCESSORY MINERALS

Unweathered granitic rocks suitable for thin sections are found in the Southeastern States mainly at quarries, in deep road cuts, on pavements, and at places where streams have eroded through the saprolite. The geologic restrictions thereby imposed prevent an adequate representation regionally of the rocks in thin section, even where hundreds of thin sections were studied, as here. Therefore, the writer undertook from the outset of this investigations to pan the saprolites and to recover thereby characteristic suites of the accessory minerals of the granitic rocks. A few of these accessory minerals may be visible in thin sections, but many are not. Generally neither their character, their percentages in the rocks, nor their mutual ratios can be obtained by petrographic study of thin sections. Practically they are obtained by the panning of saprolite. These accessory minerals may also be obtained by crushing, milling, and panning samples of fresh rock, but such work takes so much time that it was done only under special conditions where the results could not be otherwise obtained.

These panned concentrates are suitable for the recognition and quantitative appraisal of minerals that are too scarce to be recognized under the petrographic microscope or by chemical analysis. It is not possible to determine directly from accessory minerals the petrographic character of granitic rocks, but such minerals have great value in the correlation of igneous rocks observed and sampled as unweathered rock at quarries or at nearby outcrops. Thus indirectly, in lieu of exposures of fresh rock, the petrographic chacter of the saprolitic rocks may be indicated. Finally, it is now known that the character and amounts of accessory minerals have high significance in deciphering the genesis of their host rocks.

The evaluation of accessory minerals in the study of granitic and other igneous rocks is not a new geologic technique, though it has not been practiced heretofore on a large scale in the Southeastern Atlantic States. The American geologist, O. A. Derby, utilized this method intensively in his Brazilian work, and published a number of papers on this subject (Derby, 1889, 1891a, 1891b). Derby also vigorously advocated with little success the use of this technique in the United States. By practicing on a large scale the study of panned suites of accessory minerals taken directly from bedrock, the writer has so supplemented Derby's recommendations that others in the Southeastern States are now employing these methods (Hurst, 1953, Overstreet, 1962; Overstreet and others, 1963a).

The study of accessory minerals in igneous rocks, however, found early acceptance abroad, though not for the same objectives sought by Derby, nor by his exact methods. In the late 1920's, Brammall (1928), Ghosh (1928), Chatterjee (1929), and Leech (1929), as well as others before them, made comprehensive studies of the accessory minerals of residual and eluvial deposits that were derived from granitic rocks in the west of England. These men were sedimentary petrologists interested in the provenance of such minerals found elsewhere in sedimentary rocks. A petrographer, A. W. Groves, interested mainly in the correlation of igneous rocks by means of their accessory minerals, developed a method for studying them (Groves, 1927a, 1927b, 1930a, 1930b, 1931; Kennedy, 1946, p. 74). This technique consisted of powdering in a mortar a sample of rock weighing about 100 g and removing the accessory minerals from the powder by separation in bromoform. The accessory minerals were then divided into magnetic and nonmagnetic fractions which were examined microscopically. Quantitative data on the tenors of the accessory minerals were not reported, but the minerals were generally arranged in their order of abundance. Much attention was also given to the separated essential minerals, which in the panning of saprolite are lost. The origin of the host rocks was not generally inferred by Groves from relationships among the accessory minerals.

PANNING

Accessory minerals having very low tenors in bedrock may readily be recovered by panning saprolite or crushed rock (Mertie, 1954; Theobald, 1957). Let it be assumed that a sample contains 0.0002 percent of accessory minerals, including 0.00003 percent of monazite. A moderately heaped pan of saprolite has a mean weight of 22 lb, about 10 kg. If the sample consists of four pans, which represents approximately the average sample used in this investigation, the recoverable heavy minerals and the monazite will amount respectively to 80 and 12 mg. This amount of monazite, or of any other accessory mineral, may be separated and weighed, though for mineralogical analysis or examination using a hand spectroscope, a larger amount is desirable. Samples may be taken, however, as large as needed, so that still smaller tenors are determinable. Many samples of 300–500 lb (14 to 23 pans) were taken by the writer, and three samples weighing between 1,300 and 1,500 lb (59 to 68 pans) were processed. It is evident that neither thin sections nor chemical analyses would be useful in the evaluation of accessory minerals having tenors of 0.0005 to 0.00001 percent. Tenors as low as these may have high significance in genetic interpretations.

The methods used in collecting and panning saprolite have been described (Mertie, 1954). It needs to be emphasized, however, that the best panning cannot be done either in a large washtub (Junner, 1955) or in a fast-moving stream of water. In the washtub a return wavelet from the side of the tub interferes with the panning, particularly in its last stages; in swift water some of the concentrates will be washed out of the pan. An excavated basin in a gravel bar close to the stream, where a small flow of water can be admitted, or a quiet pool that is bypassed by the main stream, are the best sites. Figure 1 shows a stream running swiftly on bedrock in Spalding County, Ga., and a quiet pool inside a small gravel bar, which ideally fits these requirements.

FIGURE 1.—Photograph of panning for heavy minerals in a quiet pool that is bypassed by a swiftly flowing stream.

FIELD PROCESSING OF PANNED CONCENTRATES

The panned concentrates of accessory minerals were carefully folded in high-grade paper and air dried, after which they were bottled and labeled. Later, parts of the larger samples and all the smaller ones were separated into four fractions by the use of a series of Alnico magnets of different power. These are the fractions of magnetite, of ilmenite and other minerals having the same magnetic susceptibility; of monazite and minerals of similar susceptibility; and of zircon, rutile, and other nonmagnetic minerals. Xenotime has a susceptibility somewhat greater than monazite and somewhat less than ilmenite; therefore, if present it was in both the second and third fractions. The presence of monazite and xenotime was verified using a hand spectroscope, by methods later to be described. The percentages of these four fractions were estimated in the field, but later were determined by weighting in the laboratory. The percentages of different minerals in each fraction were estimated by examination under the binocular microscope or were determined by counting.

The readily applied field procedures for the separation of four fractions by the use of easily transported magnets has been modified by personnel of the U.S. Geological Survey who have designed special van trucks to serve as heavy-mineral laboratories in the field. Mounted therein are a Frantz magnetic separator, equipment for the use of heavy liquids, and microscopes for the identification of minerals and for counting grains. These heavy-mineral vans have been successfully used in studies of beach placers (Clifton and others, 1967) and in geochemical and exploration (Griffitts and Alminas, 1968).

The determination of the percentages of heavy minerals in a rock is subject to three principal errors. The first arises from inexact weights of the rock samples, that are panned, due to variations in the compaction and contained water in saprolites and to differences in weight between saprolite and pulverized fresh rock. All moderately heaped samples of saprolite in a 16-inch gold pan and all unheaped samples of powdered fresh rock are in the present investigation arbitrarily assigned weights of 22 pounds (10 kg). It is true, however, that the ratio between a large number, representing the weight of a sample, and a small number, representing the weight of the concentrate, is changed little by an error in the larger number. Thus, the average tenor of concentrates in all the granitic rocks panned in the Southeastern States is 0.14 percent. An error of 10 percent in the weight of a sample will change the overall tenor only by one significant figure, that is, to 0.15 or 0.13 percent.

The other errors are to some degree compensatory. An error results from losses of accessory minerals in panning, caused by the inability of a good panner to recover more than 80–90 percent of minerals in the range of specific gravity from 4.0 to 5.5. This error is compensated to some extent because all the rock-forming minerals cannot generally be removed from a panned sample, so that some of these, mainly quartz, are included with and are weighed as a part of the recovered heavy minerals. Samples yielding large amounts of concentrate offer particular difficulties to the removal of a high percentage of the quartz by panning. Separation of quartz in the field by the use of heavy solutions is not feasible, nor is this technique practicable for one man working with many samples in the office without the help of an assistant. Therefore, the inclusion of quartz in the weighed concentrates tends to increase slightly the recorded tenors of the total accessory minerals, but is compensatory to the other error produced by losses of the heavy minerals in panning. The included quartz reduces somewhat the percentages of the accessory minerals in the concentrates, but this reduction is immaterial when the percentages of these minerals in bedrock are computed.

In this investigation of monazite in the granitic rocks of the Southeastern States, the writer panned 55,415 pounds of saprolite and powdered unweathered rock, representing 677 samples from 134 counties in 5 states. These samples ranged in weight from 15 to 1,500 pounds, and the average weight was about 82 pounds. About one third of these samples proved to be monazite bearing (pl. 1).

CLASSIFICATION OF GRANITIC ROCKS PROPOSED FOR WEATHERED REGIONS

NOMENCLATURE

The granitic rocks of the Southeastern Atlantic States are the principal sources of the monazite- and xenotime-bearing concentrates discussed herein. Pegmatites, of course, are granitic rocks, but few have been sampled by the writer and they are not considered in this investigation.

The term "granite" and "granitic rocks" are frequently used in the following pages. Granite is used generically to mean massive granitic rock having a composition ranging from granite, as defined below, to tonalite. Granitic rocks include also the gneissic and schistose derivatives of the same composition, regardless of origin. Thus, the term "granitic rocks" is a broader designation than granite, and is used where the structure or origin or both are obscure. Such usage is commonplace where saprolite is exposed but not the fresh rock from which it is derived by weathering.

The original granitic crust of the earth is nowhere visible, even in the most deeply eroded geological sections; therefore, the writer infers that most visible granitic rocks are necessarily remelts, either of the original crust or of sediments derived directly or indirectly therefrom. Most small masses of magmatic granite are probably not derived directly from the earth's crust, though some larger masses of such rocks may have had a deep-seated origin in the sialic part of the crust. This origin implies that in the remelted granitic rocks, all the primary essential and accessory minerals have crystallized directly and completely from magmatic melts. Radioactive minerals of such rocks are particularly adapted to radiometric determinations of age.

The terms "orthogneiss" and "paragneiss" of this report are used as nearly as possible in the sense proposed by Rosenbusch (1910, p. 596). The genetic terms "palingenesis" and "anatexis," on the other hand, are restricted to migmatitic rocks. Granitic gneiss of rheomorphic or migmatitic origin may have been rendered sufficiently plastic by either of these processes to flow from its origin site and to have acquired characteristics that appear to relate it to magmatic intrusive rocks. Either or both of two characteristics, however, show that such rocks are not magmatic derivatives. First, relics of their original structure may be preserved; second, some of their original minerals, particularly the accessory minerals, may have persisted even during palingenesis and certainly persisted during rheomorphism or anatexis. Radioactive minerals taken from an orthogneiss are suitable for radiometric determinations of age. Radioactive minerals from rheomorphic or migmatitic rocks are not generally suitable for this purpose, as such minerals are heterogeneous in character and age. A laborious separation of accessory minerals into distinctive fractions, however, if this can be accomplished, may render it possible to determine the ages of such minerals. Such determinations will generally still fail to indicate the ages of the host rocks.

Several methods have been proposed to identify magmatic rocks, to distinguish metasedimentary from metaigneous rocks, and to recognize the existence of migmatitization. Such methods include field relationships; showing transition from unaltered to altered types of rocks; diagnostic fabrics and structures of many kinds; mineralogical compositions and tenors, both of the essential and accessory minerals; and chemical composition. No single method or combinations thereof have been found to yield irrefutable proof for all igneous and metamorphic rocks, but those methods which are applicable frequently indicate the probability of specific origins. Most of these methods, for obvious reasons, are inapplicable to granitic saprolites ,but one of the most reliable of them—the study of the accessory minerals—is particularly applicable in a region where saprolite is common, though this line of investigation may also be applied to unweathered rocks.

The names, characters, and boundaries of the granitic rocks are not well defined on the reconnaissance geologic maps of Virginia (Virginia Geological Survey, 1928), North Carolina (North Carolina Division of Mineral Resources, 1958), South Carolina (Overstreet and Bell, 1965), Georgia (Georgia Division of Mines, Mining, and Geology, 1939), and Alabama (Alabama Geological Survey, 1926). Therefore, when it is stated that a sample was taken from a certain formation, no precise petrographic character is implied. Instead, it must be understood merely that the sample came from an area mapped under that formation name. In Georgia this uncertainty is partly clarified by the use on the State geologic map of subheadings under the general petrographic designation in the explanation, such as "Stone Mountain type" under the general heading of "biotite and muscovite granite." Numerous granitic formations and many granitic rocks to which no formational names have been assigned, exist within the three monazite belts recognized by the writer in the Southeastern States (pl. 1). None of these rocks may be characterized as generally monazite bearing, because outside the belts they cease to contain monazite. Even within the belts these rocks do not universally contain monazite, and the amounts of monazite present vary from place to place within the belts. Outside the belts, with a few exceptions that will be discussed, the granitic rocks are barren of monazite. Of the 700 thin sections of the granitic rocks of the Southeastern States studied by the writer, about a third being from the monazite belts, monazite was rarely recognizable. The monazite-bearing granitic rocks, so defined from the mineral composition of their panned concentrates, have no distinctive or unifying characteristics. They are indistinguishable in thin section from granitic rocks that lack monazite. They are similar merely in that they contain monazite. Thus it is improper to use the presence of monazite as a distinguishing feature to define a granitic formation. For these reasons, no general description of the petrographic character of the monazite-bearing rocks is possible.

The phanerocrystalline granitic rocks, containing and not containing modal quartz, are commonly classified by threefold or fivefold divisions based primarily upon the ratios of alkali feldspar to total feldspar. The alkali feldspar is commonly orthoclase or microcline, though in sodium-rich rocks it may be albite. In the threefold division these rocks are designated as granite and syenite, adamellite (quartz monzonite) and monzonite, and tonalite (quartz diorite) and diorite. The fivefold division of these rocks results in the terms granite, monzogranite, adamellite, monzotonalite (granodiorite), and tonalite, together with their quartz-free equivalents. The terms quartz monzonite, quartz diorite, and granodiorite are not used in this report except as a quotation from prior work.

No univesal agreement exists regarding the limits of the feldspar ratios, either in the threefold or fivefold subdivisions. Owing to perthitic intergrowths and solid solution, it is rarely possible to determine accurately these feldspar ratios under the microscope. Therefore the threefold subdivision is generally adequate for modal descriptive purposes, whereas the fivefold subdivision is better adapted for a classification by normative minerals. The ratios 1.00–0.65, 0.65–0.35, and 0.35–0 constitute the basis for a threefold system of classification. The limiting ratios of alkali feldspar to total feldspar in the fivefold classification, as advocated by Johannsen (1932, p. 318–321), are 1.00–0.95, 0.95–0.65, 0.65–0.35, 0.35–0.05, and 0.05–0; these ratios are followed in this report.

CHEMICAL COMPOSITION

About 125 analyses of unweathered granitic rocks in Virginia, North Carolina, South Carolina, and Georgia were published as of 1957 (Alfred and Schroeder, 1948; Clarke, 1900; Darton and Keith, 1898; Day, 1898; Genth, 1862; Herrmann, 1954; Jones, 1909; Kerr, 1875; Laney, 1910; Lewis, 1893; Pegau, 1932; Phalen, 1904; Pogue, 1909; Sloan, 1908; Steidtmann, 1945; Taber, 1913; Watson, 1902, 1904, 1907, 1909, 1910; Watson and Cline, 1913; Watson and Laney, 1906; and Watson and Taber, 1913). In addition to these, the U.S. Geological Survey has made one analysis for W. R. Griffitts, six for W. C. Overstreet (Overstreet, Yates, and Griffitts, 1963b), and nine for the writer. The writer obtained from the owners of quarries nine other analyses, of which two are of granitic rocks known to be monazite bearing and are published herewith.

Many of these analyses are of rocks within the monazite belts, but these rocks are not necessarily all monazite bearing. Chemical analyses of monazite-bearing rocks are acceptable only where samples for thin sections, samples for chemical analysis, and samples panned for their accessory minerals can be taken at essentially identical localities in order to know that the rock contains monazite. Generally, samples of monazite-bearing granitic rocks may be obtained only at localities where unweathered rock is overlain by saprolite. Such localities are relatively scarce. Moreover, unweathered rock is not listed here as monazite bearing unless monazite has been recovered from saprolite essentially at the site of the sample of unweathered rock, or monazite has been recovered from the pulverized fresh rock. Some decisions are difficult. For instance, five samples of monazite-bearing saprolite were panned in an area of granite gneiss between Franklin and Texas, Heard County, Ga.; one chemical analysis of this rock from the Flat Rock quarry, about 3 miles southwest of Franklin, was published by Watson (1902, p. 67). But a sample of saprolite taken close to this quarry lacked monazite. Therefore, this analysis is not included with the 18 analyses of monazite-bearing granitic rocks given in table 1.

Samples I and Q of table 1 are granite gneiss; the remainder are massive granite, though samples A, B, and O have locally primary gneissic habits. Sample C is a pegmatitic phase of samples A and B. Samples A, B, C, D, E, F, I, J, K, L, and O are represented by superior analyses from which norms can be precisely computed. The other seven are deficient in determinations of one or more of the oxides FeO, TiO_2, and P_2O_5. The ratio Fe_2O_3:FeO = 0.398, which was determined from sample F, was applied to analyses G and H; the mean ratio Fe_2O_3:FeO = 0.279 of all the superior analyses was applied to analyses M, N, P, Q, and R. Thus, the values of normative quartz, orthoclase, albite, and anorthite were computed for all samples (tables 2 and 3).

The normative ratio orthoclase:feldspar indicates that most samples are adamellite, but samples F, G, H, I, and Q are monzotonalites. The mean value of the ratio orthoclase:feldspar (table 3) classifies the group as basic adamellite. The mean ratio of anorthite:plagioclase for the group is 0.20 (table 3) corresponding to oligoclase, An_{20}.

TABLE 1.—*Chemical analyses of 18 samples of monazite-bearing granitic rocks from North Carolina, South Carolina, and Georgia*

[N.d., not determined; tr., trace; leaders (---), not reported]

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	Mean
SiO_2	72.62	72.50	73.37	72.26	72.55	73.90	72.9	70.70	70.37	73.32	71.90	71.93	72.56	71.66	68.41	71.10	69.51	69.88	71.75
Al_2O_3	14.79	15.02	14.13	14.85	15.07	14.30	15.5	16.50	16.16	14.51	14.72	14.75	14.81	16.05	15.36	15.70	16.32	16.42	15.28
Fe_2O_3	.19	.33	.22	.21	.41	.35	1.6	2.34	.31	.05	.70	.41	.94	.86	.84	1.17	2.38	1.96	.38
FeO	1.81	1.54	.97	1.24	.71	.88	N.d.	N.d.	1.85	.99	.99	1.27	N.d.	N.d.	2.16	N.d.	N.d.	N.d.	1.27
MgO	.35	.26	.27	.37	.33	.45	.2	.29	.78	.32	.52	.46	.20	.17	1.01	.43	1.28	.36	.45
CaO	2.18	2.24	1.19	1.63	1.60	1.72	1.3	2.96	3.18	1.30	1.61	1.49	1.19	1.07	1.65	2.55	1.84	1.78	1.80
Na_2O	3.33	3.51	2.22	3.98	4.17	4.58	4.6	4.56	4.64	3.27	3.99	3.51	4.94	4.66	3.35	1.53	3.82	4.46	3.84
K_2O	4.00	3.90	6.67	3.97	4.24	2.95	2.8	2.45	1.83	5.13	4.45	5.18	5.30	4.92	5.01	4.12	3.47	5.63	4.22
H_2O+	.21	.14	.41	.40	.15	.16	---	---	.28	.31	.24	.23	.70	1.00	.56	---	---	---	---
H_2O-	.05	.05	.05	.03	.11	.03	---	---	.01	.01	.03	.02	---	---	.05	---	---	---	---
CO_2	.12	.13	.28	.43	.03	.01	---	---	.13	.06	.05	.00	---	---	.00	---	---	---	---
TiO_2	.12	.12	.15	.32	.16	.24	tr.	---	.35	.22	.31	.34	---	---	.74	.40	---	---	---
ZrO_2	.00	.00	.00	.03	.00	.00	tr.	---	---	.00	.00	.01	---	---	.02	---	---	---	---
P_2O_5	.06	.05	.05	.06	.05	.10	---	---	.11	.06	.10	.10	---	---	.38	---	---	---	---
Cl	.01	---	.02	.02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
F	.01	---	.03	.04	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
V_2O_3	---	---	---	---	---	---	tr.	---	---	---	---	---	---	---	---	---	---	---	---
MnO	.04	.03	.01	.02	.02	.01	tr.	---	.04	.05	.03	.02	---	---	.08	.08	---	---	---
CuO	---	---	---	---	---	---	tr.	---	---	---	---	---	---	---	---	---	---	---	---
BaO	---	.05	---	---	.09	.11	tr.	---	---	.05	.11	.05	---	---	.13	---	---	---	---
SrO	---	---	---	---	---	---	tr.	---	---	---	---	---	---	---	---	---	---	---	---
PbO	---	---	---	---	---	---	tr.	---	---	---	---	---	---	---	---	---	---	---	---
GaO	---	---	---	---	---	---	tr.	---	---	---	---	---	---	---	---	---	---	---	---
FeS_2	---	---	---	---	---	---	---	.09	---	---	---	---	---	---	---	---	---	---	---
Loss on ignition	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	.98	1.11	.36	.82
Total	99.89	99.87	100.04	99.86	99.69	99.79	98.9	99.89	100.04	99.65	99.75	99.77	100.64	100.39	99.75	98.06	99.73	100.85	99.81

Sample descriptions

A. Composite sample of Toluca Quartz Monzonite from small quarry at pavement called Acre Rock, 0.7 mile S. 45° W. of Toluca, Cleveland County, N.C. W. C. Overstreet, collector; L. C. Peck, analyst.

B. Composite sample of Toluca Quartz Monzonite from small quarry at pavement called Acre Rock, 0.7 mile S. 45° W. of Toluca, Cleveland County, N.C. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

C. Pegmatitic material from small quarry at pavement called Acre Rock, 0.7 mile S. 45° W. of Toluca, Cleveland County, N.C. W. C. Overstreet, collector; L. C. Peck, analyst.

D. Composite sample of Toluca Quartz Monzonite from small quarry about 1.5 miles west of Hollis, Rutherford County, N.C. W. C. Overstreet, collector; L. C. Peck, analyst.

E. Composite sample of granite from pavement on west side of paved road, about 1.25 miles S. 22° E. of Rolesville, Wake County, N.C. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

F. Pulverized granite from quarry of North Carolina Granite Corp. about 1.0 mile northeast of Mt. Airy, Surry County, N.C. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

G. Pulverized granite from quarry of North Carolina Granite Corp. about 1.0 mile northeast of Mt. Airy, Surry County, N.C. J. P. Frank, President, North Carolina Granite Corp., donor; analyst unknown.

H. Sample of granite from quarry of North Carolina Granite Corp. about 1.0 mile northeast of Mt. Airy, Surry County, N.C. J. V. Lewis, collector; analyst unknown.

I. Sample of pegmatized laminated gneiss from small quarry about 0.6 mile north of Highlands, Macon County, N.C. W. R. Griffitts, collector; Lois Trumbull and Faye Neuerburg, analysts.

J. Composite sample of granite from quarry of Rion Crush Stone Corporation, about 3.0 miles S. 27° W. of Winnsboro Post Office, Fairfield County, S.C. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

K. Composite sample of granite from Blair quarry, about 0.5 mile east-southeast of Blairs Station on Southern Railroad, Fairfield County, S.C. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

L. Composite sample of granite from Liberty quarry (Parker Hunt Co.), about 11.6 miles N. 49° E. of Lexington, Oglethorpe County, Ga. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

M. Sample of granite from Hayne quarry, Stone Mountain, DeKalb County, Ga. W. S. Yeates, collector; R. L. Packard, analyst.

N. Sample of granite from Hayne quarry, Stone Mountain, DeKalb County, Ga., W. S. Yeates, collector; R. L. Packard, analyst.

O. Composite sample of granite from pavement on east side on unpaved road, about 2.0 miles S. 20° E. of Zetella, Spalding County, Ga. J. B. Mertie, Jr., collector; E. J. Tomasi, analyst.

P. Sample of granite from quarry of Tyrone Rock Products Co., about 1.0 mile south of Tyrone, Fayette County, Ga. T. P. Maynard, formerly geologist for Atlantic Coast Line Railroad Co., collector; analyst unknown.

Q. Sample of granite gneiss from old quarry at site of power plant on North Fork Oconee River, at east side of Athens, Clarke County, Ga. T. L. Watson, collector and analyst.

R. Sample of granite from abandoned quarry on northeast side Greenville Creek, 0.7 mile northeast of Greenville, Meriwether County, Ga. T. L. Watson, collector and analyst.

TABLE 2.—*Normative salic minerals in 18 samples of monazite-bearing granitic rocks from North Carolina, South Carolina, and Georgia*

Sample (table 1)	Field No.	Quartz	Orthoclase	Albite	Anorthite	Plagioclase	Feldspar
A	49 Ot 10	31.91	23.66	28.16	9.37	37.53	61.19
B	53 Mt 30	31.36	23.05	29.69	10.02	39.71	62.76
C	49 Ot 15	32.47	39.41	18.62	3.60	22.22	61.63
D	49 Ot 21	30.69	23.44	33.51	4.73	38.24	61.68
E	53 Mt 18	27.96	25.05	35.30	7.58	42.88	67.93
F	53 Mt 47	31.40	17.42	38.76	8.03	46.79	64.21
G	53 Mt 47-A	31.57	16.53	38.92	6.45	45.37	61.90
H	None	26.87	14.47	38.60	14.69	53.29	67.76
I	55 NC 3	27.69	10.80	39.28	14.23	53.51	64.31
J	53 Mt 14	30.99	30.34	27.69	5.76	33.45	63.79
K	53 Mt 16	27.41	26.28	33.78	7.23	41.01	67.29
L	53 Mt 10	27.38	30.62	29.69	6.84	36.53	67.15
M	None	20.86	31.34	41.80	2.59	44.39	75.73
N	None	22.69	29.06	39.44	5.31	44.75	73.81
O	53 Mt 12	24.73	29.62	28.32	5.87	34.19	63.82
P	None	39.89	24.33	12.95	12.66	25.61	49.94
Q	None	26.83	20.49	32.31	9.13	41.44	61.93
R	None	17.05	33.29	37.76	8.12	45.88	79.17
	Mean	28.32	24.96	32.48	7.90	40.38	65.33

TABLE 3.—*Ratios of normative salic minerals in 18 samples of monazite-bearing granitic rocks from North Carolina, South Carolina, and Georgia*

Sample (table 1)	Field No.	Quartz: feldspar	Quartz: orthoclase	Orthoclase: feldspar	Anorthite: plagioclase
A	49 Ot 10	0.52	1.35	0.39	0.25
B	53 Mt 30	.50	1.36	.37	.25
C	49 Ot 15	.53	.82	.64	.16
D	49 Ot 21	.50	1.31	.38	.12
E	53 Mt 18	.41	1.12	.37	.18
F	53 Mt 47	.49	1.80	.27	.17
G	53 Mt 47-A	.51	1.91	.27	.14
H	None	.40	1.86	.21	.28
I	55 NC 3	.43	2.56	.17	.27
J	53 Mt 14	.49	1.02	.48	.17
K	53 Mt 16	.41	1.04	.39	.18
L	53 Mt 10	.41	.89	.46	.19
M	None	.28	.67	.41	.06
N	None	.31	.78	.39	.12
O	53 Mt 12	.39	.84	.46	.17
P	None	.80	1.64	.49	.49
Q	None	.43	1.31	.33	.22
R	None	.22	.51	.42	.18
	Mean	0.45	1.27	0.38	0.20

The normative percentages of apatite, ilmenite, and magnetite may be calculated for 11 samples, but owing partly to inherent inaccuracies in the analyses of the minor elements and partly to the inclusion of TiO_2 and P_2O_5 in other than the normative minerals, these percentages bear little relation to the modal percentages, as determined by panning. For example, the mean values of normative magnetite and ilmenite in these 11 samples are respectively 0.62 and 0.49 percent, whereas the mean modal tenors for all the monazite-bearing rocks of the Southeastern States, as obtained by panning saprolite and unweathered rock, are respectively 0.017 and 0.029 percent. Thus, the amount of normative iron ores (magnetite and ilmenite) is nearly 25 times as large as the observed tenors; some of the difference may be accounted for by loss of magnetite during weathering. The norms also show preponderance of magnetite over ilmenite, whereas in fact the reverse is observed. Apatite is not generally preserved in saprolites, but in these rocks a small part of the P_2O_5 exists in modal monazite.

All but two of the specimens in table 1 contain an excess of Al_2O_3, after allocation to the normative feldspars; hence, 16 rocks show amounts of normative corundum ranging from 0.64 to 4.09 percent, and a mean value of 1.49 percent. Corundum seldom appears in concentrates panned from these rocks.

ACCESSORY MINERALS

The accessory minerals of the granitic rocks have great genetic significance, both with reference to their own origin and the origin of their host rocks. The principal accessory minerals that occur in granitic rocks are ilmenite, magnetite, zircon, rutile, garnet, epidote, apatite, sphene, monazite, xenotime, pyrite, and tourmaline, though sillimanite, kyanite, and staurolite are also present in feldspathic schists of granitic composition. Many of these granitic rocks appear to be of metasedimentary origin and have therefore passed through one or more sedimentary cycles during their long histories. They also have been subjected to dynamic metamorphism and possibly to complete or partial remelting. In the genetic interpretation of such rocks, those accessory minerals which resist metamorphism, remelting, and subsequent weathering and erosion have the highest importance. Attention must be given to the morphological character of these accessory minerals, to their tenors, and to the ratios of these tenors in genetic interpretations.

STABILITY AND GENETIC SIGNIFICANCE

Zircon has much genetic significance because it has a higher melting temperature than any other accessory mineral and is less likely to be modified in partial melting of a rock; it is hard, tough, and highly resistant to mechanical deformation and rupture, and preserves to the greatest degree its original morphology. Zircon is almost immune in temperate climates to chemical alteration, so that its characteristics in fresh rock may be examined in concentrates panned from saprolite. Also, zircon is generally present in granitic rocks, though only as traces in some of them. Panning renders such traces observable. Owing to all these properties, zircon is the most dependable of all the accessory minerals for the recognition of inherited characteristics that bear upon the origin of the host rocks.

Rutile, being an oxide, is also highly resistant to chemical alteration, but it has a lower melting temperature than zircon, is mechanically weaker and more subject to rupture, and is much scarer than zircon in granitic rocks. Hence rutile, though often yielding useful collateral data, is generally less dependable that zircon for the formulation of genetic interpretations.

Monazite and xenotime are mechanically weak minerals, but they are fairly immune to chemical alteration. Locally and rarely a thin veneer of a white unidentified mineral develops on monazite during saprolitization, but it is quickly removed by later erosion. Conclusions regarding the histories of these two minerals are therefore dependent largely on collateral data.

Magnetite and ilmenite, called here the iron ores, may form and reform at much lower temperatures than zircon and rutile, are readily recrystallized, and are more or less altered in saprolitization, though magnetite is more vulnerable than ilmenite. Inherited characteristics from earlier sedimentary or igneous cycles are rarely preserved, but the absolute and relative tenors of these two minerals in the granitic rocks are highly significant for genetic interpretations.

Garnet is not commonplace in ordinary granitic rocks, but if present at all is likely to occur in considerable volume. Some varieties of garnet show little chemical alteration from weathering, but others are almost completely destroyed in saprolitization. Manganese garnets, for example, show generally in saprolite as brownish clots of manganese oxide having cores of spessartite.

Epidote is uncommon in granitic rocks, but where present is also likely to occur in considerable volume. This mineral is generally interpreted as a late component of the accessory minerals and is almost devoid of early genetic implications.

Apatite and pyrite are vulnerable to weathering and are rarely recovered in the panning of saprolites.

The tenors of the iron ores, monazite, xenotime (where recognized), and zircon are invariably stated in the tables given here showing the composition of concentrates, and where possible, the amounts of rutile, garnet, and epidote are also given. The absence of zircon in any of these tabulations is not to be interpreted literally, as almost invariably at least traces of zircon are present.

MINERALOGICAL CRITERIA RELATING TO THE ORIGIN OF GRANITIC ROCKS

The establishment of homogeneity or heterogeneity among the accessory minerals of a granitic rock or group of granitic rocks is of fundamental importance in the application of this method of recognizing the metasedimentary and migmatitic origin of granitic rocks. Seven criteria (table 4) have been formulated for detecting the origin of granitic host rocks on the basis of their accessory minerals.

PRESERVATION OF INHERITED CHARACTERISTICS

The rounding of mineral grains is the most important of inherited characteristics. The presence of rounded accessory minerals, particularly zircon, but including also rutile and monazite, suggests strongly that these were original detrital minerals that have retained their sizes and shapes in the subsequent evolution of the host rock. All such minerals in a granitic rock do not have to be rounded. In fact, metasedimentary of migmatitic origin of the rock is more cogently indicated if some minerals of the same or different species are rounded and

TABLE 4.—*Mineralogical criteria relating to the origin of the source rock*

1. Preservation of inherited characteristics in one or more accessory minerals.
2. Variations in the color, size, crystallographic habit, degree of rounding, and other physical properties of any accessory mineral in a single sample.
3. Unusually high or low tenors for all accessory minerals.
4. Unusually high or low tenors for one or two accessory minerals in a single sample, with the possible exclusion of all others.
5. Anomalous amounts and composition of the iron ores, the predominance of ilmenite over magnetite, the alteration of ilmenite to leucoxene, or the absence of all iron ores.
6. Marked variations in the amount and character of one or more accessory minerals in multiple samples taken either along or across the regional trend of a granitic formation.
7. The presence of minerals such as corundum that are not ordinarily present in granitic rocks.

others are quite unrounded. The establishment of heterogeneity in the accessory minerals merely proves that the rock is not truly magmatic. It may be semimagmatic containing unmelted residues of preexisting detrital minerals; it may be a paragneiss or even an orthogneiss, if the latter was incompletely melted in its magmatic stage; or it may be a migmatitic rock, produced by the granitization of an older sedimentary rock. Rounding alone, moreover, does not necessarily indicate metasedimentary or migmatitic origin, as ellipsoidal, ovoidal, or spheroidal outlines may be produced by magmatic resorption. But this process is likely to yield some recognizable reentrant cavities, analogous to the corroded phenocrysts of intratelluric quartz commonly present in rhyolite porphyry.

VARIATIONS IN PHYSICAL PROPERTIES

Variations in the color, size, crystallographic habit, degree of rounding, and other physical properties of one species of accessory mineral in a sample are strongly suggestive of detrital provenance and therefore of the metasedimentary or migmatic origin of the granitic rock. A single sample of granitic gneiss may contain zircons of different color, sizes, number of ferromagnetic inclusions, or crystallographic habit. Some of the zircons may be rounded, others unrounded, and there may be a mixture of slender elongate colorless prisms, shorter and thicker prisms of light amber color, and largely deeply colored or almost opaque crystals. Any of these variants may be decisive factors, one or two overbalancing the absence of the others. Thus, a metasedimentary or migmatic origin of the host rock may be inferred even if all the zircons are unrounded.

Another phenomenon that may indicate metasedimentary or migmatic origin of the rock, though also otherwise explainable, is the existence of accessory minerals, notably zircon, that consist of well-rounded cores bounded by recrystallized peripheral zones. If the cores and shells have different colors, the evidence of a detrital provenance is strengthened. Obviously the peripheral shells grew at a later stage in the evolution of the host rock, either by dynamic recrystallization, rheomorphic melting, migmatitic action, or other process. The inference is that the original host rock was probably a sediment of metasediment.

The crystalline structure of the zircon is partly or wholly destroyed under certain conditions by long exposure to alpha radiation, presumed to have originated in small amounts of contained thorium or uranium. This effect is called metamictization. It produces an amorphous or pseudoamorphous state, accompanied by a decrease in density, decrease in the mean index of refraction, and increase in magnetic characteristics. Metamict zircon can be separated magnetically from nonmetamict zircon. If crystals of zircon are of different ages or if they contain different amounts of included radioactive elements, they may possibly show different degrees of metamictness, ranging from crystals that are paramagnetic to those that are quite nonmagnetic. Such heterogeneity of zircon in a concentrate indicates that the host rock is of nonmagmatic origin and is presumably of metasedimentary or possibly of migmatitic origin. The choice between these two alternatives must be based upon other collateral criteria.

The proposal has been made that by measurement of the degree of metamictness of metamict zircon the age of the host rock can be determined (Kulp, Volchok, and Holland, 1952). Uncertainty exists whether metamictness is produced by alpha radiation that exceeds some minimum value, or whether it is produced cumulatively by weaker radiation acting over a long period of time. Most lower Precambrian granitic rocks contain zircon that appears not to be metamict, and certainly the proportion of recognizably damaged zircon in granitic rocks exclusive of pegmatites, and in derived alluvial deposits, is small. These facts suggest that there may be a threshold of alpha activity below which zircon is not appreciably damaged and that this method is not dependable for determination of the age of an individual crystal of zircon or of its host rock. Obviously this method, or any of the several methods dependent upon the determinations of isotopic ratios in radiogenic elements, will be worthless if applied to bulk samples of zircon or other accessory minerals separated from granitic rocks of undetermined origin. Such methods may be applied only to rocks of proved magmatic origin.

UNUSUAL TENOR FOR ALL ACCESSORY MINERALS

The amount of accessory minerals in the granitic rocks of the Southeastern States is varied. The mean tenor of 677 samples was found to be 0.14 percent using cumulative means, and the mean value did not change appreciably after the first third of the samples had been summed and averaged. Variations of considerable magnitude from this mean value exist, and these may be differently interpreted in attempting to understand the origin of a granitic rock. For example, a large increment in the amount of accessory minerals and a correspondingly large increase in the amount of magnetite suggests, though it does not prove, a magmatic origin. A large increment in the amount of accessory minerals and a correspondingly large increase in ilmenite accompanied by a small tenor in magnetite suggests some kind of an alluvial concentration and therefore a metasedimentary rock. A large volume of accessory minerals containing little or no iron ores is still better evidence of metasedimentary rock. On the other hand, a very low tenor in total accessory minerals, approaching zero, may indicate a type of sedimentary origin similar to some of the Pleistocene deposits of the Atlantic coastal plain, where the tenor in accessory minerals may be as low as 0.02 percent.

An outstanding aberrancy was found in the tenors of accessory minerals in the concentrates recovered from monazite-bearing granitic rocks. Data obtained by panning 246 samples of such rocks indicate that the mean tenor of total accessory minerals is 0.072 percent, as compared with 0.18 percent for the monazite-free rocks, and 0.14 percent for all the granitic rocks in the Southeastern States. As the iron ores constitute a major part of most concentrates, a tenor of 0.072 percent for all accessory minerals indicates low tenors in iron ores and suggests very active or long-continued weathering during one or more early sedimentary cycles in the history of the monazite-bearing granitic rocks.

TABLE 5.—*Mean tenors, in percent, of principal accessory minerals in monazite-bearing granitic rocks in the Southeastern Atlantic States*

Accessory minerals	Bedrock	Concentrates
Total accessory minerals	0.072	([1])
Magnetite	.017	12.9
Ilmenite	.029	29.1
Monazite	.0047	21.9
Zircon	.0022	11.3
Rutile	.0008	1.7

[1] Not applicable.

UNUSUAL TENOR FOR ONE OR TWO ACCESSORY MINERALS

Unusually high or low tenors for one or two accessory minerals in a single sample must be judged from some standard. Such regional standards have not been determined for all the granitic rocks, but can be stated for magnetite, ilmenite, monazite, zircon, and rutile in the monazite-bearing granitic rocks (table 5). Two other significant tenors are 0.028 percent, the amount of magnetite in bedrock, and 29.5 percent, the amount of magnetite in concentrates, for all the granitic rocks of the Southeastern States, regardless of whether they do or do not contain monazite.

No close correlation necessarily exists between the mean tenor of any one mineral in the concentrates and its tenor in bedrock, as the values recorded for the concentrates depend upon factors other than abundance alone, such as the tenors of the other accessory minerals, the variable effects of chemical weathering on accessory minerals having different degrees of solubility, and the volume of quartz and other minerals of low density that are not completely eliminated in preparing the concentrates. Iron ores are commonly the predominant accessory minerals, and a large volume of these or of quartz and other low-density minerals produces correspondingly lower percentages of the other accessory minerals in the concentrates. Rare large amounts of minerals like garnet, epidote, or sillimanite produce the same result. The percentages in bedrock (table 5), however, were computed by multiplying the percentages in the concentrates by the total percentages of accessory minerals in bedrock, thereby eliminating these several inconsistencies. The tabulated percentages of monazite and xenotime and the percentages of the other accessory minerals in bedrock which may be obtained from the tables are the most significant values. Marked variations of the tenors of minerals in the concentrates usually suggest genetic differences which, however, are subject to corroboration and refinement by comparison with bedrock tenors. Thus, the proportions of the heavy minerals reflect the geologic cycles undergone by the granitic rock, and the relative abundance of these minerals in concentrates even one or two generations farther along in the geologic cycle, such as concentrates from fluviatile sediments, are of use in interpreting previous geologic cycles (Overstreet and others, 1968, p. 11–16).

The mean tenors of ilmenite in bedrock and in the concentrates for all the granitic rocks of the Southeastern Atlantic States have not been accurately determined, but a partial summation leads to the belief that these two values are appreciably greater respectively than the 0.029 percent and 29.1 percent of ilmenite (table 5) which apply to the monazite-bearing rocks. The mean magnetite:ilmenite ratio for the bedrock tenors of the monazite-bearing rocks is about 1:1.9, but this ratio for all the southeastern granitic rocks is believed to lie somewhere between 1:1 and 1:1.5. Thus the total iron ores for the monazite-bearing rocks is 0.046 percent of bedrock; for all the southeastern granitic rocks, this tenor may be as great as 0.070 percent of bedrock. For magmatic rocks alone, the magnetite:ilmenite ratio is closer to 1:1.

Iron ores are the principal accessory minerals, and the lower percentage of the total accessory minerals and the iron ores, particularly magnetite, in the monazite-bearing granitic rocks is interpreted to mean that a greater amount of such rocks are of metasedimentary origin than the southeastern granitic rocks as a group. The comparative values given above are also interpreted to mean that all the southeastern granitic rocks include a significant volume of metasedimentary rocks, though not as great as the monazite-bearing granitic rocks. These interpretations are further amplified in the later discussion of the iron ores of the monazite-bearing rocks.

An unusual tenor for one or two accessory minerals may have considerable genetic significance. Some sets of concentrates consist entirely of zircon, or monazite, or rarely of rutile, and few if any iron ores. Others consist almost entirely of ilmenite and one other mineral, such as monazite or zircon. The final assemblage of accessory minerals will depend primarily upon the minerals in the original primitive eroded source in crystalline rocks, and secondarily, but to a high degree, upon the ensuing history of the resultant sedimentary rocks. An unusual tenor for one or two accessory minerals in bedrock suggests a metasedimentary origin that included a sedimentary cycle or cycles during which the less resistant accessory minerals were destroyed by chemical action or mechanical abrasion. The presence of only one of the resistant minerals, without any others, suggests further that only one such resistant mineral was present in the original source rocks from which the metasedimentary rock was derived. This in turn suggests the formation of one metasedimentary rock from the erosion of an earlier one.

ANOMALOUS AMOUNTS AND COMPOSITION OF THE IRON ORES

The fifth criterion for metasedimentary or migmatitic origin of granitic rocks, as identified by the panned accessory minerals, is the character and plenitude of the iron ores, their reaction to weathering and erosion in any sedimentary cycles through which they may have passed, and the bearing of these facts upon the origin and history of the host rocks. Magnetite and ilmenite are the principal iron ores found in the granitic rocks and are also commonly the principal accessory minerals, though exceptions exist.

Most granitic rocks are believed by the writer to have originated directly or indirectly from sediments derived from the original crust of the earth, rather than by direct remelting of parts of the crust. The processes involved in these transformations are thought to be dynamic metamorphism, remelting of older rocks of sedimentary or igneous origin, migmatism, or combinations of these. This interpretation implies the existence of at least one, and possibly several, antecedent sedimentary cycles in the history of many granitic rocks, including possibly one or more cycles of surficial alteration. Owing to the enormous span of Precambrian time, it is probable that most of this earlier alteration took place then; the geologic history of the granitic gneiss of the Southeastern States likewise points to this conclusion. Too little is known, however, of the condition of the atmosphere, hydrosphere, and lithosphere in Precambrian time to permit the writer to draw definite conclusions, but in the light of present geomorphic processes, the conclusion seems warranted that ancient sedimentary cycles may have been effective in altering the character and proportions of the original accessory magnetite and ilmenite.

The changes in the iron ores that resulted from saprolitization and subsequent erosion of granitic host rocks in the Southeastern States between Cretaceous and Holocene time, particularly Pleistocene to Holocene time, are better known. Magnetite is not entirely destroyed by saprolitization, but gen-

TABLE 6.—*Tenors, in percent, of total accessory minerals, magnetite, and ilmenite in 20 selected granitic rocks from North Carolina, South Carolina, and Georgia*

[Leaders (---), absent]

Field No.	Source	Accessories in bedrock	Magnetite in bedrock	Ilmenite in bedrock	Magnetite in concentrates	Ilmenite in concentrates
		North Carolina				
47 Mt 17	Saprolite[1]	0.067	0.057	0.009	84.3	12.9
48 Mt 2	do	.14	---	.063	---	44.9
49 Mt 119	do[1]	2.45	1.25	.92	51.3	37.7
49 Mt 182	do	.12	.016	.071	12.5	58.1
50 Mt 164	do	.31	.26	.033	83.0	10.6
50 Mt 274	do	.05	Trace	.044	Trace	82.4
53 Mt 17	Fresh rock	.11	.017	.085	14.7	75.2
		South Carolina				
51 Mt 105	Saprolite	0.13	0.021	0.10	15.9	78.0
51 Mt 110	do	.14	.076	.06	52.8	41.5
51 Mt 126	Fresh rock[1]	.31	.15	.13	48.8	41.8
51 Mt 140	Saprolite	.10	.04	.053	40.1	52.6
53 Mt 13	Fresh rock	.086	.07	.011	82.2	12.9
53 Mt 15	do	.11	.053	.046	48.1	41.8
		Georgia				
49 Mt 15	Saprolite	0.36	---	0.28	---	78.3
49 Mt 27	do[1]	.15	Trace	.12	Trace	78.2
50 Mt 68	do	.17	0.04	.11	23.6	65.2
50 Mt 70	do	.54	.31	.21	56.9	38.8
52 Mt 154	do	.063	.021	.037	34.0	59.2
53 Mt 9	Fresh rock	.038	.012	.021	32.8	54.9
53 Mt 11	do	.41	.029	.22	7.1	53.1
Mean		0.29	0.12	0.13	34.4	50.9

[1] Does not contain monazite.

Localities of the monazite-bearing samples are shown on plate 1. The locaities of the monazite-free samples are:

47 Mt 17 Saprolite of Henderson Granite Gneiss, atop northwest side of Balfour quarry about 3.5 miles N 15° W. of Hendersonville, Henderson County, N.C.

49 Mt 119 Saprolite of a quartz-bearing syenite from pit on west side of U.S. Route 29, about 3.5 miles S. 20° W. of Concord, Cabbarus County, N.C.

51 Mt 126 Powdered granite from Anderson quarry, about 9.4 miles S. 67½° W. of Winnsboro quarry, Fairfield County, S.C. Sample taken from base of milling machine of Phillips Granite Co., adjacent to Anderson quarry.

49 Mt 27 Saprolite of granitic rock from west side of State Route 77, about 2.6 miles by road south of Elberton, Elbert County, Ga.

erally shows definite oxidation. The crystals from saprolite are inclined to be brownish and dull and some show solutional reentrant angles. They also crumble readily and are specially vulnerable to destruction during subsequent erosion and transportation. Ilmenite derived from saprolite gives little outward appearance of alteration, and the crystal faces are generally black and shiny. Nevertheless, incipient alteration has taken place. Because of these different styles and degrees of alteration, detrital magnetite has disappeared almost entirely from the present and elevated beaches of Florida, and the iron ores in beach sands are essentially ilmenite and minerals derived from ilmenite. Thus even ilmenite is eventually much altered, but the degree of alteration cannot be predicted on any presumptive basis. Certainly the relative degrees of alteration of magnetite and ilmenite do not necessarily hold in cold climates such as those of New England and Alaska; still less may any definite generalization about alteration be extrapolated backward into geologic time. It is fair to suppose, however, that processes akin to saprolitization have at other times been effective, even during the Precambrian.

The general ratio of magnetite to ilmenite in truly magmatic granitic rocks in the Southeastern States ranges from 1.5:1 to 1:1.5 though rarely this ratio may considerably exceed 1.5:1. The postulated prevalence of sedimentary cycles might thus be expected to produce a reduced ratio in granitic rocks of metasedimentary origin. Other changes might be recognizable in the chemical composition of the ilmenite. Among the monazite-bearing granitic rocks of the Southeastern States the general magnetite:ilmenite ratio has been found to be approximately 1:1.8. Moreover, 57 percent of these rocks contain no magnetite, 12 percent contain no ilmenite, and 9 percent contain neither magnetite nor ilmenite. These numerical data, obtained from panning 246 samples, indicate clearly an impoverishment in magnetite with regard to ilmenite. The reverse argument might also be used to prove the metasedimentary origin of rocks having these characteristics, and this in fact is the principal thesis implied in the fifth criterion for the metasedimentary origin of granitic rocks.

The bearing that the magnetite:ilmenite ratios and the composition of ilmenite have on interpretations of the origin of granitic rocks is illustrated by 20 concentrates panned from saprolite and unweathered rock and two concentrates from beach sand (tables 6–10). Sixteen of the samples are from monazite-bearing granitic rocks of North Carolina, South Carolina, and Georgia (Mertie, 1978), and four are from rocks that contain no monazite. Two were taken from commercial concentrates recovered in ilmenite placer mines in Florida. The total amounts of accessory minerals separated from bedrock, including both saprolite and unweathered rock, the tenors of magnetite and ilmenite in bedrock, and the tenors of magnetite and ilmenite in the panned concentrates are given in table 6. Table 7 shows analyses for major oxides in 20 samples of ilmenite from bedrock and two samples from Florida placers. Semiquantitative spectrographic analyses for minor elements in nine samples are listed in table 8, and the mineral composition of 10 samples, as determined by X-ray diffraction, is given in table 9. Ten chemical analyses are listed in table 10 as five pairs; each pair was taken from unweathered rock and saprolite at virtually identical localities.

TABLE 7.—*Analyses, in percent, of 22 samples of ilmenite from North Carolina, South Carolina, Georgia, and Florida*

[Analyses by L. N. Tarrant and J. I. Dinnin, U.S. Geological Survey]

Field No.	TiO_2	FeO	MgO	MnO	Fe_2O_3
North Carolina					
47 Mt 17	31.50	21.21	0.01	2.74	44.54
48 Mt 2	54.10	40.59	.23	.52	4.56
49 Mt 119	45.13	27.56	.24	3.49	23.58
49 Mt 182	23.08	15.53	.01	.97	60.41
50 Mt 164	52.92	4.64	.00	3.96	38.48
50 Mt 274	50.70	18.59	.00	3.26	27.45
53 Mt 17	19.27	14.24	.03	.96	65.50
South Carolina					
51 Mt 105	47.24	26.90	0.02	7.97	17.87
51 Mt 110	48.27	26.40	.01	8.30	17.02
51 Mt 126	46.73	42.18	1.32	2.97	6.80
51 Mt 140	27.34	14.39	.01	1.41	56.85
53 Mt 13	50.08	34.10	.06	8.27	7.49
53 Mt 15	26.32	15.48	.04	1.44	56.72
Georgia					
49 Mt 15	51.85	32.80	0.05	4.48	10.82
49 Mt 27	30.42	8.31	.01	1.27	59.99
50 Mt 68	27.26	18.26	.00	2.27	52.21
50 Mt 70	37.86	18.93	.01	1.67	41.53
52 Mt 154	46.18	25.24	.01	1.75	26.82
53 Mt 9	42.66	31.07	.02	1.64	24.61
53 Mt 11	47.97	34.91	.11	4.17	12.84
Mean	40.34	23.57	0.11	3.17	32.80
Florida					
45 Mt 18	61.59	9.16	0.09	1.68	27.48
48 Mt 103	68.88	1.92	.03	.64	28.53
Mean	65.23	5.54	0.06	1.16	28.00

Localities of placer ilmenite samples from Florida

45 Mt 18 Commercial grade of ilmenite separated from Pleistocene littoral sands, about 54 feet above sea level, at mining plant of National Lead Co., about 6 miles east of South Jacksonville, Duval County, Fla.

48 Mt 103 Commercial grade of ilmenite separated from Pleistocene littoral sands, about 180 feet above sea level, at mining plant of E. I. DuPont de Nemours Co., about 5 miles east-southeast of Starke, Clay County, Fla.

The mean tenor of all the accessory minerals in the rocks from which these 20 samples were taken is 0.29 percent (table 6), whereas the mean regional tenor is 0.14 percent. The mean tenors of magnetite in bedrock and in the concentrates are respectively 0.12 and 34.4 percent, as compared with the corresponding regional tenors of 0.028 and 29.5 percent. The percentage of ilmenite in the concentrates and in bedrock for these 20 samples cannot be compared with corresponding regional averages for all the granitic rocks, as the regional averages have not been determined. But 16 of these 20 samples are monazite bearing, and comparable data are available for all the monazite-bearing rocks of the region. The tenors of all accessory minerals in bedrock, magnetite and ilmenite in bedrock, and magnetite and ilmenite in the concentrates for these 16 samples are respectively 0.18, 0.059, 0.090, 30.9, and 53.0 percent. The corresponding regional tenors for all monazite-bearing rocks of the Southeastern Atlantic States are respectively 0.072, 0.017, 0.029, 12.9 and 29.1 percent (table 5). These 16 samples have 2 to 3 times as many accessory minerals and iron ores as the average of such rocks. This disparity, insofar as tenors in bedrock are concerned, exists even between the 16 monazite-bearing samples and the total 20 samples. Most of the monazite-bearing granitic rocks of the region are thought by the writer to be metasedimentary in origin. The differences cited above may be interpreted as losses in iron ores during one or more ancient sedimentary cycles.

Samples 49 Mt 119, 50 Mt 164, 51 Mt 110 (53 Mt 13), 51 Mt 126, 51 Mt 140 (53 Mt 15), 50 Mt 70, 52 Mt 154 (53 Mt 9) are of probable magmatic or migmatitic origin. The mean tenors of magnetite and ilmenite in these samples are respectively 53.0 and 39.2 percent and have a mean magnetite:ilmenite ratio of about 1.4:1 These data suggest that the magnetite:ilmenite ratios are relatively high in

TABLE 8.—*Semiquantitative spectrographic analyses, in percent, of 9 samples of ilmenite from North Carolina, South Carolina, Georgia, and Florida*

[0, not detected. Looked for but not found: Cu, Ag, Au, Hg, Pd, Ir, Pt, Mo, W, Ge, As, Sb, Bi, Zn, Cd, Tl, Co, Ni, Na, P, B. The presence of Ti and Mn interferes with the determination of Cu. The presence of Fe interferes with the determination of Mo at concentrations of 0.01 percent or less. The presence of Ti interferes with the determination of Zn at concentrations of 0.1 percent or less. Analyses by J. D. Fletcher, U.S. Geological Survey.]

Field No.	Source	Be	Ca	Cr	Ga	La	Nb	Pb	Sc	Sn	Sr	Th	V	Y	Yb	Zr
							North Carolina									
49 Mt 182	Saprolite	0	0.0X	0.000X	0.00X	0.0X	0.0X	0.00X	0.00X	0.00X	0.000X	0	0.X	0.00X	0.00X	0.0X
53 Mt 17	Fresh rock	0.000X	.0X	.00X	.00X	.00X	.0X	.00X	.00X	.00X	.000X	0	.X	.0X	.00X	.0X
							South Carolina									
51 Mt 100	Saprolite	0	0.00X	0.000X	0	0.X	0.X	0.00X	0.00X	0.00X	0.000X	0	0.0X	0.0X	0.00X	0.0X
53 Mt 13	Fresh rock	0	.X	.000X	0	.X	.X	.0X	.0X	.00X	0.000X	0.0X	.0X	.0X	.00X	.0X
53 Mt 15	do	0	.X	.00X	0.00X	.00X	.0X	.00X	.00X	.00X	.00X	0	.X	.00X	.000X	.0X
							Georgia									
53 Mt 9	Fresh rock	0	X	0.000X	0	0.0X	0.0X	0.00X	0.00X	0.00X	0.000X	0	0.0X	0.00X	0.000X	0.0X
53 Mt 11	do	0	.X	.000X	0	.0X	.0X	.00X	.00X	.00X	.000X	0	.0X	.00X	.000X	.0X
							Florida									
45 Mt 18	Placer	0	0.00X	0.0X	0.00X	0	0.0X	0.0X	0.00X	0.00X	0.00X	0	0.0X	0	0.000X	0
48 Mt 103	do	0	.00X	.0X	.0X	0	.0X	.0X	.00X	.00X	.00X	0	.0X	0	0	0

TABLE 9.—*X-ray diffraction studies of the mineralogical compostion of 10 separates having the physical properties of ilmenite in concentrates from North Carolina, South Carolina, and Georgia*

[D, dominant; P, present; A, absent. Analyses by Eric Force, U.S. Geological Survey]

Field No.	Source	Ilmenite	Magnetite	Hematite	Goethite	Rutile
			North Carolina			
53 Mt 17	Fresh rock	P	P	D	A	A
49 Mt 182	Saprolite	P	P	D	A	A
			South Carolina			
53 Mt 13	Fresh rock	D	P	A	A	A
51 Mt 110	Saprolite	D	A	A	A	A
53 Mt 15	Fresh rock	P	P	D	A	P
51 Mt 140	Saprolite	P	A	D	P	A
			Georgia			
53 Mt 11	Fresh rock	D	A	P	A	P
49 Mt 15	Saprolite	D	A	A	A	A
53 Mt 9	Fresh rock	D	A	P	A	P
52 Mt 154	Saprolite	D	A	P	A	P

TABLE 10.—*Comparison of analyses of ilmenite from unweathered rock and saprolite, North Carolina, South Carolina, and Georgia*

[+, gain, and —, loss, of elements as a result of weathering]

Field No.	Source	TiO_2	FeO	MgO	MnO	Fe_2O_3
53 Mt 17	Unweathered rock	19.27	14.24	0.03	0.96	65.50
49 Mt 182	Saprolite	23.08	15.53	.01	.97	60.41
Differences		+3.81	+1.29	—.02	+.01	—5.09
53 Mt 13	Unweathered rock	50.05	34.10	0.06	8.27	7.49
51 Mt 110	Saprolite	48.27	26.40	.01	8.30	17.02
Differences		—1.78	—7.70	—.05	+.03	+9.53
53 Mt 15	Unweathered rock	26.32	15.48	0.04	1.44	56.72
51 Mt 140	Saprolite	27,34	14.39	.01	1.41	56.85
Differences		+1.02	—1.09	—.03	—.03	+0.13
53 Mt 11	Unweathered rock	47.97	34.91	0.11	4.17	12.84
49 Mt 15	Saprolite	51.85	32.80	.05	4.48	10.82
Differences		+3.88	—2.11	—.06	+.31	—2.02
53 Mt 9	Unweathered rock	42.66	31.07	0.02	1.64	24.61
52 Mt 154	Saprolite	46.18	25.24	.01	1.75	26.82
Differences		+3.52	—5.83	—.01	+.11	+2.21
Mean differences		+2.09	—3.09	—.02	+.08	+.95

magmatic and migmatitic granitic rocks and low in metasedimentary rocks.

Magmatic granitic rocks are thought by the writer mainly to be remelts of preexisting metasedimentary and metaigneous rocks, or of mixtures of these. If magmatic granitic rocks have relatively high magnetite:ilmenite ratios, it follows that in melting and recyrstallization of metasedimentary rocks a new generation of magnetite was developed from iron that preexisted as ilmenite and other iron-bearing minerals. Remelted metasedimentary rocks should therefore have lower overall tenors in iron ores than magmatic rocks derived from preexisting igneous rocks that never passed through a sedimentary cycle. This inference appears generally to be true. It therefore constitutes one line of evidence favoring the interpretation that most of the magmatic granitic rocks in the Southeastern States are in fact remelted rocks of sedimentary origin.

The composition of ilmenite has also been cited as a criterion that may bear upon the origin and subsequent history of the iron ores. The analyzed samples of ilmenite (tables 7–10) may be utilized to test this hypothesis. The samples of ilmenite from saprolite and unweathered rock were separated magnetically from the other minerals of the panned concentrates, using the field procedures for separation previously described. Contamination with other minerals having about the same magnetic susceptibility as ilmenite was reduced by avoiding concentrates that contained epidote, garnet, or xenotime. Examination of the samples by hand spectroscope showed exceedingly low tenors in xenotime and monazite, an observation confirmed by the semiquantitative spectrographic analyses (table 8) that disclosed thorium to be absent or very sparse and the rare earths to be sparse.

A source of error in the chemical analyses (table 7) that is unavoidable in the field procedure used for separation of minerals having the magnetic susceptibility of ilmenite is the presence of grains composed of two or more intergrown minerals producing an aggregate susceptibility equivalent to ilmenite. That this is a factor, indeed an important factor, is shown by the results of X-ray diffraction studies of the powdered ilmenite separates (table 9). Ilmenite is the dominant mineral in three of the five pairs of concentrates representing unweathered rock and saprolite from the same general locality. Hematite intergrown with the ilmenite is the dominant mineral phase in two pairs. Some magnetite is present in the ilmenite from both unweathered rock and saprolite in the pair from North Carolina, but in the pairs from South Carolina the magnetite has disappeared in the grains of ilmenite from saprolite though it is intergrown with ilmenite from unweathered rock. Magnetite is not present in the ilmenite from Georgia. The other intergrown minerals noted by X-ray diffraction are goethite and rutile (table 9). The goethite is evidently a weathering product in one sample from South Carolina. The distribution of rutile is particularly puzzling; it was noted in ilmenite from fresh rock at one locality in South Carolina and both localities in Georgia. However, rutile was absent in the ilmenite from saprolite in the sample from South Carolina and one of the samples from Georgia. Had the rutile been formed by the weathering of ilmenite, it should appear preferentially in the ilmenite samples that came from saprolite. Possibly its absence in two samples of saprolite is the result of slight differences between the original composition of the ilmenite at the sources for the samples of fresh rock and saprolite, and that some, at least, of the rutile is an original component of the rock. The hematite also may be an original component intergrown with ilmenite in the source rocks, because in those ilmenite grains where hematite is a dominant component, the hematite is present in material from unweathered rock as well as saprolite, and at one locality in Georgia, hematite is actually absent from the material from saprolite.

The results of the spectrographic analyses (table 8) were interpreted to show that the ilmenite from saprolite tends to be depleted in beryllium and calcium compared to ilmenite from unweathered rock. Ilmenite from beach-sand deposits is depleted in beryllium, calcium, lanthanum, yttrium, ytterbium, and zirconium compared to the ilmenite from fresh rock and saprolite. The ilmenite from the beach placers also has undergone residual enrichment in chromium, lead, and strontium compared to the ilmenite from fresh rock and saprolite.

The results of the chemical analyses from major oxides in these magnetically separated ilmenite samples (table 7) show some unusual and anomalous characteristics, which appear to relate both to the complex mineralogical composition of these ilmenite samples (table 9) and to degree of weathering. The oxides do not approach closely to the theoretical composition of ilmenite which is $FeO = 47.35$ percent and $TiO_2 = 52.65$ percent. The tenor of FeO in samples from bedrock is uniformly less than that of theoretical ilmenite, and the mean tenor of FeO is only half the theoretical value. Some Fe_2O_3 is reported in most published analyses of ilmenite (Palache, Berman, and Frondel, 1944, p. 537) but the mean value for Fe_2O_3 in these published analyses is substantially less than the mean value of 32.80 percent in table 7. Similarly, with two exceptions, the tenor of TiO_2 is less than that of theoretical ilmenite, and the mean tenor is only three-fourths as great.

Evidently the presence of intergrown hematite in the grains of ilmenite accounts for an appreciable part of the excess Fe_2O_3. For example, the maximum percentage of Fe_2O_3 given in table 7 is 65.50 percent for sample 53 Mt 17 taken from unweathered rock in North Carolina. X-ray diffraction studies of this sample disclosed that it consists dominantly of hematite (table 9). Likewise, its matching sample from saprolite, 49 Mt 182, consists dominantly of hematite (table 9), and was found to contain 60.41 percent of Fe_2O_3. The pair of ilmenite samples from South Carolina representing unweathered rock (53 Mt 15) and saprolite (51 Mt 140) and having high values for Fe_2O_3 of 56.72 and 56.85 percent respectively (table 7), likewise are dominated by intergrown hematite (table 9).

These four samples of intergrown ilmenite and hematite having 56.72 percent or more of Fe_2O_3 also have the lowest values for TiO_2 in table 7, from 19.27 to 27.34 percent TiO_2. Several other samples in table 7 are lean in TiO_2 and rich in Fe_2O_3 (47 Mt 17; 49 Mt 27; 50 Mt 68). Doubtless they also are hematite rich, but X-ray data are lacking.

Among the three pairs of samples in table 9 in which ilmenite is dominant, as shown by X-ray diffraction analysis, the content of TiO_2 ranges from 42.66 to 51.85 percent (tables 7 and 9), the content of Fe_2O_3 is from 7.49 to 26.82 percent, and the content of FeO is from 25.24 to 34.91 percent. None of these analyses conforms closely to the theoretical composition of ilmenite, nor do they reflect compositions that would be expected to be produced by the weathering of theoretical ilmenite, except for their tenors in TiO_2, which increase in the ilmenite samples from saprolite as compared to the abundances found for ilmenite from equivalent unweathered rocks (table 19).

The effects of weathering during the formation of saprolite are shown in table 10. With one exception, the differences between the analyses of ilmenite from unweathered rock and those from derived saprolite show small but significant gains in TiO_2, losses in FeO, gains in MnO, and equivocal gains and losses in Fe_2O_3, having a mean average gain of small magnitude. The changes in FeO and Fe_2O_3 correspond in kind, though not necessarily in magnitude, with predictable changes caused by weathering, but mainly they reflect changes in the amount of intergrown hematite. The increments in TiO_2, FeO, and Fe_2O_3 likewise conform in character but differ greatly in magnitude from those shown in table 7 for the ilmenite from Florida, which is extremely weathered and has been partly altered to leucoxene, a process that actually begins in saprolitization with the increase in TiO_2.

The fifth criterion of metasedimentary or migmatitic origin of granitic rocks has been shown to depend upon the character and relative plenitude of the iron ores and upon the chemical composition of ilmenite, but some equivocal results were found. In general, however, magnetite:ilmenite ratios in excess of 1:1.5 suggest the presence of magmatic or migmatitic rocks, and low ratios extending downward to zero indicate the existence of metasedimentary rocks. Some of the chemical analyses of ilmenite are not completely understandable, even in terms of intergrown minerals, but tenors of FeO that are far below the theoretical tenor for ilmenite, and high tenors of Fe_2O_3, reflecting the presence of included hematite, are interpreted here as evidence that the granitic rocks have passed through one or more sedimentary cycles in their history. The excess of Fe_2O_3 as compared with that provided by available ferrous iron is interpreted as original Fe_2O_3 in hematite in the original ilmenite.

REGIONAL VARIATION OF ACCESSORY MINERALS AND PETROGRAPHICALLY ANOMALOUS MINERALS

The sixth criterion for the metasedimentary or migmatitic origin of granitic rocks, the regional variation in the suite of accessory minerals, would occur to any geologist familiar with placer deposits. For example, the tenor of a placer changes laterally and longitudinally to a marked degree, and at some gold placer mines even the fineness of the gold varies in the same way. The concentrates from placers likewise range laterally and longitudinally in plenitude and character. Variations of this sort, found in granitic gneissic rocks, afford the basis for the sixth criterion.

The seventh criterion, petrographically anomalous minerals such as rounded grains of corundum in concentrates from granitic saprolite, is so obvious as to require no discussion. An example of its application appears below in a description of samples 54 Mt 57 and 54 Mt 58 from the western Piedmont monazite belt in Henry County, Va.

MONAZITE AND XENOTIME

Monazite and its counterpart xenotime are orthophosphates of the rare earths, containing numerous substitutions of other elements. The general crystallographic, optical, and other physical constants of monazite and xenotime are well known and tabulated, but their properties range within considerable limits as a result of inconstant composition. Variations in density, optical orientation, indices of refraction, optic angle, pleochroism, and solubility in acids are well shown in the compilation by Tröger (1952, p. 33–34). Owing to this indeterminate inconstancy, little correlative work relating chemical composition to physical properties has yet been done.

Monazite in the granite and granitic gneiss of the Southeastern States is a weakly magnetic, brittle, monoclinic mineral which occurs as small, nearly equant yellowish grains that may be prismatically elongate or tabular. Commonly these crystals are resinous and translucent, but in saprolite they may be iron stained and opaque as noted by Molloy (1959) and Baker (1962). Some monazite grains from the saprolite of the Southeastern States have a very thin veneer of a white opaque mineral of undetermined character. These surficial features are lost by abrasion and are generally absent from detrital monazite. The monazite found in pegmatite consists generally of reddish-brown opaque crystals of large size (Overstreet, Warr, and White, 1970).

Monazite has a variable tenor in the rare earths, commonly 55–65 percent. Seven determinations made on monazite from Cleveland, Burke, and Rutherford Counties, N.C., show maximum, minimum, and mean tenors respectively of 71.7, 56.0, and 67.6 percent. Variations in the valences of cerium, praseodymium, and samarium render possible the substitution of many bivalent, trivalent, and tetravalent metallic elements, of which at least 17, including thorium and uranium, have been identified. Further complexity to the composition of monazite is added by the substitution of silicon for phosphorus. The same possibilities for the substitution of positive and negative ions apply also to xenotime.

The average distribution of the rare earths in 26 samples of monazite have been determined spectrographically by Murata and collaborators (1953, p. 292–300; 1957, p. 148; 1958, p. 7), in 56 samples by Vainshtein, Tugarinov, and Turanskaya (1956) and in eight samples by Wylie (1950). The Lindsay Chemical Co. (1956) has also made many similar analyses. The mean values agree very well (table 11), and appear to indicate that monazite approaches a constant mean composition, insofar as the rare earths are concerned. More detailed investigations of monazite samples from known sources, however, have shown characteristic abundances of these elements from rocks of certain genetic types. For example, a review of 440 analyses in the world literature disclosed certain ranges of the rare earths in monazite samples from carbonatite and alkalic rocks, from granitic rocks, and from gneissic and schistose rocks (Fleischer, 1965; Fleischer and Altschuler, 1969; Michael Fleischer, written commun., 1970).

The content of ThO_2 in monazite is highly variable. The average tenor lies between 3 and 10 percent, but as much as 31 percent has been reported (Bowie and Horne, 1953, p. 94). The content of U_3O_8 is generally between 0.2 and 0.6 percent, or roughly about one tenth that of the ThO_2. It has been shown to reach as much as 2.34 percent in monazite samples from some granitic rocks in the Southeastern States (Overstreet, White, and Warr, 1970). The radiogenic decomposition products of thorium, uranium, lutecium, neodymium, and samarium are necessarily present in monazite, and the decomposition products of lutecium are also to be expected in xenotime.

Xenotime is a tetragonal mineral commonly characterized by double pyramids and poorly developed or undeveloped prismatic faces, but the mineral is brittle, wherefore many grains do not show good crystal outlines. The grains are transparent to translucent lemon yellow to bright green, though some are brownish, white, or colorless. The white opaque veneer that occurs on some crystals of monazite in saprolite is generally absent on xenotime. Xenotime has a greater magnetic susceptibility than monazite but is less magnetic than ilmenite. For this reason a clean magnetic separation of xenotime is not feasible, and its proportion in concentrates must be determined by counts of the ilmenite and monazite fractions. Where xenotime has the color of monazite and both minerals are fractured, as they generally are in metasedimentary rocks, it is very difficult to determine their true tenors. In fact, under such conditions, xenotime is likely to be overlooked entirely, particularly if its tenor is low. A good test for its presence is to examine carefully the ilmenite fraction, where xenotime may be found accompanied

TABLE 11.—*Mean composition, in percent, of rare earths in monazite*

[N.d., not determined]

Source	La_2O_3	CeO_2	Pr_6O_{11}	Nd_2O_3	Sm_2O_3	Gd_2O_3	Others
Murata, Dutra, Da Costa, and Branco, 1958, Murata, Rose, and Carron, 1953, Murata, Rose, Carron, and Glass, 1957	21.7	45.5	5.1	19.2	4.0	1.9	2.6
Vainshtein, Tugarinov, and Turanskaya, 1956	24.6	46.6	5.1	18.2	3.5	2.0	N.d.
Wylie, 1950	24.4	44.6	5.3	19.0	4.0	N.d.	2.7
Lindsay Chemical Co. 1956	23.8	47.7	6.0	18.8	2.0	.5	1.2

TABLE 12.—*Mean composition, in percent, of rare earths in xenotime*

[N.d., not determined]

Y_2O_3	Dy_2O_3	Ho_2O_3	Er_2O_3	Tm_2O_3	Yb_2O_3	Lu_2O_3	Gd_2O_3	Tb_4O_7	Sm_2O_3	La_2O_3
74.1	6.3	1.7	5.3	1.1	6.1	N.d.	2.2	0.9	0.9	1.4

by little or no monazite. The presence of xenotime in the monazite fraction may also be detected by the optical method of Murata and Bastron (1956). Both xenotime and zircon are tetragonal, but owing to the prismatic habit of zircon and its nonmagnetic character, no difficulty arises in the separation of these two minerals.

Xenotime has been identified in about 10 percent of the monazite-bearing concentrates from granitic rocks in the Southeastern States. Where present, the tenor as compared with monazite is generally small, averaging possibly 2 percent of the heavy minerals. A few concentrates have been collected in which the tenor of xenotime ranged from 15 to 50 percent, and one concentrate was found that consisted largely of xenotime. Further examination of the concentrates described in this paper would probably reveal the presence of xenotime in many where it has not been specifically identified.

The composition of xenotime is less well known than that of monazite. It is primarily a yttrian orthophosphate but contains many other metallic elements. The tenor in yttrium is so high, however, that most of the substituted metals should have a valence of III. Terbium is the only element of the terbium and yttrium groups that exists normally with a valence of IV, and as the tenor of terbium and cerium earths in xenotime is low, the tenor of thorium and uranium should likewise be lower than in monazite. Uranium, however, tends to be more abundant in xenotime from the Southeastern States than in monazite. The mean tenor in rare earths for xenotime, as determined spectrographically from nine samples by Vainshtein, Tugarinov, and Turanskaya (1956) is shown in table 12.

Monazite and xenotime can be identified in the field using a hand spectroscope in sunlight (Derby, 1889, p. 111; Kithil, 1915, p. 8; Mertie, 1960, p. 624) or even by artificial illumination, but the light from a concentrated filament giving a continuous spectrum, when amplified by means of a condenser, is most satisfactory. With such strong illumination, a narrow slit may be used in the hand spectroscope making it possible to recognize absorption bands that are not otherwise visible. If a narrow slit is used in sunlight, allowance must be made for the presence of the Fraunhofer lines, particularly in the examination of xenotime. Pure monazite will commonly show a broad double, less commonly a triple, absorption band in the yellow, caused dominatly by neodymium but amplified by praseodymium. Also visible is a fairly strong band in the green, and less commonly two weak lines, one in the blue green and one in the bright red. Concentrates that contain as little as 5 percent monazite will show the yellow absorption. Pure xenotime will show no absorption in the yellow, but a strong double line will be visible in the blue green, a strong line in the deep red having faint lines on both sides, one or more faint lines in the green, one faint line in the yellow green, and one faint line in the bright red. The strong line in the blue green is most likely to show in concentrates having a low tenor of xenotime.

Another method for the recognition of monazite and other minerals high in neodymium has been devised by Murata and Bastron (1956, p. 888). If such minerals are illuminated by unfiltered ultraviolet light from a mercury-vapor lamp, they will under certain specified conditions become emerald green. A few samples of monazite have been found that do not respond to this test.

No dependable data are available regarding the comparative mean tenors of the rare-earth elements and thorium in minerals of granitic rocks, but small amounts of the elements have been identified in all of them, including both the essential and accessory minerals, except possibly quartz and rutile. The common essential minerals of the granitic rocks that may contain these elements are the mica minerals, to a lesser degree the feldspar minerals, and, if present, the amphibole and pyroxene minerals. Garnet and epidote, which may also contain these elements, are uncommon essential minerals, but in a few rocks occur in large amounts. The common accessory minerals that may contain small amounts of the rare-earth elements and thorium are garnet, zircon, apatite, sphene, allanite, and the iron ores. The rare earths and thorium are more concentrated in monazite and xenotime than in any of the common accessory minerals. Thus, if a monazite-bearing granitic rock contains significant amounts of some mineral such as biotite, garnet, or epidote, the total of the rare-earth elements and thorium will exceed the amounts contained in the monazite. Smaller increments may also be added by feldspar, mica, and other accessory minerals.

Monazite occurs in magmatic granite, in granitic gneiss, in contact metamorphic and hydrothermal environments, and in certain schist within areas where this mineral is generally distributed, but it is virtually unreported from volcanic rocks. Metasedimentary gneiss and schist are the principal sources of monazite in the Southeastern States (Overstreet, 1967, p. 184–189) though it is also contained in massive granite and orthogneiss. Probably monazite is an accessory mineral in certain sectors of the Earth's crust, possibly in restricted zones that might qualify as rare-earth metallogenic provinces. Monazite is an accessory mineral in some magmatic granites in the Southeastern States. The writer believes that in some of the metasedimentary granitic gneiss, monazite is little altered from its original detrital condition, a contention supported by the work of Savel'ev and Shuleshko (1971) and opposed to the concept advocated by Overstreet (1967, p. 11–25, 184–189) that in metasedimentary rocks, monazite passes through a metamorphic cycle involving recrystallization with concomitant balance between the composition of monazite and the prevailing grade of regional metamorphism. In orthogneiss its origin is magmatic; however, in some metamorphic gneiss, monazite may be a reconstituted mineral produced by dynamic recrystallization and little or no fusion .Its destruction at low metamorphic grades, however, and the distribution of its elements in other minerals is regarded by this writer as questionable in unfused metamorphic rocks.

MONAZITE BELTS

Monazite was found in bedrock in Virginia, North Carolina, South Carolina, Georgia, and Alabama mainly within three principal belts. The configuration of the belts (pl. 1) was established largely by panning the accessory minerals of bedrocks, principally samples of saprolite, as the tenors in monazite are too small to be determined either by petrographic study or by chemical analysis. Within these 5 States, 677 samples of accessory minerals were collected from granitic rocks of all kinds, and 246 samples, or 36 percent, were found to contain monazite (Mertie, 1957).

Other belts of minerals are known in the vicinity of the monazite belts, the longest of which are the gold belts of the southern Appalachians (Becker, 1895; Pardee and Park, 1948). Smaller belts abut or are coextensive with one or more of the monazite belts or lie between these belts. Examples include the tin-spodumene and manganese belts on the eastern flank of the western Piedmont monazite belt in North and South Carolina (Keith and Sterrett, 1931); the tin belt in Coosa County, Ala. (Pallister, 1955); tin localities along the east side of the eastern Piedmont monazite belt (Henry Bell, III, written commun., 1973); the sillimanite belt along the western Piedmont monazite belt in North Carolina (Hunter and White, 1946); and the titaniferous magnetite belts in North Carolina and Georgia (Nitze, 1893; Singewald, 1913; Murdock, 1947). Others also are known, but the relations of these belts to the monazite belts in the Southeastern Atlantic States were not investigated.

DISCOVERY AND DEFINITION

The most important of the belts outlined on plate 1 is now known as the western Piedmont monazite belt. The central part was located originally by early prospecting and mining in North and South Carolina as shown by a map by Pratt (1916, p. 50). The then known linear extent of the single monazite belt in the Carolinas was about 160 miles. The investigations described in this paper have extended this belt northeastward nearly to Richmond, Va., southwestward into and across Georgia, and westward across Alabama to the zone where the crystalline rocks are overlapped by the deposits of the Coastal Plain. The length of this belt is about 620 miles. The width is varied ranging from a maximum of 40 miles in Cleveland County, N.C., to 2 or 3 miles at certain sites in Virginia. The western Piedmont monazite belt meets an eastern Piedmont monazite belt about 10 miles northwest of Richmond, Va., and it is a matter of interpretation whether it is the eastern or western belt that continues northward. The first alternative has been adopted.

The eastern Piedmont monazite belt was discovered by the writer in October 1949. Prior to that time an isolated occurrence of monazite had been described by Fontaine (1883, p. 330) from a pegmatite near Amelia, Amelia County, Va., where it had been recognized earlier by König (1882, p. 15). The original discovery leading to the recognition of a belt, however, was made near Rolesville, Wake County, N.C., whence the belt was traced north-northeastward into Spotsylvania County, Va., and southwestward intermittently to the Broad River, S.C. This belt probably extends still farther southwestward or westward. Its length is now known to be about 420 miles.

The possible presence of a mountain monazite belt had been suspected by the writer since 1945 when he identified monazite in the alaskite of the Spruce Pine district, North Carolina. Other evidence for it included references to monazite in early literature. Monazite had been known for many years to exist in certain pegmatites of the Spruce Pine district, where it first was reported by Hidden (1881b). A large crystal of monazite, later described by Schaller (1933), and many smaller ones were found about 1930 in a pegmatite about 3 miles S. 58° W. of Mars Hill, Madison County, N.C. The presence of monazite much farther southwest, in Jackson and Clay Counties, N.C., was also recorded by Pratt and Sterrett (1910, p. 315–316) and Sterrett (1907, p. 1196). One of these localities was 2 miles east of Highlands, Macon County, N.C., and W. R. Griffitts (written commun., 1956) described another locality about 6 miles northwest of Highlands. Monazite was first recorded in western Georgia by Nitze (1895a, p. 682) in the gold placers of Flat Creek and its four principal tributaries near The Glades, a now abandoned townsite about 11 miles N. 30° E. of Gainesville, Hall County, Ga. This area was visited by the writer in May 1950, and the bedrock sources of the monazite were identified. In this general vicinity, alluvial monazite had been found near Gillsville, about 10 miles east of Gainesville (Sterrett, 1907, p. 1196). Sterrett also recorded the presence of alluvial monazite in Rabun County, Ga., and A. S. Furcron (oral commun., 1949) reported the occurrence of alluvial monazite in Habersham County. Monazite was identified by the writer in 1950 in the granite at and near Franklin and Texas in Heard County, Ga. The clinching evidence for the presence of a mountain monazite belt, however, came later in Virginia and North Carolina.

Monazite was found by the writer in 1952 at two localities in Culpepper and Rappahannock Counties, Va., a short distance east of the Blue Ridge. In the following year, radioactive granitic rock in Rappahannock County a short distance east of Thornton Gap was brought to the writer's attention by R. S. Cannon of the U.S. Geological Survey. The milling and panning of this rock disclosed that it contained monazite. Further work by the writer in 1955, 1956, and 1957 confirmed the presence of the mountain monazite belt extending from Fauquier and Warren Counties, Va., southwestward for at least 140 miles. However, an unexplored gap of 170 miles exists in the mountain monazite belt (pl. 1) in Virginia and North Carolina.

Corroboratory evidence of the mountain monazite belt was found in 1956 by the writer in North Carolina about 90 miles southwest of the monazite locality in the Spruce Pine Alaskite of Hunter and Mattocks (1936). Numerous concentrates taken in Jackson and Macon Counties, N.C., northeast and southwest of Highlands contained monazite and identified the belt. Thence the belt was found to extend northeastward into Transylvania County, N.C., and southwestward into Rabun County, Ga., whence it was already known to extend intermittently southwestward to Heard County, Ga., near the Alabama State line. Unexplored gaps in the mountain belt thus exist in Virginia, North Carolina, and Georgia, but it is probable that further work will verify its essential continuity. Moreover, no reason is known why this belt may not extend into Maryland and Alabama, but the belt is too far west to appear in South Carolina. Its recognized length, including unexplored gaps, is about 610 miles. The total extent of the three belts in five States is about 1,650 miles, of which nearly 1,500 miles were identified from explorations described in this paper.

The sequence followed below in discussing the monazite-bearing rocks in the belts and the occurrence of monazite and other accessory minerals is the historical order of discovery of the belts: the western Piedmont monazite belt is described first, then the eastern Piedmont monazite belt, and lastly the mountain monazite belt. Within each belt the geographic sequence of the descriptions is from Virginia southwestward into the Carolinas, Georgia and Alabama. Owing to the intermittent distribution of unweathered rock, it is described only locally, and specific reference to intermediate saprolite localities is made only where such have special significance. Not all localities shown on the figures to have yielded monazite-bearing concentrates are discussed; however, each such concentrate is individually described in another report (Mertie, 1978).

For the purpose of general reference and for the discussion which follows, the mean tenors of total accessory minerals, monazite in the concentrates and in bedrock, and magnetite, ilmenite, and zircon in concentrates are shown in table 13.

WESTERN PIEDMONT MONAZITE BELT

VIRGINIA

BEDROCK

Monazite-bearing unweathered bedrock is scarce within the western Piedmont belt of Virginia; the

TABLE 13.—*Summary by State, in percent, of accessory minerals in concentrates from the three monazite belts in the Southeastern Atlantic States*

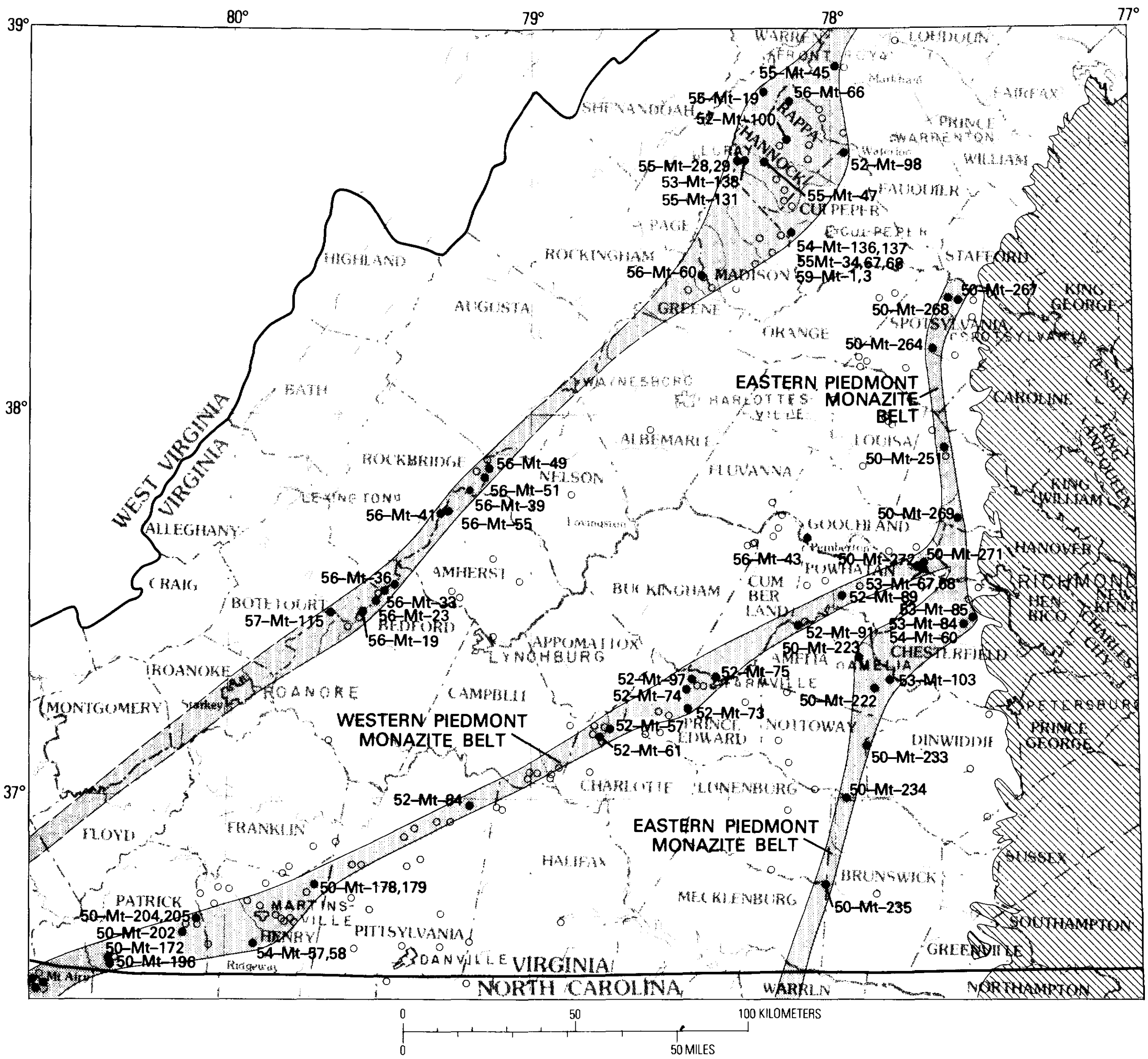
State	Bedrock		Concentrates				
	Total accessory minerals	Monazite	Magnetite	Ilmenite	Monazite	Zircon	Others
Western Piedmont belt							
Virginia	0.044	0.0019	19.5	27.7	18.1	6.2	28.5
North Carolina	.086	.0091	.4	16.3	42.6	10.7	30.0
South Carolina	.041	.0076	5.4	16.2	30.9	9.7	37.8
Georgia	.11	.0062	18.0	30.9	18.9	5.6	26.6
Alabama	.01	.0006	21.2	9.6	18.1	21.6	29.5
Mean	.070	.0057	12.5	21.7	26.2	9.7	29.9
Eastern Piedmont belt							
Virginia	0.033	0.0067	5.4	40.3	30.9	10.7	12.7
North Carolina	.089	.0043	22.4	57.3	6.8	.7	12.8
South Carolina	.19	.0034	60.4	32.8	2.5	.3	4.0
Mean	.091	.0050	24.3	44.9	15.4	4.6	10.8
Mountain belt							
Virginia	0.13	0.0017	3.9	56.6	3.1	24.9	11.6
North Carolina	.012	.0026	7.5	13.4	33.6	15.9	29.6
Georgia	.023	.0015	10.8	30.8	16.7	13.3	28.4
Weighted mean	.066	.0019	6.7	37.0	15.8	19.3	21.2
Mean, three monazite belts	.072	.0047	12.9	29.1	21.9	11.3	24.8

sources for monazite are generally known from outcrops of saprolite in Goochland, Powhatan, Cumberland, Prince Edward, Charlotte, Pittsylvania, Henry, and Patrick Counties (pl. 1 and fig. 2). The geologic units as shown on the geologic map of Virginia (Virginia Geological Survey, 1928) known to be partly monazite bearing are the Precambrian Wissahickon Granitized Gneiss and Wissahickon Schist, hornblende gneiss and white granite intruded into the Wissahickon, an unnamed mass of granite southeast of Red House in Charlotte County, and possibly the Precambrian Leatherwood Granite of Jonas (1928). No monazite has actually been found within the areas shown on the State geologic map to be underlain by Leatherwood Granite, but monazite-bearing saprolite has been recognized in rocks adjacent to this formation. Inherent inaccuracies of the map make it possible that a part of the Leatherwood Granite contains monazite.

Monazite-bearing tonalite gneiss is exposed in the Boscobel quarry in Goochland County about 12 miles west-northwest of Richmond. A small part of the rock is a fine-grained greenish-gray gneiss, and a third component consists of sills and dikes of fine-grained granite and coarse-grained pegmetite ranging in thickness from 3 to 10 feet. This quarry exemplifies the occurrence of unweathered rock overlain by "saprock" which in turn is overlain by true saprolite. The "saprock" is so coherent that it requires blasting before it can be moved with a power shovel. Two samples of the saprolite were panned: one (53 Mt 67) was taken at the base of the saprolite; the other (53 Mt 68) came from about 20 feet higher (Mertie, 1978). Probably both samples were mixtures of tonalite gneiss and intrusive granite.

The essential minerals of the tonalite gneiss are quartz, altered plagioclase feldspar, microcline, and secondary albite. Chloritized biotite is the main mafic mineral, but a little muscovite is also present. Apatite, garnet, and pyrite are visible in thin sections. The pinkish granitic sills and dikes have generally the composition of adamellite and contain the felsic minerals quartz, microcline, and sericitized and kaolinized plagioclase. Muscovite is more plentiful than biotite, and the common accessory mineral is garnet. Monazite and other accessory minerals were identified in the concentrates. The tonalite gneiss is thought by the writer from the appearance of its accessory minerals to be a metasedimentary gneiss largely granitized, probably at the time when the granitic sills and dikes were injected.

Saprolite of granitic gneiss was sampled at two other sites (50 Mt 271 and 50 Mt 272) in Goochland County within an area of granitized gneiss of the Wissahickon Formation (Virginia Geological Survey, 1928). Two samples of saprolite were taken in Powhatan County. One of these was derived from



EXPLANATION

Monazite belt—Dashed where inferred

Unconsolidated sedimentary rocks of Atlantic Coastal Plain

• Sample locality and field number of monazite-bearing concentrate panned from saprolite or unweathered rock; description of locality and material sampled in Mertie (1978)

○ Sample locality of monazite-free concentrate panned from saprolite or unweathered rock, used to define the monazite belts

FIGURE 2.—Distribution and field numbers of monazite-bearing concentrates in Virginia.

granitized gneiss (52 Mt 89), the other from a pegmatitic gneiss (52 Mt 91); both localities are within an area of granitized gneiss of the Wissahickon Formation. Northwest of the samples mentioned above, a sample (56 Mt 43) was taken north of Pemberton in Goochland County where the Precambrian Cartersville Granite of Jonas (1928) is exposed. The rock is a granite gneiss that is almost schistose. This monazite locality is too far to the northwest to be included within the recognized western Piedmont monazite belt.

Four monazite localities are close to Farmville, of which one is in Cumberland County (52 Mt 75) and three are in Prince Edward County (52 Mt 73, 52

Mt 74, and 52 Mt 97). All are within the area shown by Virginia Geological Survey (1928) as Wissahickon Schist intruded by hornblende gneiss and white granite. Three of these samples, including the one from Cumberland County, were taken from granitic gneiss; one (52 Mt 97) came from a small intrusion of granitic rock. Two monazite-bearing concentrates (52 Mt 57 and 52 Mt 61) from Charlotte County came from granitic intrusives that lie near the western limit of the Wissahickon Schist intruded by hornblende gneiss and white granite. A monazite-bearing concentrate from Pittsylvania County (52 Mt 84) was taken from granitic gneiss within the Wissahickon Schist, but close to an intrusive rock mapped as part of the Leatherwood Granite (Virginia Geological Survey, 1928).

Four samples of monazite-bearing saprolite were taken in Henry County, of which two were from granitic gneiss and aplitic granite within Wissahickon Schist (50 Mt 178 and 50 Mt 179), but close to the main body of the Leatherwood Granite. The other two samples (54 Mt 57 and 54 Mt 58) came from one locality at the southeastern limit of the western Piedmont monazite belt, within an area shown by the Virginia Geological Survey (1928) as Wissahickon Schist, which exemplify a Precambrian metasedimentary monazite placer somewhat similar to fossil placers recognized elsewhere in Virginia (Bloomer and de Witt, 1941). The fossil placer, called to the writer's attention by Philip R. Barbour of Martinsville, is about 4 miles northwest of Ridgeway and consists of a black reef that is best exposed along the southwest side of County Road 687. Other exposures continue along the road southeastward and northwestward from the principal outcrop. A steep valley wall of bedrock and a thin veneer of soil or saprolite bounds the outcrop on the southwest, and a timber-covered alluvial fill lies to the northeast. Some exploratory work has been done, but the size and extent of the body had not been completely determined in 1954 at the time of the writer's visit. Further prospecting might be undertaken to best advantage northwestward of the bounding spur and beyond.

The rock adjacent to the fossil placer consists of thin layers of schist and quartzite, having a secondary structure parallel to original bedding planes and to the placer. The hanging wall of the fossil placer is kyanite-biotite schist, but several varieties of schist are present, including quartz-biotite schist, quartz-albite-biotite schist, biotite-kyanite schist, and biotite-sillimanite schist. Quartzite and sericite-quartzite schist are also exposed.

The fossil placer consists of a black layered reef, 12–20 inches thick, that dips generally southeastward at angles ranging from 40° to 75°. The layering is due partly to structure but mainly to inconstant composition, whereby thin laminae of leaner concentration of heavy minerals containing some rock-forming minerals interfinger with richer concentrations of heavy black minerals. The deposit consists mainly of iron ores and subordinately of monazite, zircon, and corundum. The light-colored laminae are composed of quartz, kyanite, chlorite, hematite, and some iron ores. One sample consisted of the indurated black material, which was crushed, milled, and panned to eliminate rock-forming minerals. The second sample consisted of fines that crumbled from the fossil placer when the first sample was being cut. Five thin sections of the black material were also prepared. The data obtained from the concentrates and thin sections indicate that the composition of the black material is variable but consists generally of 60–70 percent magnetite, 15–18 percent ilmenite, 10–12 percent monazite, 4–5 percent zircon, and about 2 percent corundum. The iron ores show little evidence of their sedimentary origin, as the detrital grains have grown together, then been shattered and cut by quartz-bearing veinlets. In laminae containing sparse iron ores within the placer, however, the partly rounded shapes of the detrital grains of iron ores are visible. The grains of monazite and zircon within the black layers are distinctly rounded, zircon being more rounded than monazite. Corundum is sparse, but shattered crystals as much as 4 mm in size were recognized in thin sections and one large crystal was seen that had a subrounded shape and rounded edges. Smaller grains have only slightly rounded edges. Most of the corundum is intergrown with iron ore so that it has sufficient magnetic susceptibility to be separated with the ilmenite fraction.

Monazite recovered from the concentrates that were crushed but not milled was sieved to determine the grain size (table 14). Most of the grains are about 0.13 mm, few grains are smaller than 0.04 mm, and very few grains are larger than 0.3 mm. The mean size is about 0.1 mm.

An outstanding characteristic of this deposit is the 4:1 ratio of magnetite to ilmenite and the unaltered condition of the magnetite. These conditions are not generally true in nearby rocks. A monazite-free concentrate from decomposed quartzite and schist, taken at the Mt. Zion Baptist Church about 0.2 mile north-northwest of this fossil placer, consists of 30 percent magnetite and 45 percent

TABLE 14.—*Grain sizes of monazite in sample 54 Mt 57 from a Precambrian fossil placer near Ridgeway, Henry County, Va.*

[>, greater than; <, less than]

Grain size (mm)	Percent of sample
> 0.31	0.5
.30–.21	5.9
.20–.15	21.1
.14–.11	43.6
.10–.074	18.6
.073–.061	5.8
.060–.043	2.7
<.043	1.8

ilmenite, and has a ratio of magnetite to ilmenite of 1:1.5. Ratios of this order are common in concentrates from saprolite of these gneisses and schists. Moreover, the magnetite of the sample near the church is appreciably altered; this alteration of magnetite also is commonplace in the metamorphic rocks. These conditions suggest that the magnetite of this fossil placer departs from the theoretical composition by the substitution of some element, possibly magnesium, that has rendered it less vulnerable to surficial alteration. A local source for the iron ores and corundum is also suggested, but corundum has not been identified in the adjacent metamorphic rocks. A sample of magnetite-corundum ore was collected by G. H. Espenshade of the U.S. Geological Survey in 1951 from a site 1.17 miles N. 60° W. of Whittles Depot on the Southern Railway in Transylvania County, N.C. This ore has a high percentage of unaltered magnetite and a very low tenor of ilmenite. Some such source rock may have been close to the site of deposition of the Precambrian placer here described.

Five samples of monazite-bearing saprolite were panned in Patrick County (50 Mt 172, 50 Mt 196, 50 Mt 202, 50 Mt 204, and 50 Mt 205). All came from the area shown by the Virginia Geological Survey (1928) as Wissahickon Schist, though two of them, 50 Mt 172 and 50 Mt 196, lie close to the boundary with a small body of Leatherwood Granite. Somewhat weathered rock that probably correlates with that panned for sample 50 Mt 172 crops out in a roadcut about a mile west of this sample. This rock is a light-gray, fine-grained adamellite gneiss, consisting of quartz, microcline, plagioclase, biotite, and muscovite. The plagioclase is partly replaced by sericite and epidote. No iron ores are visible in thin section; this lack of iron ores conforms to the mineral composition of concentrate 50 Mt 172, which contains no magnetite and only 0.7 percent ilmenite. Sample 50 Mt 196 is derived from a massive granite and may in fact be part of the small body of Leatherwood Granite in this vicinity. Sample 50 Mt 202 is derived from a gneissoid granite. The other two samples taken in Patrick County are derived from granitic gneiss.

ACCESSORY MINERALS

Accessory minerals that include monazite have been collected from 22 localities in the western Piedmont monazite belt of Virginia (fig. 2). All samples, except the two from the fossil placer in Henry County, were panned from saprolite. The principal accessory minerals constitute 0.0032–0.29 percent of these rocks, and have a mean tenor of 0.044 percent (table 15) which is 0.028 percent less than the regional average for the monazite-bearing rocks (table 13) and 0.096 percent less than the regional average for all the granitic rocks. Seven samples, however, have high tenors in magnetite, and for these the total concentrates constitute 0.084 percent of the rocks. The tenor in magnetite for these seven samples ranges from 29.0 to 90.3 percent of the concentrates, and has a mean value of 55.8 percent; their mean ilmenite-magnetite ratio is 1:2.25. Most of these rocks that are high in magnetite are orthogneiss, granite, or migmatite.

All these concentrates contain ilmenite, but 12 lack magnetite. The tenor in ilmenite ranges from 0.7 to 85.0 percent, and has a mean value of 27.7 percent. The average tenor of the total iron ores is about 47.2 percent of the concentrates, and about 0.21 percent of the rocks. Omitting the seven samples rich in magnetite these two values are respectively 29.3 and 0.13 percent. Most of the samples that are free or essentially free of magnetite are from metasedimentary gneisses.

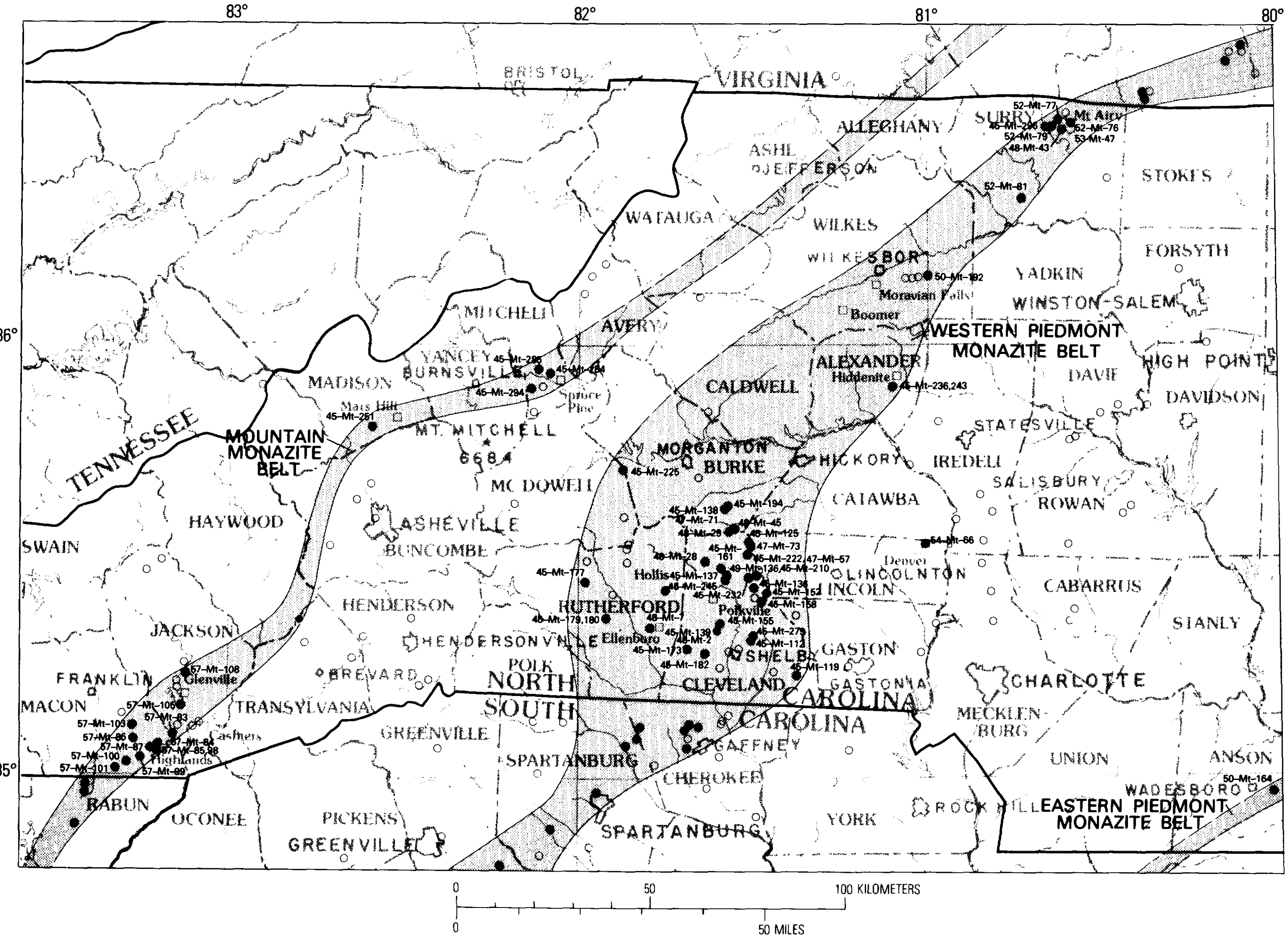
Monazite constitutes 0.1–87.4 percent of the concentrates and has a mean value of about 18.1 percent (table 15). The tenor of monazite in bedrock ranges from 0.0001 to 0.012 percent and has a mean value of 0.0019 percent. Regional tenors in the concentrates and in bedrock in the three belts are respectively 21.9 and 0.0047 percent (table 13). The number of samples in table 15 is too small to yield dependable conclusions, but apparently the mean tenor of monazite in the rocks of the western Piedmont belt of Virginia is substantially less than the regional mean tenor.

The other accessory minerals include xenotime, zircon, garnet, epidote, rutile, leucoxene, and hematitic pseudomorphs of pyrite. Xenotime was recognized in only three samples, but in two of these (table 15) xenotime constituted respectively 70.0 and 34.0 percent of the concentrates and 0.012 and

TABLE 15.—*Accessory minerals and amounts, in percent, in concentrates from 20 samples from the western Piedmont monazite belt in Virginia*

[Leaders (---), absent]

Field No.	Minerals in bedrock			Minerals in concentrates								
	Total	Monazite	Xenotime	Magnetite	Ilmenite	Monazite	Xenotime	Epidote	Garnet	Zircon	Rutile	Quartz and others
Goochland County												
50 Mt 271	0.29	0.0006	0.0003	46.7	48.4	0.2	0.1	---	---	0.1	---	4.5
50 Mt 272	.017	.0017	.012	---	4.0	10.0	70.0	---	---	.5	---	11.0
53 Mt 67	.0061	.0006	---	---	76.0	10.0	---	---	---	---	---	14.0
53 Mt 68	.0037	.0004	---	---	63.4	12.0	---	---	---	---	---	35.4
Powhatan County												
52 Mt 89	0.0068	0.0024	---	---	5.0	35.0	---	---	---	29.0	9.0	22.0
52 Mt 91	.0063	.0003	0.0021	---	43.0	5.0	34.0	---	1.0	4.0	1.0	12.0
Cumberland County												
52 Mt 75	0.028	0.0011	---	58.0	3.0	4.0	---	0.5	---	2.0	---	32.5
Prince Edward County												
52 Mt 97	0.0034	0.0004	---	---	47.0	11.0	---	---	1.0	7.0	17.0	17.0
52 Mt 74	.24	.0012	---	61.0	32.0	.5	---	2.0	---	.2	.2	4.1
52 Mt 73	.0064	.0030	---	---	1.0	47.0	---	4.0	6.0	3.0	---	39.0
Charlotte County												
52 Mt 57	0.05	0.0005	---	40.0	44.0	1.0	---	---	1.0	1.5	---	12.5
52 Mt 61	.044	.0030	---	---	5.0	7.0	---	---	---	---	---	88.0
Pittsylvania County												
52 Mt 84	0.0069	0.0005	---	29.0	29.0	7.0	---	---	---	25.0	---	10.0
Henry County												
50 Mt 178	0.0044	0.0002	---	---	20.0	5.0	---	---	---	44.0	---	31.0
50 Mt 179	.0032	.0009	---	---	26.0	29.0	---	---	---	2.0	---	43.0
Patrick County												
50 Mt 205	0.054	0.0001	---	90.3	1.5	0.1	---	7.0	---	0.1	---	1.0
50 Mt 204	.087	.0064	---	65.4	15.5	7.3	---	---	---	.5	---	11.3
50 Mt 202	.0096	---	---	---	85.0	.2	---	7.8	---	1.0	---	6.0
50 Mt 172	.013	.012	---	---	.7	87.4	---	---	---	.9	---	11.0
50 Mt 196	.0034	.0028	---	.5	4.5	83.0	---	---	---	3.4	---	8.6
Means	0.044	0.0019	0.007	19.5	27.7	18.1	5.2	1.1	0.4	6.2	1.3	20.7



EXPLANATION

Monazite belt—Dashed where inferred

Unconsolidated sedimentary rocks of Atlantic Coastal Plain

● Sample locality and field number of monazite-bearing concentrate panned from saprolite or unweathered rock; description of locality and material sampled in Mertie (1978)

○ Sample locality of monazite-free concentrate panned from saprolite or unweathered rock, used to define the monazite belts

FIGURE 3.—Distribution and field numbers of monazite-bearing concentrates in western North Carolina.

0.0021 percent of the bedrock. Xenotime is hard to separate magnetically from the other minerals of the concentrates; thus, small amounts possibly are more generally present than are shown in table 15, where the mean tenors in xenotime for the concentrates and for bedrock are respectively 5.2 and 0.007 percent.

Zircon is significant, partly on account of its tenor but mainly on account of its morphology. The tenor in the concentrates ranges from 0.1 to 44.0 percent and has a mean value of 6.2 percent (table 15); the average tenor in the rocks is about 0.0005 percent. Thus both tenors are definitely less than those of monazite. In nearly half the samples the grains of zircon are heterogeneous in color, size, and crystalline outline; in most of these samples some of the zircons are partly or wholly rounded. Several other samples contain homogeneous zircons that are more or less rounded.

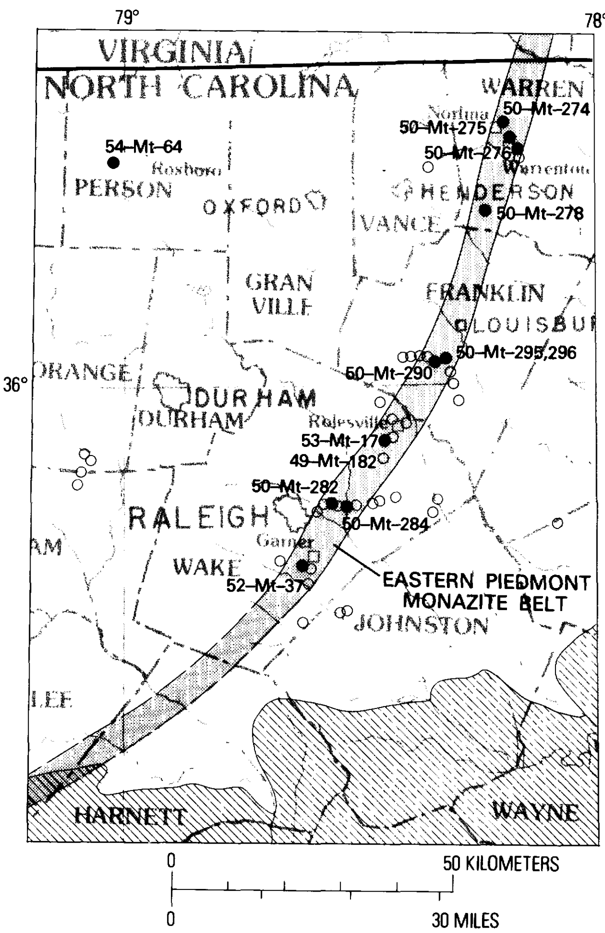
These data on the accessory minerals suggest that most of the monazite-bearing granitic rocks of the western Piedmont belt of Virginia are metasedimentary rocks. Some of these, however, have been granitized to produce migmatites. Few are typical magmatic granites, but even these yield mineralogical evidence that they are remelts of sedimentary or metasedimentary rock.

NORTH CAROLINA

BEDROCK

Monazite was found in bedrock within the western Piedmont monazite belt of North Carolina in Surry, Wilkes, Alexander, Burke, McDowell, Cleveland, and Rutherford Counties; monazite is also known to be present in the alluvial deposits of Catawba, Gaston, and Polk Counties (pl. 1 and fig. 3). Two isolated sites of monazite-bearing bedrock were also found in Person County (fig. 4) and Lincoln County (fig. 3). The locality in Person County (54 Mt 64) is about midway between the western and eastern Piedmont monazite belts. The locality in Lincoln County (54 Mt 66) is not far southeast of the western belt, but it is too far to justify the widening of the belt. Monazite was recovered from 36 placer localities in the western belt in Cleveland, Rutherford, Burke, McDowell, and Alexander Counties, N.C., and analyzed for thorium and uranium (Mertie, 1953).

The geologic formations that contain monazite, as shown by the geologic map of North Carolina (North Carolina Division of Mineral Resources, 1958), are the Paleozoic(?) Mount Airy Granite of Stuckey



EXPLANATION

Monazite belt—Dashed where inferred

Unconsolidated sedimentary rocks of Atlantic Coastal Plain

● Sample locality and field number of monazite-bearing concentrate panned from saprolite or unweathered rock; description of locality and material sampled in Mertie (1978)

○ Sample locality of monazite-free concentrate panned from saprolite or unweathered rock, used to define the monazite belts

FIGURE 4.—Distribution and field numbers of monazite-bearing concentrates in central North Carolina.

and Conrad (1958), several masses of unnamed granitic rocks, mica gneiss, the Paleozoic Toluca Quartz Monzonite, and some of the mica schist in Cleveland County, N.C., but none of these units is universally monazite bearing. The western Piedmont monazite belt is widest and economically most important in Cleveland and Rutherford Counties, where it attains a maximum width of 40 miles, and monazite placers were formerly mined (Overstreet and others, 1968, p. 6).

The largest and best exposure of monazite-bearing rock in the Southeastern States is in Surry County, N.C., where a pavement of massive granite crops out 1–2 miles east-northeast of Mount Airy (pl. 1). This granite is part of the formation described on the geologic map of North Carolina as the Mount Airy Granite and called in a detailed report by Dietrich (1961) a leucogranodiorite. The outcrop has a length from west to east of about 4,500 feet and a maximum width at its eastern end of about 2,000 feet. It is the site of the quarry of the North Carolina Granite Corp.

Wilkes County, N.C., has been little explored for monazite, though a part of this county lies within the western Piedmont monazite belt. Monazite apparently was first found in Wilkes County by Sterrett (1907, p. 1196), where it was discovered in the gravels of Cub Creek a short distance south of Wilkesboro. Sterrett also found alluvial monazite southwest of Wilkesboro near Boomer. One monazite-bearing concentrate (50 Mt 192) was taken by the writer about 8 miles east of Wilkesboro from saprolite of a cream-colored, fine-grained banded gneiss. Two small elongate masses of unsampled granite lie southwest of this locality (A. J. Stose, oral commun., 1952), one on Hunting Creek and the other extending from Boomer to Moravian Falls and thence southward. Another unsampled body of granite that may contain monazite extends 21 miles from Stone Mountain, at the boundary between Wilkes and Alleghany Counties (pl. 1), southwestward almost to Parsonville in Wilkes County. This granite is said to be very similar to the Mount Airy Granite.

The monazite-bearing concentrate (54 Mt 64) from Person County, N.C. (fig. 4) is from a small body of gneissic granitic rock that ranges in composition from adamellite to monzogranite and is exposed both as unweathered rock and saprolite. The rock is porphyritic and has medium-size phenocrysts of andesine and pinkish microcline set in a fine-grained groundmass of quartz and orthoclase. The plagioclase is partly replaced by sericite and epidote. Fine-grained chloritized biotite is the only mafic mineral. The character of this granitic rock and the nature of its accessory minerals indicate that it is related to the Mount Airy Granite (Dietrich, 1961). Its position between the western and eastern Piedmont monazite belts is anomalous, as other monazite-bearing rocks have not been found by the writer between these belts farther to the southwest.

Monazite was found by Hidden (1881a, p. 159) in Alexander County, N.C., at Milholland's Mill on Third Creek in saprolitic garnetiferous mica schist. In later years the gravels of Third Creek, which heads at the site of Hiddenite mine, were worked for monazite. About 2.5 miles N. 30° E. of Milholland's Mill alluvial monazite is also present in a small tributary to the Yadkin River. The monazite occurrence of greatest interest, however, is at the old Hiddenite mine about 0.4 mile west of Hiddenite where the gem variety of spodumene known as hiddenite, as well as emerald (beryl), were discovered in 1879.

The rock at the Hiddenite mine is dark-gray, fine-grained, vitreous quartzite that has been intruded by dikes of light-gray granitic rock, almost free of mafic minerals, that grades into pegmatite. Some of this granitic rock is garnetiferous. Numerous narrow layers and laminae of recrystallized biotitic quartzite are in the intrusive rock, and locally the quartzite has been converted to a migmatitic gneiss. Hiddenite and emerald, together with muscovite, quartz crystals, dolomite, siderite, apatite, tourmaline, rutile, monazite, zircon, and other minerals, were found in vugs within or alongside the granitic dikes. One of these vugs measured 10 by 6 by 2 feet, and others of smaller size have been recorded (Hidden and Washington, 1887). Monazite is also disseminated in small amounts in the granitic intrusive and in the migmatitic quartzite, as proven by panning samples of the pulverized granitic intrusive rock (45 Mt 243) and the migmatized quartzite (45 Mt 236).

Five samples of monazite-bearing saprolite were panned in Burke County, N.C., (pl. 1 and fig. 3), of which four (45 Mt 138, 45 Mt 194, 47 Mt 71, and 48 Mt 29) represent granites that correlate with the Toluca Quartz Monzonite in Cleveland County, N.C., (Mertie, 1978). The fifth (48 Mt 48) appears to represent granitized rock. A single concentrate (45 Mt 225) taken in McDowell County from saprolite of granitic gneiss contains a minute amount of monazite. An outcrop of saprolite and unweathered granitic gneiss in Lincoln County, near Denver, N.C., about 20 miles southeast of the western Piedmont monazite belt, yielded a monazite-bearing concentrate (54 Mt 66). The rock has well-developed nearly horizontal foliation suggestive of original bedding planes. It is probably a paragneiss.

Cleveland County, N.C., is in the widest part of the western Piedmont monazite belt. The saprolites of many granitic rocks exposed therein were panned by the writer in 1945 (Mertie, 1953) and were found to be monazite bearing (pl. 1, and fig 3). The distribution of accessory minerals in nine mapped units of rock in the area of the Shelby quadrangle, which includes a large part of Cleveland County, was determined by the panning of about 1,100 concentrates (Overstreet, Yates, and Griffitts, 1963a). The principal granitic rock, the Toluca Quartz Monzonite, was found to contain monazite in 93 percent of the samples. Other monazite-bearing rocks in the area are biotite schist, biotite gneiss, sillimanite schist, hornblende gneiss, and pegmatites of two types, but these rocks are not universally monazite bearing. As few as 45 percent of the samples of biotite schist contained monazite.

The Toluca Quartz Monzonite crops out as fresh rock at the type locality of Acre Rock, a small pavement about 11.9 miles N. 5° E. of Shelby in Cleveland County. Pulverized samples (45 Mt 222 and 47 Mt 57) of the Toluca Quartz Monzonite were found to contain monazite by the writer as early as 1945. Concentrates have also been taken by the writer at other sites in Cleveland County from saprolite which is considered to be part of the Toluca Quartz Monzonite (45 Mt 125, 45 Mt 136, 45 Mt 137, 45 Mt 152, 45 Mt 173, 45 Mt 232, 45 Mt 245, and 47 Mt 73). Additional concentrates have been taken in Cleveland County from saprolite and unweathered rock of an older granitic gneiss (48 Mt 28 and 49 Mt 136).

The Toluca Quartz Monzonite at Acre Rock is distinctly gneissic, perceptibly sheeted, and the foliation wraps around small mafic xenoliths. These relationships indicate that this is a magmatic granitic intrusive rock having a primary gneissoid fabric. A few small but fairly well defined dikes and stringers of pegmatite cut the Toluca Quartz Monzonite at its type locality but they split into numerous veinlike branches which disappear within short distances.

The Toluca Quartz Monzonite is a medium gray, hypidiomorphic granular rock whose essential minerals are quartz, microcline, orthoclase, plagioclase biotite, and muscovite. Garnet is so prevalent as to assume almost the status of an essential mineral. The accessory minerals visible under the microscope are garnet, apatite, iron ores, sphene, zircon, and rarely monazite. The quartz generally has an undulatory extinction, some grains being ruptured or granulated, and it commonly contains clusters of minute inclusions. Microline is somewhat more plentiful than orthoclase, and both may contain inclusions of biotite and quartz. The composition of the plagioclase corresponds closely with that computed from the norms (An_{25}), and some of it is considerably sericitized. Biotite is more plentiful than muscovite.

The two available chemical analyses of the Toluca Quartz Monzonite at Acre Rock (table 1, samples A and B) yield norms that show plagioclase (An_{25}) constituting about 63 percent of the feldspar; thus the rock may be classified as an adamellite (quartz monzonite) that is almost monzotonalite (granodiorite). Microscopic examination of numerous specimens from different localities revealed that the composition is inconstant, ranging from monzogranite to monzotonalite. The chemical analyses (table 1) of the pegmatitic phase of the Toluca Quartz Monzonite at Acre Rock show that the plagioclase has a composition of An_{16} and constitutes only 36 percent of the feldspar. This rock also is adamellite, but it is also almost a monzogranite.

Concentrate 45 Mt 112, collected from the east wall of Hickory Creek in Cleveland County, is from mica schist that has been pegmatized along certain layers to produce a migmatite. The migmatite is monazite bearing, but the nonpegmatized rock is barren of monazite. This locality has historic interest in that it was the site of early monazite mining in Cleveland County by the British Monazite Co. The principal work was done on the monazite placers of Hickory Creek, but at one stage of this operation an attempt was made to mine saprolite and unweathered rock at the sample site. Insufficient migmatite of workable grade was found to make such mining successful.

The eastern part of Rutherford County is within the western Piedmont monazite belt (pl. 1 and fig. 3) and contains granitic rocks of the same general type as those in Cleveland County. Four samples of monazite-bearing saprolite were panned, of which one was derived from granite (45 Mt 177) and three from granitized schist and gneiss (45 Mt 179, 45 Mt 180, and 48 Mt 7). Monazite-bearing strongly gneissoid dark-gray granitic rock with which pegmatite is associated is exposed at a small quarry about 1.5 miles west of Hollis and seems to be the same as the saprolite represented by 45 Mt 177. The essential minerals are quartz, microcline, plagioclase, biotite, and muscovite. The ratio of microcline to plagioclase is about 3:2. The plagioclase, which has the composition of oligoclase, is considerably sericitized. Iron ores and zircon are noticeable in thin section. A composite sample of the granitic rock at this quarry was analyzed (table 1, sample D), and the calculated norm shows that plagioclase having a composition of An_{12} constitutes 62 percent of the feldspar. This rock correlates generally with the Toluca Quartz Monzonite at Acre Rock, except that it is somewhat more sodiac, contains more muscovite, and has a much more distinct foliation.

The Louisa Smart property, on a fork of Webbs Creek about 2.5 miles west-northwest of Ellenboro, Rutherford County, N.C., was the site of extensive mining of monazite placers prior to 1910. Bedrock is not well exposed but appears to be mainly mica schist that has been granitized to gneiss. Residual boulders of such granite gneiss are in the woods near Webbs Creek and have been proved to be monazite bearing by crushing and panning. One of these boulders was found to have an uncommon composition, in that its feldspars were almost entirely orthoclase and microcline. Biotite was much more plentiful than muscovite. Other minerals noted were clinozoisite, calcite, iron ores, and apatite. Saprolite of this granite gneiss at the Smart property was the source of a monazite-bearing concentrate (48 Mt 7).

ACCESSORY MINERALS

Forty-three concentrates of accessory minerals from monazite-bearing granitic rocks of the western Piedmont monazite belt were collected in North Carolina (fig. 3). A few of these concentrates are duplicates from the same locality, and others are so close together that they cannot be shown individually on figure 3. Most of the concentrates came from saprolite, but one from Surry County, two from Alexander County, and two from Cleveland County were panned from pulverized unweathered rock. The concentrates from Surry, Wilkes, and Alexander Counties are discussed with tabular summaries of the mineral composition, but the accessory minerals found in 31 concentrates from Burke, Cleveland, and Rutherford Counties are assembled in table 16. The two concentrates from saprolite in Person and Lincoln Counties, N.C., southeast of the belt, are discussed separately.

Five concentrates from saprolite (45 Mt 296, 48 Mt 43, 52 Mt 76, 52 Mt 77, and 52 Mt 79) and one from powdered fresh rock (53 Mt 47) were taken near Mount Airy in Surry County, N.C. (fig. 3). Though these appear to represent a single intrusive body, they vary considerably in the volume of accessory minerals recovered by panning and in other respects. The concentrates range from 0.005 to 0.03 percent of bedrock and have a mean value of 0.015 percent. This is only a fifth of the average tenor of concentrates for the monazite-bearing rocks of the region (tables 5, 13), and is about a ninth of the mean tenor for all the granitic rocks. Magnetite is absent except in the sample of powdered granite, where it constitutes 4.1 percent of the concentrates and 0.0009 percent of the bedrock. Ilmenite is universally present, making up 8.0–79.5 percent of the concentrates and having a mean tenor of 29.5 percent. The range of ilmenite in bedrock is 0.0015–0.007 percent having a mean value of 0.004 percent. The six cited samples are monazite bearing, but another sample, taken about 2 miles north of Mount Airy (fig. 3) represents a peripheral phase of the granite that contains no monazite. The tenor of monazite in the six monazite-bearing samples ranges from 0.5 to 45.0 percent of the concentrates and has a mean value of 0.0003 percent. Zircon was in all bedrock is 0.000025–0.0053 percent, and has a mean value of 0.0018 percent. Epidote is generally present, making up 20–53 percent of the concentrates and 0.003–0.016 percent of the rock, and has a mean value of 0.009 percent. Rutile was observed in three samples, making up 1.8–5.0 percent of the concentrates and 0.0003–0.001 percent of the rock and has a mean value of 0.0003 percent. Zircon was in all samples, but its tenor was almost unmeasurably low. Apatite rarely survives saprolitization, but in the sample of powdered granite it constituted 25 percent of the concentrates and 0.005 percent of the rock.

The Mount Airy Granite is so uniform in appearance and composition and so lacking in inherited mineralogical or structural features that it is regarded as a magmatic intrusive rock, though it shows certain features that are abnormal in magmatic granites of deep-seated origin (Dietrich, 1961, p. 56). Unusual features are the low tenor in accessory minerals, the almost universal absence of magnetite and a correspondingly low tenor in total iron ores, the paucity of zircon, and the presence of much epidote. The virtual absence of magnetite and the low tenor in iron ores suggests that the source rock was a sedimentary or metasedimentary rock that had passed through one or more cycles of erosion before it was melted to produce the Mount Airy Granite. The low tenor in accessory minerals, including zircon, also suggests a sedimentary source rock, but one in which the heavy minerals were not appreciably concentrated. Few if any granites in the Southeastern States that have high tenors in epidote are believed to be entirely of magmatic origin, and this doubt applies also to the Mount Airy Granite. Dietrich (1961, p. 42–45) recognized

TABLE 16.—*Accessory minerals and amounts, in percent, in concentrates from 31 samples from the western Piedmont monazite belt in Burke, Cleveland, and Rutherford Counties, N.C.*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock		Minerals in concentrates							
	Total	Monazite	Magnetite	Ilmenite	Monazite	Garnet	Zircon	Rutile	Sillimanite	Quartz and others
Burke County										
45 Mt 138	0.0039	0.0028	------	19.0	72.0	1.0	5.0	1.0	------	2.0
45 Mt 194	.0067	.0034	------	33.0	51.0	------	1.0	------	------	15.0
47 Mt 71	.011	.0052	------	6.7	49.8	------	1.9	------	------	41.6
48 Mt 29	.023	.017	------	.8	72.0	------	3.9	4.0	------	19.3
48 Mt 45	.005	.0019	------	1.8	38.5	------	7.7	8.2	------	43.8
Cleveland County										
45 Mt 112	0.071	0.059	------	6.0	83.0	------	------	------	------	11.0
45 Mt 119	.0017	.0004	------	40.0	22.0	------	4.0	------	1.0	33.0
45 Mt 125	.011	.0067	------	2.0	61.0	------	8.0	9.0	------	20.0
45 Mt 136	.0012	.0005	------	7.0	43.0	4.0	11.0	------	------	35.0
45 Mt 137	.0041	.0023	------	1.0	55.0	2.0	13.0	------	------	29.0
45 Mt 139	.012	.003	------	47.0	25.0	1.0	12.0	1.0	6.0	8.0
45 Mt 152	.05	.031	------	16.0	63.0	1.0	12.0	2.0	------	6.0
45 Mt 155	.017	.0007	------	60.0	4.0	15.0	10.0	------	5.0	6.0
45 Mt 158	.0015	.0002	------	49.0	16.0	------	16.0	5.0	------	14.0
45 Mt 161	.0028	.0008	------	8.0	30.0	1.0	33.0	------	------	28.0
45 Mt 173	.0085	.0065	------	3.0	77.0	1.0	7.0	------	------	12.0
45 Mt 182	.067	.019	0.5	61.3	29.0	------	------	------	1.0	8.2
45 Mt 210	.014	.0024	------	4.0	17.0	72.0	6.0	------	1.0	------
45 Mt 222	1.61	.013	------	------	.8	98.2	1.0	------	------	------
45 Mt 232	.0092	.0042	------	5.0	46.0	------	37.0	------	------	12.0
45 Mt 245	.0019	.0007	------	7.0	35.0	------	33.0	------	------	25.0
45 Mt 279	.044	.035	------	9.0	81.0	1.0	6.0	------	1.0	2.0
47 Mt 57	.44	.0022	------	------	.5	99.0	.5	------	------	------
47 Mt 73	.018	.011	------	9.6	64.3	------	.6	8.4	------	17.1
48 Mt 2	.14	.0074	------	44.9	5.3	22.3	------	4.5	1.3	21.7
48 Mt 28	.0082	.0009	9.2	1.3	10.9	Tr.	60.1	------	------	18.5
49 Mt 136	.0046	.002	------	2.5	43.1	3.7	23.3	------	------	27.4
Rutherford County										
45 Mt 177	0.015	0.0095	------	1.0	62.0	------	4.0	------	------	33.0
45 Mt 179	.013	.0099	4.1	2.0	78.0	1.0	4.0	------	------	10.9
45 Mt 180	.0083	.0032	------	54.0	39.0	------	1.0	1.0	------	5.0
48 Mt 7	.042	.019	------	2.0	46.2	15.9	9.4	7.6	------	18.9
Means	.086	.0091	0.4	16.3	42.6	10.9	10.7	1.7	0.5	16.9

two generations of epidote, the earlier of which he regarded as of magmatic origin.

Another sample of accessory minerals (53 Mt 47) was collected in the southern part of Surry County (pl. 1 and fig. 3) from a fine-grained granitic gneiss. The concentrates, which constitute 0.03 percent of the rock, include 40 percent ilmenite, 16 percent monazite, 3 percent xenotime, 5 percent hematite, 18 percent zircon, and other minerals. The host rock is interpreted as the derivative of some metasedimentary gneiss.

The concentrate (50 Mt 192) collected from gneiss about 8 miles east of Wilkesboro in Wilkes County N.C. (fig. 3) constitutes 0.0043 percent of the gneiss, and includes 22 percent ilmenite, 49 percent monazite, 13 percent zircon, and no magnetite. The prisms of zircon are heterogeneous in size, habit, and color but are not perceptibly rounded. The host rock containing these minerals appears from field examination and from interpretation of the concentrates to be a paragneiss.

Two concentrates were taken from bedrock at the Hiddenite mine in Alexander County. The concentrate (45 Mt 236) made from quartzite from the mine dump amounts to 0.013 percent of the rock and contains 15 percent magnetite, 8 percent ilmenite, 17 percent monazite, 22 percent garnet, 8 percent zircon, and other minerals. The concentrate (45 Mt 243) panned from pulverized pegmatite constitutes 0.012 percent of the rock and contains no magnetite, 54 percent ilmenite, 8 percent monazite, and 3 percent zircon, together with garnet and other minerals. The proportions of magnetite and ilmenite are strikingly different; a possible explanation is that a considerable part of the iron ores were original detrital grains in the quartzite before it was metamorphosed. Gravel from a brook that heads at the Hiddenite mine contained 0.3 percent heavy minerals, a nearly 25-fold increase over the tenor in bedrock, and the concentrate consisted of 0.5 percent magnetite, 58 percent ilmenite, 21 percent monazite, and 17 percent other minerals. Thus, the fluvial concentration of monazite into a workable placer about 3 miles downstream on Third Creek, at Milholland's Mill, is quite understandable.

A concentrate (54 Mt 64) was panned from saprolite of the monazite-bearing gneissic granite near Roxboro in Person County, an anomalous locality between the western and eastern Piedmont monazite belts. The concentrate constitutes 0.0055 percent of the rock and includes 46 percent magnetite, 33 percent ilmenite, 5 percent monazite, and 8 percent zircon. The zircon occurs as uniformly small prisms, about 0.05 by 0.1 mm in size, having perfect crystallographic edges. This rock, judged from its ilmenite:magnetite ratio of 1:1.4 and uniformly prismatic zircon grains, should be of magmatic origin, but the low tenor in total accessory minerals appears to vitiate this conclusion. The nature of the source rock is therefore indeterminate from the quantity and composition of the accessory minerals.

Five concentrates were collected from monazite-bearing bedrock in Burke County, 22 from Cleveland County, and 4 from Rutherford County (table 16). The mean tenor of accessory minerals in bedrock for these concentrates is 0.086 percent, an insignificant 0.014 percent more than the regional average for monazite-bearing rocks. More striking, however, is the low tenor in the total iron ores. Thirty-one concentrates listed in table 16 contain virtually no magnetite and have a mean tenor of only 16.3 percent of ilmenite or 0.0048 percent in bedrock. Hence the tenor of ilmenite in monazite-bearing granitic rocks from the heart of the western Piedmont monazite belt is only one-sixth of that in all the monazite-bearing rocks of the Southeastern States (table 5).

The mean tenor of monazite in these 31 concentrates is relatively high, as might be expected from the area in which they were collected, which is the widest and highest grade part of the western Piedmont monazite belt. The highest tenor of monazite in bedrock is 0.059 percent (45 Mt 112), and the lowest tenor is 0.0002 percent (45 Mt 158), both from rocks in Cleveland County. The mean tenor of monazite in bedrock for 20 of these samples that came from the Toluca Quartz Monzonite and the older gneiss is 0.006 percent, as compared with 0.009 percent for the whole group. The range from maximum to minimum values in the granitic rocks is great, showing that monazite is not evenly distributed in these rocks. The work of Overstreet, Yates, and Griffitts (1963a, table 1) showed the older gneiss to be slightly richer in monazite than is the Toluca.

Xenotime is also present in many of these concentrates, possibly in a tenth of them, but it has been included with monazite in table 16. The presence of xenotime was first observed by the writer in 1945 in alluvial concentrates from the headwaters of Grassy Creek about 0.6 mile southeast of Polkville, Cleveland County. At this locality, monazite and xenotime constitute respectively 72 and 5 percent of the alluvial concentrates, so this ratio may be expected to apply to the bedrock in that vicinity.

Comparison of the tenors of monazite and ilmenite in the panned concentrates emphasizes the relatively low content of iron ores: monazite constitutes more than two-fifths of the concentrates, and is 2.7 times as plentiful as ilmenite in the concentrates and 1.9 times as plentiful as ilmenite in bedrock. The tenors of garnet and zircon are about equal, but zircon is more generally distributed. Two very high tenors in garnet from pulverized samples of the Toluca Quartz Monzonite (45 Mt 222 and 47 Mt 57) show that garnet is more plentiful than indicated by table 16, but it tends to distintegrate during saprolitization. Rutile is relatively rare, having been identified in only 11 samples, and it is also erratically distributed. Sillimanite occurs in only a few of the sampled rocks, mainly in granitized or pegmatized schist and in pegmatites, but it is a major component of the very widespread sillimanite schist of the region, where it is commonly accompanied by accessory rutile and monazite (Overstreet and others, 1968, pl. 2).

One concentrate was taken from an anomalous locality of monazite-bearing granite gneiss in Lincoln County (54 Mt 66) outside the monazite belt (pl. 1 and fig. 3). The accessory minerals constituted 0.017 percent of the rock, and monazite was 0.0024 percent of the rock. The minerals in the concentrate included 2.7 percent magnetite, 57.6 percent ilmenite, and 14.1 percent monazite. The tenor of accessory minerals is only one-fourth that of the average tenor for monazite-bearing granitic rocks in the Southeastern States, and the magnetite:ilmenite ratio is 1:11.3. These values are consonant with the interpretation of this rock as a paragneiss.

SOUTH CAROLINA

BEDROCK

Monazite has been found in saprolite of bedrock at 23 localities within the western Piedmont monazite belt of South Carolina in Cherokee, Spartanburg, Greenville, Laurens, and Anderson Counties (fig. 5). Monazite has also been reported by Alfred and Schroeder (1958, p. 2) at the Liberty quarry in Pickens County, S.C., but saprolite just south of this quarry was found by the writer to contain no monazite. Sixteen other localities in Cherokee, Spartanburg, and Greenville Counties have been listed (Mertie, 1953) where alluvial monazite was collected and analyzed for thorium and uranium. According to Sloan (1908) fluvial monazite has also been found in York and Abbeville Counties, S.C., along the southeastern flank of the western

TABLE 17.—*Number of samples in different types of monazite-bearing rocks in 5 counties in the western Piedmont monazite belt, South Carolina*

[Leaders (---), not sampled]

County	Granitic gneiss and schist	Granitic dike	Pegmatite	Granitized bedrock	Gneissic granite
Anderson	1	1	--	--	--
Cherokee	1	--	2	2	--
Spartanburg	2	--	1	--	1
Greenville	3	1	--	3	3
Laurens	2	--	--	--	--
Total	9	2	3	5	4

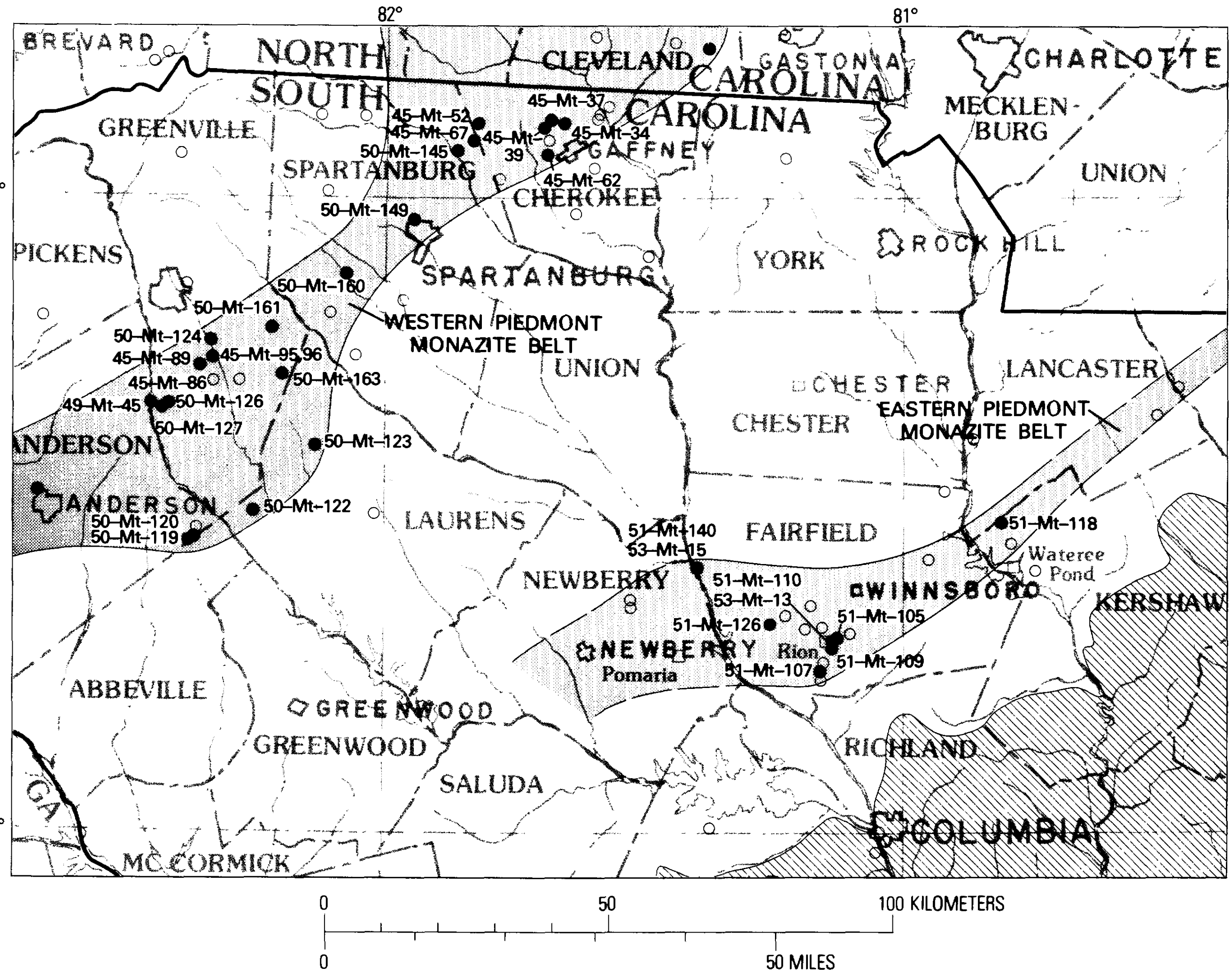
Piedmont monazite belt, and Overstreet and others (1968, pl. 3) noted the presence of alluvial monazite also in Abbeville and Greenwood Counties on the southeast and in Oconee and Pickens Counties, S.C., on the northwest.

The petrographic character of the rocks of South Carolina was only known in a reconnaissance way at the time this investigation was made. Within the western Piedmont monazite belt the general character of the bedrock was inferred by the writer from the saprolites that were sampled and panned for their accessory minerals. From North Carolina across South Carolina and southwestward to Georgia this belt includes no large intrusive bodies of granitic rocks but consists dominantly of gneiss of various types, granitic dikes, mainly pegmatitic, and some small bodies of gneissic granite that appear to intrude the older country rock (Overstreet and Bell, 1965). The types of bedrock observed at the sites where saprolite was sampled are listed in table 17. In South Carolina, as elsewhere in the western Piedmont monazite belt, the granitic gneisses are more important sources of monazite than the massive granitic rocks.

ACCESSORY MINERALS

The principal accessory minerals in panned concentrates from saprolite of monazite-bearing rocks in South Carolina, arranged from northeast to southwest, are listed in table 18, where it is shown that the tenor of the accessory minerals in bedrock ranges from 0.2 percent to 0.0015 percent, and the mean value is 0.041 percent. This mean is 0.031 percent less than the mean tenor for all the monazite-bearing rocks (table 5); as iron ores constitute a major part of the accessory minerals, a low tenor in iron ores is suggested for these rocks.

The iron ores of the concentrates are mainly ilmenite; only three samples contain significant amounts of magnetite, and two samples contain mere traces of magnetite. Thus, in samples 50 Mt 163, 50 Mt 123, and 50 Mt 122, the tenors in mag-



EXPLANATION

Monazite belt—Dashed where inferred

Unconsolidated sedimentary rocks of Atlantic Coastal Plain

● Sample locality and field number of monazite-bearing concentrate panned from saprolite or unweathered rock; description of locality and material sampled in Mertie (1978)

○ Sample locality of monazite-free concentrate panned from saprolite or unweathered rock, used to define the monazite belts

FIGURE 5.—Distribution and field numbers of monazite-bearing concentrates in South Carolina.

netite are respectively 15.0, 63.9, and 45.5 percent. All but four of the samples, however, contain ilmenite, though in highly variable amounts, ranging from 69.8 to 0.1 percent of the concentrates and having a mean tenor of 16.2 percent for the 23 samples. The highest amounts of ilmenite are in samples 50 Mt 149, 50 Mt 163, and 50 Mt 126, which have tenors respectively of 69.8, 66.0, and 50.7 percent. The total mean percentage of iron ores in the concentrates is 21.6 percent, as compared with the average tenor of 42.0 percent for all the monazite-bearing rocks of the region (table 5), which is a deficit of 20.4 percent. The corresponding local and general tenors of total iron ores in bedrock are 0.011 and 0.046, indicating a deficiency of 0.035 percent. The facts that all these concentrates were panned from saprolite and that there has been some loss of magnetite during weathering may be significant.

The maximum and minimum tenors of monazite in the concentrates are 75.5 and 2.0 percent, having

TABLE 18.—*Accessory minerals and amounts, in percent, in concentrates from 23 samples from the western Piedmont monazite belt in 5 counties of South Carolina*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock			Minerals in concentrates								
	Total	Monazite	Xenotime	Magnetite	Ilmenite	Monazite	Xenotime	Epidote	Garnet	Zircon	Rutile	Quartz and others
Cherokee County												
45 Mt 34	0.019	0.012	------	------	4.0	63.0	------	------	------	6.0	1.0	26.0
45 Mt 37	.11	.005	------	------	1.0	47.0	------	------	------	2.0	16.0	34.0
45 Mt 39	.065	.002	------	------	3.0	3.0	------	------	------	4.0	63.0	27.0
45 Mt 62	.046	.01	------	------	.1	22.0	------	------	1.0	5.0	36.0	35.9
45 Mt 52	.013	.0018	------	------	12.0	14.0	------	------	2.0	6.0	5.0	61.0
Spartanburg County												
45 Mt 67	0.032	0.0013	------	------	------	4.0	------	------	61.0	3.0	2.0	30.0
50 Mt 145	.02	.013	------	------	------	64.9	------	0.5	------	23.8	1.5	9.3
50 Mt 149	.032	.0028	------	------	69.8	8.7	------	------	------	1.0	.6	19.9
50 Mt 160	.0022	.0013	------	------	11.7	60.8	1.7	------	3.1	8.0	6.3	8.4
Greenville County												
50 Mt 161	0.0015	0.0002	------	------	------	13.0	------	4.0	------	16.0	2.0	65.0
50 Mt 163	.018	.0007	------	15.0	66.0	4.0	------	2.0	------	3.0	3.0	7.0
50 Mt 124	.0094	.0013	------	.1	6.7	14.2	------	------	------	59.0	------	20.0
45 Mt 95	.04	.015	------	------	27.0	40.0	------	------	------	1.0	1.0	31.0
45 Mt 96	.0039	.0009	------	------	15.0	23.0	------	3.0	------	1.0	1.0	57.0
45 Mt 89	.034	.018	0.0003	------	22.5	53.7	1.0	------	1.0	11.9	.8	9.1
45 Mt 86	.2	.0098	------	------	10.0	5.0	------	------	80.0	2.0	------	3.0
50 Mt 126	.016	.0041	------	.7	50.7	25.8	------	------	------	5.0	------	17.8
50 Mt 127	.075	.05	------	Tr.	------	66.7	------	.1	------	15.1	------	18.1
49 Mt 45	.011	.0083	------	------	1.1	75.5	.2	------	------	14.3	------	8.9
Laurens County												
50 Mt 123	0.053	0.0011	------	63.9	29.0	2.0	------	------	------	Tr.	Tr.	5.1
50 Mt 122	.14	.0083	------	45.5	34.6	6.0	------	------	------	2.0	.5	11.4
Anderson County												
50 Mt 120	0.0051	0.0025	0.0006	------	4.0	45.8	12.1	5.0	------	12.6	------	20.5
50 Mt 119	.0088	.0044	------	------	4.0	48.7	------	------	------	22.0	2.4	22.9
Means	0.041	0.0076	Tr.	5.4	16.2	30.9	0.7	0.6	6.4	9.7	6.2	23.8

a mean value of 30.9 percent (table 18). The maximum and minimum tenors of monazite in bedrock are 0.05 and 0.0002 percent, having a mean value of 0.0076. The mean tenors of monazite in the concentrates and in bedrock for all the monazite-bearing rocks of the Southeastern States are 21.9 and 0.0047 percent (tables 5, 13), so that the values for the western Piedmont monazite belt of South Carolina are respectively 9.0 percent and 0.0029 percent above the general average. They are smaller, however, by 11.7 and 0.0015 percent, respectively, than the corresponding mean values for the core of the belt in Burke, Cleveland, and Rutherford Counties, N.C.

Xenotime was recognized in four concentrates from saprolite (table 18) and in two from alluvium (Mertie, 1953) within the western Piedmont monazite belt of South Carolina, but these data do not suffice to establish a general xenotime:monazite ratio. Xenotime is known to be present in other placers in South Carolina (Overstreet, 1967, p. 237–246); thus, it probably occurs with monazite at an undetermined number of other saprolite localities, but these two minerals were not discriminated from one another in most samples listed in table 18.

Epidote or garnet was identified in 12 samples, though in none of these were both present. The mean tenors of these two minerals in the concentrates for 23 samples are respectively 0.6 and 6.4 percent. Two samples, 45 Mt 67 and 45 Mt 86, had very high tenors in garnet, respectively 61.0 and 80.0 percent. Rutile occurs in 17 samples, the tenors ranging from 63.0 percent of the concentrates to a trace, and having a mean tenor of 6.2 percent.

Zircon is present in all samples, having tenors ranging from 59.0 percent of the concentrates to a mere trace, and a mean value of 9.7 percent. This is nearly the same tenor as was found for monazite-bearing concentrates from Burke, Cleveland, and Rutherford Counties, N.C., (table 16); it is noteworthy that in these two areas, where monazite is most plentiful, zircon also is more plentiful than elsewhere in the monazite belts, as determined in concentrates from saprolite. The reason for this is interpreted here to be the marked dominance of metasedimentary gneiss over magmatic granitic rocks, for the reverse relationship appears to be true of the magmatic monazite-bearing granitic rocks. An examination of the grains of zircon tends to confirm this interpretation. Each of the samples thought to represent metasedimentary gneisses contains zircons of different color, crystallographic form, or size. Some in each sample are subrounded, well rounded, or ovoidal in shape. The zircons in the three samples containing magnetite are homogeneous, but also show various degrees of rounding, thus suggesting the possibility that these rocks are either partial melts of sedimentary or metasedimentary rocks, or otherwise may be such rocks that have been granitized, producing migmatites. The paucity of iron ores in these 23 samples, the scarcity of magnetite, and the high tenors in ilmenite also are interpreted to indicate rocks that originated as sediments.

The western Piedmont monazite belt attains its greatest width in Cleveland and Rutherford Counties, N.C., and remains wide to the southwest into South Carolina, but a constriction of the belt develops in the vicinity of Spartanburg, S.C., (pl. 1). These contiguous areas of North and South Carolina, northeast of the constriction near Spartanburg, are where the principal mining for monazite was done. They are the areas for which the greatest amount of information is available regarding monazite, both in alluvial deposits and in bedrock.

A comparison of the accessory minerals in the widest parts of the western Piedmont monazite belt of North and South Carolina shows many similarities through this segment of the belt. The 31 samples from Burke, Cleveland, and Rutherford Counties, N.C. (table 16), are best compared with the 19 samples from Cherokee, Spartanburg, and Greenville Counties, S.C., but the mean values of these 19 samples are little changed by including the 4 samples from farther south in Laurens County (50 Mt 122, 50 Mt 123) and Anderson County (50 Mt 119, 50 Mt 120) (table 18). The total volume of concentrates from the samples from North Carolina is about twice as great as the corresponding volumes for the concentrates from the samples from South Carolina.

Magnetite is scarce throughout this part of the belt. Ilmenite, where present in the concentrates from the three North Carolina counties, has maximum, minimum, and mean tenors respectively of 61.3, zero, and 16.3 percent, compared with the corresponding values for concentrates from the belt in South Carolina of 69.8, zero, and 16.2 percent. The total iron ores in bedrock, however, in the three principal North Carolina counties and in the five South Carolina counties, are respectively 0.005 and 0.011 percent. In general, iron ores are only half as plentiful in concentrates from North Carolina as in those from this segment of the western Piedmont belt in South Carolina. The higher volume of concentrates in the samples from North Carolina is due to a larger volume of other accessory minerals.

The tenors of monazite in the widest part of the belt in North and South Carolina are of the same general order of magnitude. The maximum, minimum, and mean tenors of monazite in the concentrates from North Carolina (table 16) have been shown to be, respectively, 83.0, 0.5, and 42.6 percent; the corresponding tenors in the concentrates from South Carolina (table 18) are, respectively, 75.5, 2.0, and 30.9 percent. Similarly, the maximum, minimum, and mean tenors of monazite in bedrock in samples from the western Piedmont monazite belt in North Carolina are, respectively, 0.059, 0.0002, and 0.009 percent (table 16), as compared with the corresponding values for South Carolina of 0.05, 0.0002, and 0.0076 percent (table 18).

Garnet and epidote are below the regional average for concentrates from both States, but where present may have high tenors; yet these two minerals are somewhat more prevalent in the samples from North Carolina than in those from South Carolina. Examples of high contents of garnet are samples 45 Mt 210, 45 Mt 222, and 47 Mt 57 in North Carolina (table 16), having tenors respectively of 72.0, 98.2, and 99.0 percent, and samples 45 Mt 67 and 45 Mt 86 in South Carolina (table 18), having tenors respectively of 61.0 and 80.0 percent. The percentages of zircon in the concentrates from saprolite are nearly the same for both States, but the percentage of rutile is greater in South Carolina than in North Carolina.

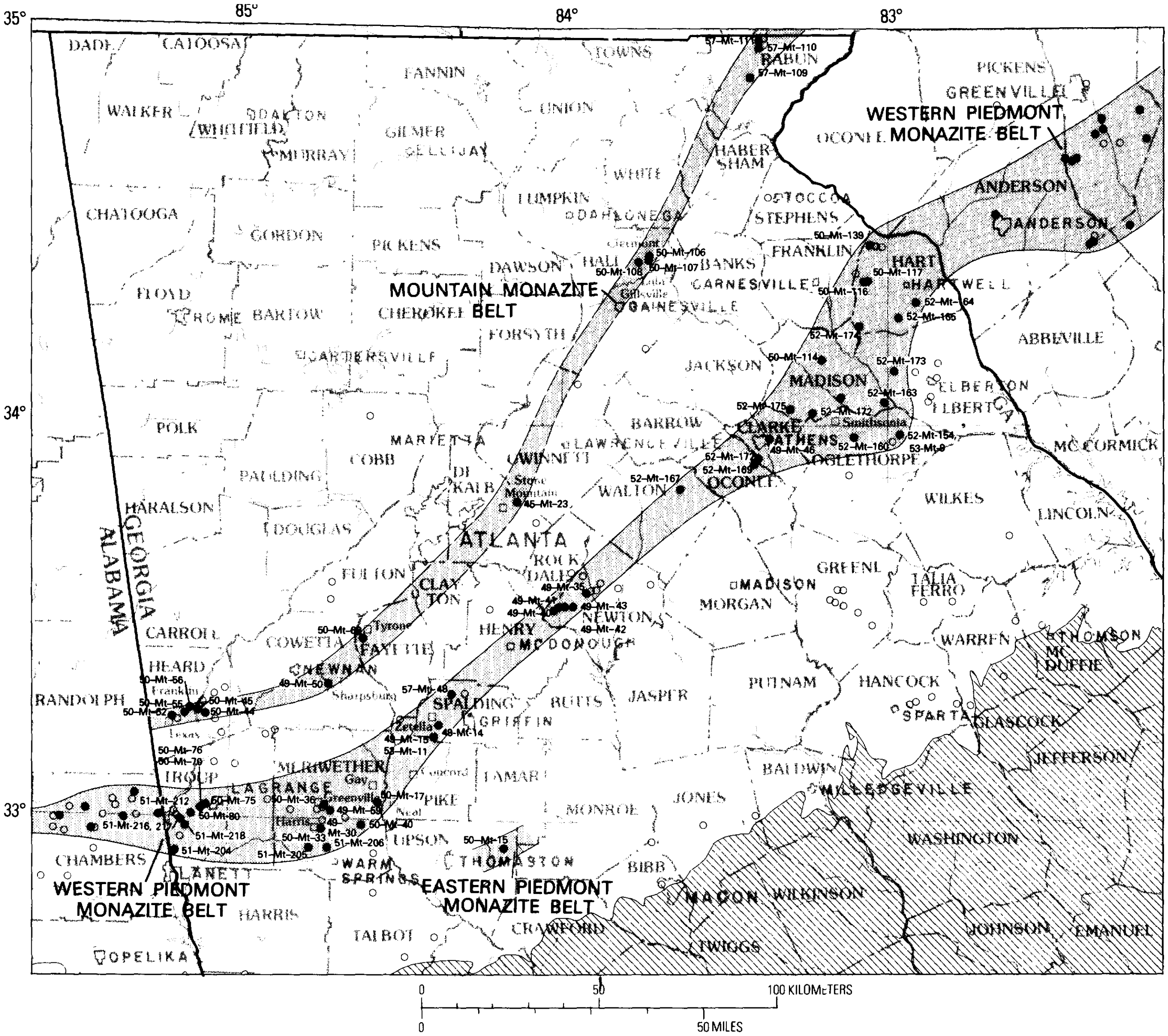
GEORGIA

BEDROCK

Monazite was known in the gold placers of Georgia in the 1880's (Engineering and Mining Journal, 1888, p. 2), but the discovery of monazite in bedrock was not made until 1949 when the writer panned it from saprolite in the western monazite belt (pl. 1 and fig. 6). The initial discoveries of xenotime in bedrock in Georgia were also made in 1949. By 1953, the writer had discovered monazite and xenotime in bedrock in Hart, Madison, Elbert, Clarke, Oglethorpe, Walton, Newton, Spalding, Meriwether, and Troup Counties. Monazite and xenotime probably also occur in Oconee and Henry Counties, and monazite most likely is present in Pike County (pl. 1 and fig. 6).

Monazite has been found in the western Piedmont monazite belt of Georgia in three units of the biotite gneiss and schist shown on the geologic map of Georgia (Georgia Division of Mines, Mining and Geology, 1939): (1) Precambrian biotite gneiss and schist that include injection gneiss, (2) biotite gneiss and schist that include granite gneiss of the Lithonia type, and (3) biotite gneiss and schist that include biotite and muscovite granitic rocks that are partly of the upper Paleozoic Stone Mountain type. In the following pages these are called respectively units 1, 2, and 3. Monazite is not omnipresent in these rocks but occurs instead only within them where they are in the western Piedmont monazite belt. The biotite gneiss and schist is part of the Carolina Gneiss of former usage, which in Georgia (Georgia Division of Mines, Mining, and Geology, 1939) was called the Carolina Series of Crickmay (1936) and consists of mica gneiss, mica schist, and granitoid layers. The granite gneiss of the Lithonia type was also described (Georgia Division of Mines, Mining, and Geology, 1939) as Precambrian but may be younger than the Carolina Gneiss. The biotite and muscovite granitic rocks that are partly of the Stone Mountain type were interpreted as upper Palezoic intrusive rocks (Georgia Division of Mines, Mining, and Geology, 1939). In Georgia, as elsewhere in the Southeastern States, the age relations of the Precambrian and the Paleozoic rocks are being revised and the rocks are being mapped as formations and groups of formations (Clarke, 1952; Grant, 1958; Herrmann, 1954; Hewett and Crickmay, 1937, Hurst, 1953; and Parizek, 1953). All these reports bear upon the geology of the western and possibly upon the eastern Piedmont monazite belts, but in these reports the presence of monazite and xenotime was recorded only by Hurst (1953) and Parizek (1953).

The geologic map of Georgia (Georgia Division of Mines, Mining, and Geology, 1939) was based upon reconnaissance surveys in which much generalization was required, with the result that rather diverse rocks were assembled in mappable units. The Carolina Series is heterogeneous in petrographic character and origin, but consists dominantly of metasedimentary rocks. The granite gneiss of the Lithonia type likewise includes rocks of different origin, but on the geologic map of Georgia it is considered to consist mainly of metaigneous rocks. The biotite and muscovite granitic rocks include rocks as diverse in character as the massive granite in Elbert County and Oglethorpe County, the gneissoid granite of Stone Mountain east of Atlanta, and the gneissic granite of the Zetella monazite district of Spalding, Pike, and Meriwether Counties. Many types of granitic rocks actually are found among these three principal groups, the monazite-



EXPLANATION

Monazite belt—Dashed where inferred

Unconsolidated sedimentary rocks of Atlantic Coastal Plain

• Sample locality and field number of monazite-bearing concentrate panned from saprolite or unweathered rock; description of locality and material sampled in Mertie (1978)

○ Sample locality of monazite-free concentrate panned from saprolite or unweathered rock, used to define the monazite belts

FIGURE 6.—Distribution and field numbers of monazite-bearing concentrates in Georgia.

bearing varieties of which are discussed below, beginning with exposures in Hart County and progressing southwestward.

Hart County is the most northeastern county of Georgia within the western Piedmont monazite belt. The two groups of Precambrian rocks and the granitic intrusives therein, shown on the geologic map of Georgia (Georgia Division of Mines, Mining, and Geology, 1939), have been divided by Grant (1958) into seven formations of metamorphic rocks and five formations of granitic rocks. Monazite and xenotime have been found by the writer in three of the metamorphic and in two of the granitic formations, and they are probably present in some of the others. The formations mapped by Grant in which monazite and xenotime have been identified are sillimanite-mica schist, sillimanite-graphite schist, biotite-plagioclase gneiss, muscovite granodiorite, and biotite granodiorite gneiss. The distribution of the monazite-bearing rocks is such that all of Hart County may be said to lie within the western Piedmont monazite belt.

The bedrock of Madison County consists dominantly of rocks of unit 1; the monazite-bearing rocks are mainly granite gneiss containing some granitic dikes. Monazite was found in saprolite of a massive granite near the border between Madison and Elbert Counties. This rock is similar to the massive granite of the area surrounding Elberton, Elbert County, which is not generally monazite bearing. However, in the western part of Elbert County, within 4 miles of Madison County, a monazite-bearing dike was found. Monazite was found in the northern part of Oglethorpe County in granite gneiss exposed 4.5 miles east-southeast of Smithonia and in massive granite at the Liberty quarry. The rock at the Liberty quarry is a gray monumental stone similar in appearance and character to monazite-free massive granite in Elbert and Oglethorpe Counties. The rock at the Liberty quarry is a monzogranite that consists of microcline, microperthite, plagioclase, quartz, biotite, muscovite, apatite, and visible iron ores. Evidently the Liberty quarry locality is far enough west so that the rock is in the western Piedmont monazite belt.

The bedrock of Clarke County is shown on the geologic map of Georgia (Georgia Division of Mines, Mining, and Geology, 1939) to consist dominantly of the rocks of unit 1: an area of about 12 square miles to the northwest, west, and south of Athens consists of the rock of unit 2. Parizek (1953) showed granite extending east of Athens and the Oconee River, occupying the central and southeastern part of Clarke County, and being bordered successively by zones of migmatite and rocks of the Carolina Series.

The granite near Athens varies considerably in color, granularity, and fabric. The color ranges from light to dark gray, according to the content of mica, and the granularity from fine to coarse. One phase is porphyritic, having phenocrysts measuring from 0.5–7.5 cm. The granite is generally massive but becomes somewhat gneissic along its periphery. Granitic stringers and pegmatite dikes invade the bounding schist. Thin sections indicate that the principal granitic rock is a biotite adamellite consisting mainly of orthoclase, microcline, oligoclase, quartz, biotite, muscovite (in part secondary), apatite, garnet, and iron ores. Epidote is present in some specimens of the rocks. Other accessory minerals have been found in panned samples of the saprolite. The norm of a chemical analysis (table 1, sample Q), of a granite gneiss from an old quarry on the east side of Athens shows that the content of plagioclase is twice that of the orthoclase, and the plagioclase is computed to be An_{22} These data suggest that this gneiss has the composition of an adamellite, though very close to monzotonalite (granodiorite). This may be a migmatitic rock.

Monazite and xenotime were discovered by the writer in 1949 in the adamellite in the vicinity of Athens, and later in the surrounding metamorphic rocks. The presence of monazite in the granitic rocks of Clarke County was confirmed by Parizek (1953, p. 25) in 1950. In 1951, Hurst (1953, p. 244–255) made a detailed study of the heavy minerals of the granitic and bordering rocks and found that the accessory minerals recovered from the granitic saprolite included both monazite and xenotime.

The monazite-bearing bedrock of Walton and Newton Counties is inferred by the writer from the appearance of saprolite to consist mainly of granite gneiss and granitized schistose and gneissic rocks, shown as parts of units 1 and 2 by Georgia Division of Mines, Mining, and Geology (1939).

The bedrock of Spalding, Pike, and Meriwether Counties comprises rocks of units 1, 2, and 3 but the most significant are the granitic rocks of unit 3 (Georgia Division of Mines, Mining, and Geology, 1939). The granitic rocks occur at two principal sites which are about 80 and 15 square miles in area. The larger mass of granitic rock crops out in all three of the counties cited, and has a major axis trending about N. 50° E. The smaller body, bounded by Gay in Meriwether County and Concord and Neal in Pike County, is a granite gneiss which differs markedly from the other granite, though both are monazite bearing.

The larger mass of granitic rock is exposed at numerous places in roadcuts and pavements in Spalding, Pike, and Meriwether Counties, but the type locality is a pavement and associated saprolite along the east side of an unpaved road about 2 miles S. 13° W. of Zetella in Spalding County. Monazite was found first by the writer in the saprolite (49 Mt 15) but later was identified in a pulverized sample (53 Mt 11) taken from the pavement (fig. 6). This granite is a nearly equigranular dark-gray massive rock that is locally foliated. In thin section it consists of microcline, oligoclase, quartz, considerable biotite, less muscovite, and accessory apatite, iron ores, zircon, and sphene. Accessory monazite is visible only in panned samples. The tenor of apatite is high, as would be expected from the percentage of P_2O_5 shown in chemical analysis O in table 1. Both the modal and normal ratios of the feldspars indicate that this granitic rock should be classified as biotite adamellite.

The smaller body of granitic gneiss bounded by Gay, Concord, and Neal may represent granitized rock genetically related to the biotite adamellite near Zetella. It is a gneissic biotite adamellite having a composition approaching monzotonalite.

The bedrock of Meriwether County comprises (Georgia Division of Mines, Mining, and Geology, 1939) rocks of units 1, 2, and 3, all of which are in part monazite bearing within the western Piedmont monazite belt. These rocks have not been studied in detail but are thought to be mainly granitic gneiss of units 1 and 2, the latter including a considerable part of the Precambrian Snelson Granite as mapped in the Warm Springs quadrangle by Hewett and Crickmay (1937, pl. 1). Only the general gneissic character of these rocks could be inferred from the saprolite.

The Snelson Granite in a small quarry along the west side of a pavement 1.6 miles east of Harris, Meriwether County, is a light-gray distinctly gneissoid rock having a well-developed sheeting parallel to the surface of the ground. The foliation is wavy and in places crenulated, but the general trend is to the north with a steep easterly dip. Vertical joints strike to the north and to the east. The rock-forming minerals are microcline, quartz, oligoclase, and biotite, in part sericitized, and the accessory minerals as seen in thin section are apatite, iron ores, and zircon. This rock is a biotite monzogranite gneiss. Monazite was identified in four panned samples of the Snelson Granite.

Monazite was not identified in massive granite at the old abandoned quarry northeast of Greenville, Meriwether County, but it was found in the superjacent soil. This rock consists of microcline and microperthite, a little sericitized plagioclase, quartz, biotite, muscovite, and accessory apatite and iron ores. From analysis R in table 1, the normative ratio of orthoclase to total feldspar is seen to be 0.42; this ratio, together with the modal mafic minerals, warrants the designation of mica adamellite.

Monazite-bearing rocks were found in Troup County, Ga., west and southwest of La Grange, but other such rocks doubtless exist east and northeast of La Grange and connect with the monazite-bearing rocks of Meriwether County. Six specimens of unweathered rock were collected within the western Piedmont monazite belt in Troup County, from two general localities where the rock is probably monazite bearing but none was crushed and panned. One locality is about 4.4 miles by road west-southwest of La Grange where a small granitic pavement on the north side of State Route 14 exposes a fine-grained granitic gneiss and locally a little massive granite. This granitic gneiss may typify some of the nine monazite-bearing saprolites of Troup County that were sampled for their accessory minerals (Mertie, 1978). It consists of untwinned and twinned andesine, orthoclase, quartz, biotite, and accessory apatite and iron ores, and appears to be a monzotonalite. A pink to reddish, slightly gneissoid granite is exposed about 900 feet northwest of the highway in another pavement. It also is a mica adamellite and consists of microcline, plagioclase that is sericitized and kaolinized, quartz, biotite, muscovite, and accessory apatite, iron ores, and zircon.

The second general locality is exposures of granitic rock on both sides of State Route 238 for some distance east of the bridge across the Chattahoochee River. These rocks consist mainly of monzotonalite, tonalite, and pegmatite. From the proximity of monazite-bearing saprolite, these granitic rocks are thought to be monazite bearing. All the monazite-bearing saprolite sampled in Troup County (Mertie, 1978), as shown in figure 6, is derived from granitic gneiss.

ACCESSORY MINERALS

Samples of accessory minerals were panned from monazite-bearing granitic rocks of the western Piedmont monazite belt of Georgia at 43 localities in Hart, Elbert, Oglethorpe, Madison, Clarke, Walton, Newton, Spalding, Meriwether, and Troup Counties (pl. 1 and fig. 6). These concentrates are described in table 19 from northeast to southwest by counties, and roughly by localities in the same order. All the concentrates except two were taken from saprolite, and those two were taken from pulverized unweathered rock where the saprolite had already been sampled. Thus concentrates 52 Mt 154 from saprolite and 53 Mt 9 from unweathered rock at the Liberty quarry in Oglethorpe County are comparable, as are concentrates 49 Mt 15 from saprolite and 53 Mt 11 from fresh rock exposed near Zetella in Spalding County.

The total accessory minerals constitute 0.11 percent of these rocks (table 19) as compared with 0.072 percent for all the monazite-bearing rocks of the Southeastern States, and 0.14 percent for all the southeastern granitic rocks, regardless of their content of monazite (tables 5, 13). The percentages of accessory minerals increase generally from northeast to southwest, and the highest tenors are in the most southwesterly samples, from Troup County, which have a mean tenor in accessory minerals of 0.17 percent. The maximum and minimum tenors of the accessory minerals shown by the 43 concentrates are 0.54 and 0.0009 percent, the former in Troup County.

The mean tenors of magnetite and ilmenite in the concentrates are respectively 18.0 and 30.9 percent (table 19) and in bedrock 0.032 and 0.047 percent. These tenors may be compared with the regional averages for the monazite-bearing concentrates of 12.9 and 29.1 percent, and for monazite-bearing bedrock of 0.017 and 0.029 percent (table 5). The magnetite:ilmenite ratio in the concentrates is 1:1.7 and in bedrock is 1:1.5. The mean tenors of magnetite in the concentrates and in bedrock, from samples collected in the Southeastern States regardless of the presence or absence of monazite, are respectively 29.5 and 0.028 percent. The corresponding mean percentage of ilmenite has not been determined, but it is known to exceed materially that of the magnetite. The tenors of magnetite and of the total iron ores, like the total accessory minerals, increase from northeast to southwest, being least in Hart, Oglethorpe, and Madison Counties and greatest in Troup County, where the tenors of magnetite and ilmenite in the concentrates are respectively 43.8 and 24.5 percent. These differences in the amounts of total accessory minerals and of magnetite and ilmenite, as compared with regional averages, have considerable significance. The regional averages represent a mixture of metasedimentary, igneous, and metaigneous rocks. The mean tenors for the western Piedmont monazite belt of Georgia (table 19) are interpreted by the writer to indicate the presence of a somewhat higher proportion of monazite-bearing rocks of igneous origin than are present in the region as a whole. The great increase in magnetite in the rocks in Troup County probably reflects a progressive increase in magmatic and migmatitic rocks to the southwest.

The tenors of monazite and xenotime in the concentrates and in bedrock in Georgia also differ from the values found farther to the northeast along the western Piedmont monazite belt. The mean tenors of monazite in the concentrates in the widest part of the western belt of North Carolina and South Carolina are respectively 42.6 and 30.9 percent and in bedrock 0.0091 and 0.0076 percent (tables 13, 16, 18). The mean tenors of monazite for 10 counties of Georgia for concentrates and bedrock are respectively 18.9 and 0.0062 percent (table 19). The ratio of xenotime to monazite in concentrates from the 10 counties of Georgia (table 19) is about 1:6. The corresponding ratios in the western Piedmont monazite belt of Virginia and North Carolina are gleaned from fragmentary data to be respectively 1:35 and 1:15. Xenotime is more plentiful in the rocks of the western belt in Georgia than farther north. Hurst (1953, p. 244–255) presented no mean value of the ratio of xenotime to monazite in the area around Athens in Clarke County, but his work agrees generally with the results given above. Actually, the disparity between these ratios in Georgia and in Virginia and North Carolina may be less than is apparent, though the increment southward probably still holds, because more attention may have been paid to the recognition and separation of xenotime in concentrates from Georgia.

Garnet is relatively scarce in the concentrates from Georgia compared with those from farther north, and epidote was identified in only a few of the concentrates in contrast to its common occurrence in some of the rocks of Virginia and North Carolina. Zircon also is scarcer in the rocks of the western Piedmont monazite belt in Georgia, as indicated by the mean tenor of 5.6 percent (table 19) in the monazite-bearing rocks in contrast to the mean tenor of 10.7 percent in Burke, Cleveland, and Rutherford Counties, N.C. (table 16). Rutile is sporadically distributed throughout this belt and seems to be no more or less prevalent in Georgia than farther northeastward. The sparseness of sillimanite indicates that the western Piedmont monazite belt of Georgia is not coextensive with a sillimanite zone, as it is farther north, a relation that has been discussed by Overstreet, Warr, and White (1969) in connection with the composition of monazite from this part of Georgia.

ALABAMA

BEDROCK

The western Piedmont monazite belt crosses Chambers, Tallapoosa, and Coosa Counties, Ala., (pl. 1 and fig. 7). The belt extends westward from the boundary between Alabama and Georgia to the vicinity of Alexander City, Tallapoosa County, where the belt veers southwestward toward the Coastal Plain, delimited at longitude 86° 15′ by the Coosa River. The length of this belt in Alabama is about 60 miles.

The geological formations crossed by the western Piedmont monazite belt, as shown on the geologic map of Alabama (Alabama Geological Survey,

TABLE 19.—*Accessory minerals and amounts, in percent, in concentrates from 43 samples from the western Piedmont monazite belt in 10 counties of Georgia*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock			Minerals in concentrates							
	Total	Monazite	Xenotime	Magnetite	Ilmenite	Monazite	Xenotime	Garnet	Zircon	Rutile	Quartz and others
Hart County											
52 Mt 164	0.016	0.0046	0.0039	------	7.0	29.0	25.0	------	3.0	1.0	35.0
52 Mt 165	.005	.0019	.001	------	2.0	38.0	19.0	------	15.0	------	26.0
50 Mt 139	.0044	.0029	------	1.0	3.7	66.5	------	Tr.	11.2	.7	16.9
50 Mt 117	.16	.015	------	------	26.0	9.0	------	------	------	Tr.	65.0
50 Mt 116	.086	.012	------	------	69.0	14.0	------	------	5.0	------	12.0
52 Mt 174	.0009	.0002	.0001	------	10.0	23.0	9.0	1.0	14.0	------	43.0
Elbert County											
52 Mt 173	0.0071	0.0024	0.0026	------	8.0	34.0	37.0	------	1.0	------	20.0
Oglethorpe County											
52 Mt 154	0.063	0.0022	------	29.0	64.0	3.5	------	------	------	------	3.5
53 Mt 9	.038	.0027	------	32.8	54.9	7.0	------	tr.	------	------	5.3
52 Mt 160	.027	.013	0.0003	------	18.0	49.0	1.0	------	------	10.0	22.0
Madison County											
52 Mt 163	0.0063	0.0001	------	Tr.	85.0	2.0	------	------	------	------	13.0
50 Mt 114	.1	.0006	------	------	79.9	5.6	------	------	.1	------	14.4
52 Mt 172	.007	.0048	0.0002	------	1.0	68.0	3.5	.5	18.0	.5	8.5
52 Mt 175	.0044	.0021	------	------	8.0	48.0	1.0	3.0	3.0	------	37.0
Clarke County											
49 Mt 46	0.039	0.0076	0.0014	2.1	23.0	19.5	3.6	------	13.4	12.1	26.3
52 Mt 170	.0076	.0046	.0003	------	7.0	61.0	4.0	.5	16.0	------	11.5
52 Mt 169	.44	.0044	.0044	44.5	46.0	1.0	1.0	------	------	------	7.5
Walton County											
52 Mt 167	0.014	0.0051	0.0061	------	1.0	36.0	43.0	------	6.0	------	14.0

Newton County											
49 Mt 35	0.056	0.0051	0.0001	54.4	0.9	9.1	0.1	------	2.7	0.2	32.6
49 Mt 43	.14	.0089	------	------	63.0	6.3	------	------	9.5	7.6	13.6
49 Mt 42	.083	.0056	------	1.7	44.5	6.8	Tr.	------	12.8	26.2	8.0
49 Mt 41	.42	.0054	.0013	3.9	77.9	1.3	.3	------	.3	tr.	16.3
49 Mt 40	.099	.016	------	5.4	50.0	16.7	------	------	9.1	9.0	9.8
Spalding County											
57 Mt 48	0.016	0.0007	------	80.4	1.6	5.3	------	------	------	------	12.7
49 Mt 14	.12	.0016	------	12.9	66.7	1.3	------	------	------	------	19.1
49 Mt 15	.36	.017	------	------	78.3	4.8	------	------	.2	------	16.7
53 Mt 11	.41	.037	0.012	7.1	53.1	9.0	3.0	------	3.0	------	24.8
Meriwether County											
50 Mt 17	0.16	0.0032	------	59.0	22.0	2.0	------	------	Tr.	------	17.0
50 Mt 40	.021	.0073	------	1.5	33.0	35.2	------	------	8.6	------	21.7
49 Mt 59	.035	.0076	------	9.7	28.5	21.4	tr.	.5	4.1	------	35.8
50 Mt 36	.012	.0027	------	1.0	------	22.0	------	------	3.0	1.0	73.0
50 Mt 33	.27	.011	------	31.0	49.0	4.0	------	------	3.0	------	13.0
51 Mt 206	.0038	.0026	0.0004	Tr.	------	69.0	9.5	------	6.0	------	15.5
51 Mt 205	.037	.013	.0065	.5	29.0	35.0	17.5	------	5.5	------	12.5
Troup County											
50 Mt 75	0.13	0.0003	------	63.2	33.0	0.2	------	------	1.0	------	2.6
50 Mt 76	.26	.0052	------	83.9	6.0	2.0	------	tr.	tr.	------	8.1
50 Mt 70	.54	.0027	------	57.0	38.8	.5	------	------	1.4	------	2.3
50 Mt 80	.42	.0008	------	50.2	47.3	.2	------	------	.5	.3	1.5
51 Mt 218	.012	.0004	0.0001	47.1	35.0	3.0	1.0	------	1.0	------	12.9
51 Mt 204	.087	.023	------	3.0	5.0	26.0	------	------	42.0	1.0	23.0
51 Mt 217	.015	.0006	.0002	57.1	15.0	4.0	1.0	------	4.0	------	18.9
51 Mt 216	.024	.0022	.0048	15.8	18.0	9.0	20.0	------	7.0	------	30.2
51 Mt 212	.019	.0009	------	16.7	22.0	5.0	------	------	10.0	------	55.3
Means	0.11	0.0062	0.0011	18.0	30.9	18.9	4.6	0.1	5.6	1.6	20.4

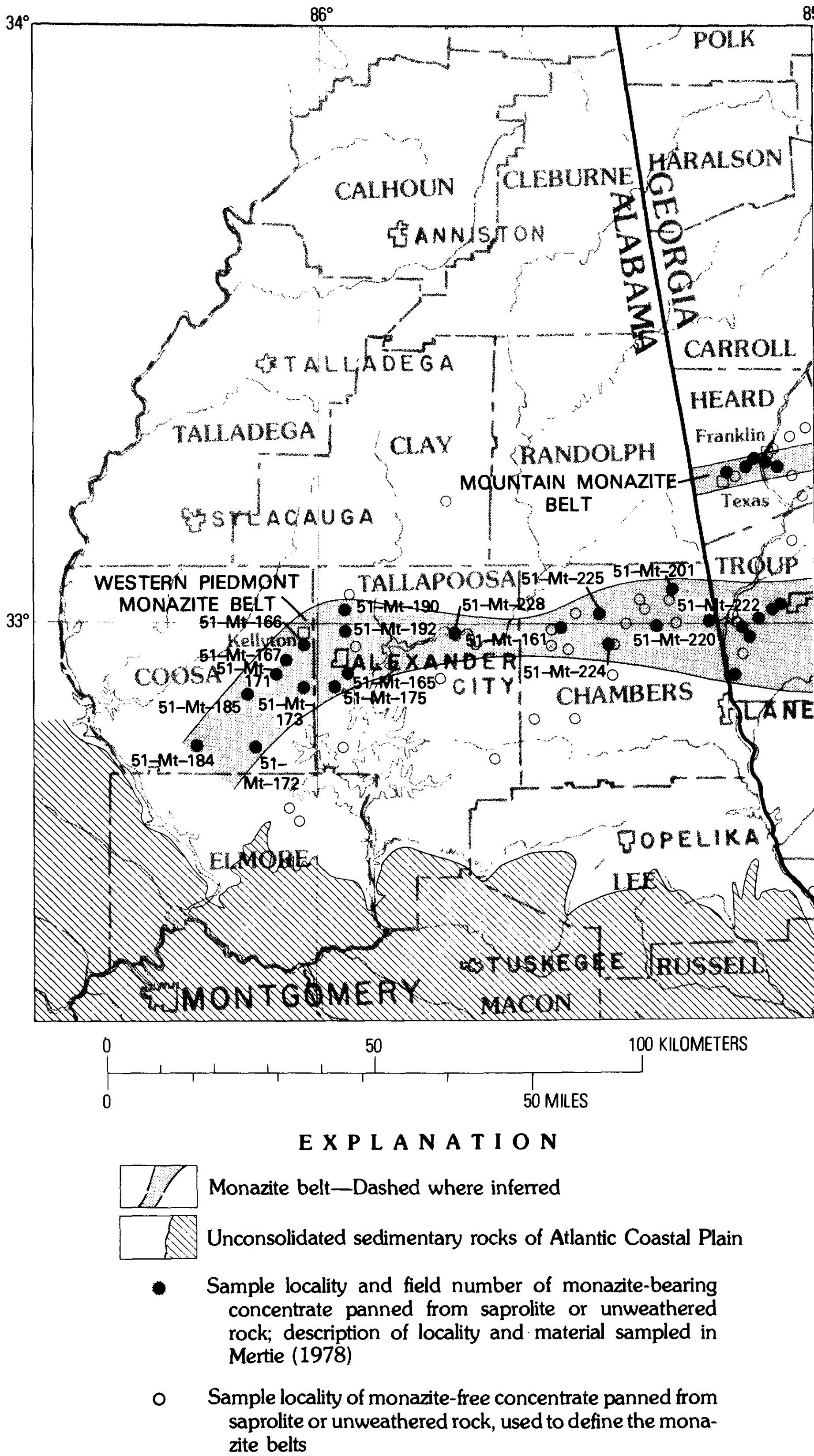


FIGURE 7.—Distribution and field numbers of monazite-bearing concentrates in Alabama.

1926), are from east to west an igneous schist and gneiss of Archean age, the Wedowee Formation of Cambrian to Carboniferous age, the biotite augen gneiss phase of the Ashland Mica Schist, the Ashland Mica Schist of Algonkian age, a second zone of the Wedowee Formation, and the Pinckneyville Granite of post-Carboniferous age. The general strike of these rocks is northeastward, but the monazite belt cuts diagonally across the first four of them, and then veers southwestward through the Pinckneyville Granite to the Coastal Plain. Monazite-bearing rocks were found in the igneous schist and gneiss, in the biotite augen gneiss phase of the Ashland Mica Schist, and in the Pinckneyville Granite but were not identified in the recognized metasedimentary formations. It should be emphasized, however, that the Pinckneyville Granite is not everywhere monazite bearing, for this formation, as shown on the geologic map of Alabama, extends 10 miles north of the northernmost monazite-bearing sites.

The igneous schist and gneiss unit of the geologic map of Alabama includes a variety of metaigneous and metasedimentary rocks which are crossed in the north by the monazite belt. Unweathered monazite-bearing granitic gneiss in this unit was identified at two localities in Chambers County (Mertie, 1957). One is about 2.8 miles N. 83° E. of Stroud and has a slightly pinkish biotite granite gneiss consisting of microcline, some oligoclase, quartz, biotite, muscovite, sericite, and accessory garnet and iron ores. This gneiss has the composition of monzogranite. The second locality is about 1.6 miles N. 5° W. of Chapel Hill and yielded two samples from residual boulders excavated from the east side of an unpaved road. Both boulders are of gneiss similar to the rock at the first locality, except they contain some epidote. One of these gneisses has the composition of monzogranite, the other of adamellite.

No unweathered sample of the biotite augen gneiss phase of the Ashland Mica Schist was collected, and only one sample of saprolite from this unit, discussed under the section on accessory minerals, was studied.

The Pinckneyville Granite (Alabama Geological Survey, 1926) has been described by Gault (1945) as the Pinckneyville Quartz Diorite. The rocks of this formation are dominantly dark-gray coarse-grained biotite gneiss that have the composition of tonalite, though variants are recognized that range through monzotonalite, adamellite, and monzogranite. Hornblende gneiss, amphibolite, and pegmatite also constitute a part of this unit. The tonalite is composed of plagioclase feldspar, very little potassium feldspar, quartz, biotite, muscovite, and epidote. The common accessory minerals are apatite, sphene, zircon, pyrite, and epidote, and rarely a little garnet or carbonate minerals which do not survive saprolitization. The more felsic varieties of the Pinckneyville Granite differ mainly in having higher tenors of quartz and orthoclase (microcline). Unweathered exposures of monazite-bearing Pinckneyville Granite were identified by the writer at six localities in Tallapoosa and Coosa Counties (Mertie, 1978). At all six localities the rocks correspond closely with the descriptions given by Gault; but at four localities the rock may be described as tonalite gneiss (51 Mt 176, 51 Mt 168, 51 Mt 169, 51 Mt 170, and 51 Mt 183) and at the other localities it has the composition respectively of an adamellite gneiss (51 Mt 191) and a monzogranite gneiss (51 Mt 174).

ACCESSORY MINERALS

Accessory minerals that include monazite were panned from 18 localities in the western Piedmont monazite belt in Alabama (table 20). The first 6 of these concentrates were collected from the igneous schist and gneiss unit as shown on the geologic map of Alabama (Alabama Geological Survey, 1926), the seventh came from the biotite augen gneiss phase of the Ashland Mica Schist, and the remaining 11 represent various types of the Pinckneyville Granite.

The total accessory minerals constitute 0.0096 percent of these rocks (table 20), but the mean tenor for the six concentrates from Chambers County is 0.024 percent. The maximum and minimum tenors in accessory minerals as determined from these 18 concentrates are respectively 0.054 and 0.0001 percent, the maximum tenor in Chambers County. These values are correspondingly much lower than in Georgia, and the mean value for accessory minerals in rocks from Chambers County is only one-ninth as great as for rocks from adjoining Troup County, Ga. The mean tenor of accessory minerals from the monazite-bearing rocks of the western Piedmont monazite belt of Alabama is exceeding low, only one-seventh of the corresponding regional average for the Southeastern States, and is less than for any other State in this belt (table 13). As most of these samples have come from the Pinckneyville Granite and from closely related rocks, it may be surmised that this formation has some unique feature. The tenors of magnetite and the magnetite:ilmenite ratio are notably low for

TABLE 20.—*Accessory minerals and amounts, in percent, in concentrates from 18 samples from the western Piedmont monazite belt in Chambers, Tallapoosa, and Coosa Counties, Ala.*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock			Minerals in concentrates								
	Total	Monazite	Xenotime	Magnetite	Ilmenite	Monazite	Xenotime	Epidote	Garnet	Zircon	Rutile	Quartz and others
Chambers County												
51 Mt 222 ----------	0.041	0.0008	0.0008	87.8	------	2.0	2.0	------	------	------	------	8.2
51 Mt 201 ----------	.017	.0003	.0002	80.6	------	2.0	1.0	------	------	1.5	------	14.9
51 Mt 220 ----------	.024	.0038	.0019	39.5	9.0	16.0	8.0	------	------	1.0	------	26.5
51 Mt 224 ----------	.0082	.0006	------	69.3	1.0	7.0	------	------	------	------	------	22.7
51 Mt 225 ----------	.054	.0029	------	82.2	------	5.5	------	------	0.5	------	------	11.8
51 Mt 161 ----------	.0013	.0006	.0001	1.0	3.0	49.0	5.0	------	------	11.0	1.0	30.0
Tallapoosa County												
51 Mt 228 ----------	0.006	0.0006	------	4.5	37.0	10.0	------	------	------	33.0	------	15.5
51 Mt 175 ----------	.012	------	0.0001	tr.	------	Tr.	1.0	75.0	------	8.0	------	16.0
51 Mt 165 ----------	.0006	.0003	------	4.1	10.0	47.0	------	------	------	15.0	4.0	19.9
51 Mt 192 ----------	.0003	.0001	------	tr.	15.0	22.0	------	7.0	------	41.0	2.0	13.0
51 Mt 190 ----------	.0006	.0003	------	tr.	4.0	52.0	------	------	------	42.0	1.0	1.0
Coosa County												
51 Mt 166 ----------	0.0011	0.0002	------	0.3	2.0	22.0	0.5	5.0	------	55.0	------	15.2
51 Mt 173 ----------	.0001	Tr.	------	11.1	43.5	tr.	------	6.5	------	10.0	------	28.9
51 Mt 167 ----------	.0018	.0003	------	tr.	2.0	15.0	------	17.0	------	43.0	------	23.0
51 Mt 171 ----------	.0014	.0002	------	tr.	2.5	12.0	------	20.0	------	52.0	------	13.5
51 Mt 185 ----------	.0002	------	------	tr.	31.0	19.0	------	7.0	------	23.0	5.0	15.0
51 Mt 172 ----------	.0004	.0001	------	2.0	12.0	19.0	------	29.0	------	26.0	------	12.0
51 Mt 184 ----------	.0025	.0006	------	------	1.0	26.0	------	34.0	------	28.0	1.0	10.0
Means -------	0.0096	0.0006	0.0002	21.2	9.6	18.1	1.0	11.1	0.0	21.6	0.8	16.5

samples from the Pinckneyville Granite. The conclusion drawn from these data is that this formation originated as sedimentary rock, and that either as such or as a metasedimentary equivalent the original rock was completely remelted to form a magmatic igneous rock.

The mean tenors of monazite in the concentrates panned from unweathered rock in the western belt appear to be about the same for Alabama and Georgia (tables 19, 20), but the ratio of xenotime to monazite is less in Alabama than in Georgia. The mean tenor of monazite in unweathered rock in this belt, however, is only a tenth as great in Alabama as in Georgia, because the total volume of concentrates is smaller. Similarly, and for the same reason, the mean tenor of xenotime in bedrock is smaller in Alabama than in Georgia.

The occurrences of epidote and zircon are different in Alabama than in Georgia. So little epidote was observed in the concentrates recovered in Georgia that the few available tenors were not presented. In Alabama, however, the mean tenor of epidote in the panned concentrates is 11.1 percent, derived entirely from the presence of epidote in nine concentrates which came from the Pinckneyville Granite (table 20). The epidote-free concentrates resemble those of Troup County, Ga. Another similarity with the concentrates of Troup County is the paucity of zircon in the first six samples in table 20 as opposed to the high percentage of zircon in the concentrates recovered from the Pinckneyville Granite. The mean tenor of zircon in bedrock in Alabama or in the Pinckneyville Granite of Alabama is less than the mean tenor of this mineral in Georgia because the mean tenor of the concentrates is 10 times greater in Georgia than in Alabama. Garnet is rather uncommon in the western Piedmont monazite belt in Alabama and Georgia. The mean tenors of rutile, with due regard to the meager information available, are not significantly different in the two States.

EASTERN PIEDMONT MONAZITE BELT

VIRGINIA

BEDROCK

Monazite has been found in bedrock within the eastern Piedmont belt in Spotsylvania, Hanover, Chesterfield, Amelia, Nottoway, Dinwiddie, and Mecklenburg Counties, Va. (pl. 1 and fig. 2). The localities in Spotsylvania and Hanover Counties north of the junction of the eastern and western monazite belts are arbitrarily considered to be in the eastern Piedmont monazite belt.

Unweathered rock is scarce in the vicinity of monazite-bearing saprolite; thus, the petrographic character of these rocks is not well known. From north to south the sites where monazite was found in saprolite are shown on the geologic map of Virginia (Virginia Geological Survey, 1928) as the Precambrian Wissahickon Schist, an unnamed granite, the Baltimore Gneiss, the Petersburg Granite, and the Wissahickon Granitized Gneiss. One concentrate from alluvium, 50 Mt 223, has been added to the list of bedrock localities (Mertie, 1957) in order to record a locality (fig. 2) in the eastern belt identified by detrital monazite derived through erosion of the Wissahickon Granitized Gneiss in the vicinity of the pegmatites near Amelia in Amelia County (fig. 2).

The eastern Piedmont monazite belt is narrow, and monazite occurs only within the belt but not universally in the formations named above from the geologic map of Virginia (Virginia Geological Survey, 1928). Nomenclature of some of those units introduce additional problems. For example, it is doubtful if the granite west of Richmond should be correlated with the granite near Petersburg that extends southward through Dinwiddie and Brunswick Counties. Other uncertainties are introduced by poor exposures. For example, it is not clear whether samples 53 Mt 84, 53 Mt 85, and 54 Mt 60 taken in Chesterfield County (Mertie, 1978) came from granite or gneiss. It is certain, however, that the Petersburg Granite from Petersburg southward is not generally monazite bearing.

The eastern Piedmont monazite belt from Amelia County southward is entirely within the area shown on the geologic map of Virginia (Virginia Geological Survey, 1928) as Wissahickon Granitized Gneiss, from which saprolite was panned to provide concentrates 50 Mt 222, 53 Mt 103, 50 Mt 233, 50 Mt 234, and 50 Mt 235 (fig. 2). Unweathered rock is not exposed at or near these localities. The unweathered rock in Amelia County that is the source of the alluvial concentrate (50 Mt 223) is a layered gneiss of the unit called Wissahickon Granitized Gneiss (Virginia Geological Survey, 1928), consisting of cream-colored layers as much as 2 in. in width alternating with laminae rich in biotite. The texture is granular, and under the microscope the essential minerals are found to be orthoclase, microcline, plagioclase, quartz, biotite, and accessory iron ores, apatite, and epidote. This rock is classified as an adamellite gneiss.

TABLE 21.—*Accessory minerals and amounts, in percent, in concentrates from 14 samples from the eastern Piedmont monazite belt in 7 counties in Virginia*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock			Minerals in concentrates							
	Total	Monazite	Xenotime	Magnetite	Ilmenite	Monazite	Xenotime	Garnet	Zircon	Rutile	Quartz and others
Spotsylvania County											
50 Mt 268	0.0013	0.0011	------	------	14.0	85.0	------	------	1.0	------	1.0
50 Mt 267	.0044	.0012	------	tr.	60.0	27.0	------	------	.5	0.5	12.0
50 Mt 264	.16	.0031	------	13.7	81.7	2.0	0.4	------	.2	.2	1.8
Hanover County											
50 Mt 251	0.051	0.0015	------	------	93.8	3.0	------	------	0.2	------	3.0
50 Mt 269	.016	.0014	------	------	82.0	9.0	------	------	.1	------	8.9
Chesterfield County											
53 Mt 85	0.0057	0.0023	------	------	------	40.0	------	------	25.0	------	35.0
53 Mt 84	.045	.02	------	1.1	35.6	43.8	------	------	15.0	------	4.5
54 Mt 60	.051	.024	------	1.7	28.5	48.3	------	------	.1	------	21.4
Amelia County											
50 Mt 223 [1]	------	------	------	tr.	57.8	8.8	0.5	5.0	15.0	2.0	10.9
53 Mt 103	0.027	0.0079	------	------	53.6	29.0	1.0	------	2.0	------	14.4
50 Mt 222	.031	.0080	------	58.6	8.1	25.4	------	------	1.0	------	6.9
Nottoway County											
50 Mt 234	0.018	0.0086	------	------	13.0	47.0	------	------	33.0	------	7.0
Dinwiddie County											
50 Mt 233	0.013	0.0081	------	tr.	5.2	61.0	------	------	2.0	7.8	24.0
Mecklenburg County											
50 Mt 235	0.0044	0.0001	------	------	31.0	3.0	------	1.0	55.0	------	10.0
Means	0.033	0.0067	------	5.4	40.3	30.9	0.1	0.4	10.7	0.7	11.5

[1] Alluvial concentrate.

ACCESSORY MINERALS

Accessory minerals that include monazite were panned from 13 bedrock localities (Mertie, 1978) of the eastern Piedmont monazite belt in seven counties in Virginia (pl. 1 and fig. 2). The tenors of the principal accessory minerals are shown in table 21.

The accessory minerals as determined by panning constitute 0.16–0.0013 percent of these rocks, and have a mean tenor of 0.033 percent, which is 0.011 percent less than in the western Piedmont monazite belt of Virginia (table 15), a little less than half the regional tenor for the monazite-bearing rocks (tables 5, and 13), and about a fourth of the regional tenor for all the granitic rocks.

The magnetite:ilmenite ratio approaches zero in all but two of these concentrates because ilmenite is abundant and magnetite is nearly absent. One of these exceptions, 50 Mt 222 from Amelia County, is apparently from a magmatic granite, the only such rock in this group. For the other exception, 50 Mt 264 from Spotsylvania County, this ratio is about 1:6.

The monazite in some of these concentrates is well rounded, and it shows the surficial covering of a white secondary product locally present on monazite from saprolite. The tenors of monazite in the concentrates range from 85.0 to 2.0 percent (table 21), and have a mean value of 30.9 percent. The tenors of monazite in bedrock range from 0.024 to 0.0001 percent, and have a mean value of 0.0067 percent. These mean values in the concentrates and in bedrock are greater than the respective means of 18.1 and 0.0019 percent in the western Piedmont monazite belt of Virginia (table 15) and compare closely with the corresponding mean tenors for all the monazite-bearing rocks of the Southeastern States, which are respectively 21.9 and 0.0047 percent (table 13). Therefore, though the eastern Piedmont monazite belt is narrow, its environs should not be neglected in the search for deposits of alluvial monazite.

Xenotime, garnet, and rutile are relatively uncommon (table 21), and epidote was recognized only in sample 53 Mt 85 from Chesterfield County, in which it constituted 20 percent of the concentrate. Zircon, however, is present in all samples, and has tenors ranging from 55.0 to 0.1 percent, and a mean value of 10.7 percent. This mean value for zircon is considerably higher than was found for zircon in rocks of the western Piedmont monazite belt of Virginia. Most of the samples contain two or three varieties of zircon including stubby amber prisms, elongate colorless prisms, and intermediate types. A few of these are well rounded, more are rounded only on the ends, and some are quite unrounded. Heterogeneity in crystalline form, color, and degree of rounding is the rule. Collectively these data are interpreted by the writer to indicate that most of the host rocks are paragneisses but that some of them have been granitized.

NORTH CAROLINA

BEDROCK

The initial discovery leading to the recognition of the eastern Piedmont monazite belt was made in 1949 at a site about 1.25 miles S. 22° E. of Rolesville, Wake County, N.C. (pl. 1 and fig. 4). Fresh rock and saprolite, separated by a few hundred feet of cover, crop out at this locality along the west side of a paved road (Mertie, 1978). Monazite was discovered first in the saprolite (49 Mt 182), and its presence in the adjacent unweathered rock was verified in 1953 by panning a sample (53 Mt 18) of the powdered rock. A chemical analysis was also made of this unweathered rock (table 1, sample E). Since 1949 the belt has been extended into Warren, Franklin, and Anson Counties, N.C.

The monazite-bearing unweathered rock south-southeast of Rolesville is pinkish, in part gray, granular, granitic rock that consists of feldspar, quartz, biotite, muscovite, and several accessory minerals. The feldspar crystals are as much as 6 mm across and include pink to cream-colored microcline, orthoclase, and plagioclase. The plagioclase has an approximate composition of An_{20} and much of it is untwinned. Quartz is graphically intergrown with each variety of feldspar. Biotite, in part chloritized, is the principal mafic mineral; muscovite is uncommon and is mainly sericitic. The accessory minerals recognizable in thin section are iron ores, apatite, zircon, sphene, and calcite. The ratio of potassium feldspar to plagioclase is somewhat illusive, owing to the dearth of albite twinning, but the chemical analysis (table 1, sample E) shows a ratio of normative orthoclase to total feldspar of 0.369, which lies within the range 0.65–0.35 and warrants the designation of the rock as adamellite.

About a mile N. 65° E. of the site of sample 53 Mt 18 massive granite is removed at the Rolesville quarry to produce railroad ballast and road metal. This rock is not quite so coarse grained as sample 53 Mt 18 but is generally very similar. Yet samples of saprolite atop the quarry, and powdered rock collected from below the jaw crusher, were panned and found to contain no monazite. This exemplified the narrowness of the monazite belt in this area. Such narrowness is corroborated to the southwest of U.S. Route 64, where samples 50 Mt 282 and 50 Mt 284 were taken less than 2 miles apart, and the concentrates are monazite bearing whereas other samples to the east and west were found to lack monazite (fig. 4). Adjacent to saprolite sample 50 Mt 284, on the south side of U.S. Route 64, monazite-bearing fresh rock crops out. This is a cream-colored to pinkish biotite adamellite similar to that at the locality south-southeast of Rolesville.

Monazite-bearing saprolite without equivalent outcrops of unweathered rock was identified northeastward from the locality near Rolesville in a narrow band extending through Franklin and Warren Counties into Virginia. The principal outcrops are in the Norlina-Warrenton area of Warren County, where a mass of granite is shown on the geologic map of North Carolina (North Carolina Division of Mineral Resources, 1958). The eastern Piedmont monazite belt continues northward into what was called in Virginia the Wissahickon Granitized Gneiss (Virginia Geological Survey, 1928). Petrographically the granitic rocks near Norlina do not correspond with the Granitized Gneiss nor geographically can they be connected with the Petersburg Granite, the next formation east of the Wissahickon in southern Virginia (Virginia Geological Survey, 1928).

Monazite-bearing granitic rocks are hard to locate south-southwest of Rolesville, owing to a dearth of outcrops and partial overlapping by sedimentary formations of the Coastal Plain (pl. 1 and fig. 4). One outcrop was found about a mile southwest of Garner in Wake County (52 Mt 37), but the next (50 Mt 164) is nearly 100 miles to the southwest at a locality east of Wadesboro, Anson County, N.C., (fig. 3). At this site, the monazite-bearing rock is entirely different from that near Rolesville. It is a very coarse grained porphyritic adamellite consisting of large phenocrysts of feldspar and smaller ones of quartz, interstitial feldspar minerals, quartz, and biotite. The phenocrysts are so plentiful as to leave little room for groundmass, thus producing a persemic fabric. The phenocrysts of feldspar consist partly of pink crystals of orthoclase, perthitically intergrown with lamellae of cloudy plagioclase. Another part of the phenocrysts are white crystals of basic oligoclase, which are either cloudy or are altered in their centers to sericite. The maximum sizes of the phenocrysts of orthoclase and plagioclase are respectively 4.0 and 2.5 cm; the anhedral crystals of quartz are smaller. Biotite forms clots as much as 5 mm in size. The accessory minerals recognizable under the microscope are iron ores and apatite. The adamellite continues southwestward into South Carolina, where it is exposed in Kershaw County east of Wateree Pond, but the rock lacks monazite (fig. 5) and is a short distance east of the eastern Piedmont monazite belt.

ACCESSORY MINERALS

Samples of accessory minerals were taken from monazite-bearing granitic rocks of the eastern Piedmont monazite belt of North Carolina at 13 localities in Warren, Franklin, Wake, and Anson Counties (pl. 1 and figs. 3, 4). These samples are arranged in table 22 from north-northeast to south-southwest by counties and roughly by localities in the same order. Twelve of the concentrates came from saprolite and one (53 Mt 17) from nearby unweathered rock (Mertie, 1978).

The accessory minerals constitute 0.31–0.0077 percent of the rocks and have a mean value of 0.089 percent, which is 0.017 percent greater than the mean regional value for monazite-bearing rocks (table 13), and 0.051 percent less than the mean regional value for all the granitic rocks. Excepting sample 50 Mt 164, however, which has the iron-ore content of a magmatic granite, the mean tenor of the other 12 samples is 0.07. This tenor is practically the same as the mean regional tenor in accessory minerals for all monazite-bearing rocks in the Southeastern States.

The iron ores of this group of samples are dominantly ilmenite, though in three samples magnetite predominates greatly over ilmenite, and in one of these ilmenite is lacking. The first four samples in table 22 are from a complex of granite and granitized gneiss (North Carolina Division of Mineral Resources, 1958) in the Norlina-Warrenton area, and may include magmatic and migmatitic granite, as well as nongranitized metasedimentary rocks. The iron ores of sample 50 Mt 295 and of its correlatives south-southeast of Rolesville (49 Mt 182 and 53 Mt 17) suggest a magmatic origin for their source rocks, and the tenors of total accessory minerals for these three samples are consonant with this interpretation.

The tenors of monazite in these concentrates (table 22) range from 15.3 to 0.03 percent and have a mean value of 6.8 percent; the tenors of monazite in bedrock range from 0.017 to essentially zero and have a mean value of 0.0043 percent. These values may be compared with the mean tenors in the con-

TABLE 22.—*Accessory minerals and amounts (in percent) in concentrates from 13 samples from the eastern Piedmont monazite belt in 4 counties in North Carolina*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock		Minerals in concentrates						
	Total	Monazite	Magnetite	Ilmenite	Monazite	Garnet	Zircon	Rutile	Quartz and others
				Warren County					
50 Mt 274	0.053	0.0054	tr.	82.4	10.2	------	0.1	0.2	7.2
50 Mt 275	.01	.0011	28.7	48.8	10.6	------	Tr.	------	11.9
50 Mt 276	.012	.0015	tr.	81.1	12.3	------	.4	------	6.2
50 Mt 278	.02	.0026	76.4	------	13.4	1.6	tr.	------	8.6
				Franklin County					
50 Mt 295	0.11	------	76.0	16.0	0.03	------	.1	------	7.9
50 Mt 296	.054	0.0013	tr.	71.5	2.4	------	tr.	------	26.1
50 Mt 290	.074	.0007	tr.	94.7	1.0	------	tr.	------	4.3
				Wake County					
49 Mt 182	0.12	0.0059	12.5	58.1	4.8	------	2.0	------	22.6
53 Mt 17	.11	.0068	14.7	64.2	6.0	Tr.	2.0	------	13.1
50 Mt 284	.18	.017	tr.	86.1	9.8	------	.5	------	3.6
50 Mt 282	.086	.013	------	57.6	15.3	------	tr.	16.5	10.6
52 Mt 37	.0077	.0002	------	73.3	2.0	6.0	tr.	------	18.7
				Anson County					
50 Mt 164	0.31	0.0009	83.0	10.6	0.3	------	4.0	------	2.1
Mean	0.089	0.0043	22.4	57.3	6.8	0.6	0.7	1.3	11.0

centrates and in bedrock of 30.9 and 0.0067 percent that apply in the eastern Piedmont monazite belt of Virginia, and with the corresponding tenors of 21.9 and 0.0047 percent that apply to all the southeastern monazite-bearing rocks (table 13). It thus appears that the tenor of monazite in the eastern Piedmont monazite belt of North Carolina is somewhat lower than that of the same belt in Virginia and considerably lower than the regional average. The increment in monazite in the direction of Virginia is indicated by the first four concentrates of table 22.

The zircons in these concentrates have considerable genetic significance. Crystals of zircon in samples 50 Mt 295, 49 Mt 182, 50 Mt 284, 50 Mt 282, and 50 Mt 164 are homogeneous in color, size, and crystal habit, and none is rounded. In the other samples the zircons are heterogeneous, including in several samples two or three kinds of zircon differing in color, size, and habit. Most of these heterogeneous crystals are unrounded, but some rounded zircons were seen in two samples. These data conform fairly well to the genetic data inferred from the total concentrates and the iron ores.

SOUTH CAROLINA

BEDROCK

The most northeasterly occurrences of monazite-bearing granitic rock in the eastern Piedmont monazite belt of South Carolina are at two sites in Kershaw County (pl. 1 and fig. 5). One of these (51 Mt 118), recognized by the writer in 1951, is near the boundary with Lancaster County and about 4 miles northeast of Wateree Pond, where the monazite-bearing rock is a uniformly medium-grained light-gray gneiss (Mertie, 1978). The second locality of a monazite-bearing granitic rock in Kershaw County is about 10 miles S. 82° E. of 51 Mt 118 and was reported by J. F. McCauley (written commun., 1959) to be an intrusive pink coarse-grained porphyritic monzogranite. Monazite is thought by the writer to be present in rocks in parts of Lancaster and Chesterfield Counties, but the principal localities in South Carolina where this mineral has been found in bedrock in the eastern Piedmont monazite belt are in Fairfield County. Almost no exploration has been done southwest of Fairfield County, but monazite probably also occurs in Newberry, Saluda, Lexington, Edgefield, and McCormick Counties. In fact, monazite was identified in a quartz-biotite gneiss by J. F. McCauley (written commun., 1959) near Pomaria, Newberry County, S.C., and alluvial monazite was found by the writer in a small northeast-flowing tributary to Rocky Creek, about 5.75 miles N. 75° W. of Lexington, Lexington County. This stream has a length of less than 3 miles, so that the bedrock source is probably in Lexington County.

Exposures in Fairfield County afford the two most important occurrences of monazite in unweathered rock in the eastern Piedmont monazite belt in South Carolina. One is at the quarry of the Rion Crush Stone Corp., about half a mile south-southwest of the post office of Rion, and the other is at the Blair quarry, about half a mile east-southeast of Blairs Station on the Southern Railway. Both saprolite and unweathered rock are available at each quarry. Samples of saprolite are numbered 51 Mt 110 from the quarry of the Rion Crush Stone Corp. and 51 Mt 140 from the Blair quarry (Mertie, 1978). Samples panned from crushed rock from these quarries are numbered respectively 53 Mt 13 and 53 Mt 15 (fig. 5). Chemical analyses of the fresh rock are listed in table 1 (samples J and K).

The rock at the Rion quarry is a massive, light-gray, moderately coarse grained, generally homogeneous, biotite adamellite. Some flow lines, accentuated by biotite, are evident, and at some places the rock is mottled by concentrations of biotite and contains a few rounded dark-colored xenoliths. The rock consists of microline, zoned plagioclase largely altered to sericite, quartz, biotite, and accessory iron ores. Some of the biotite is chloritized. The ratio of normative orthoclase to normative feldspar is 0.48 (table 3).

The rock at the Blair quarry is also a biotite adamellite generally similar to that described above, but it is finer grained and contains secondary zoisite after biotite and plagioclase. The plagioclase is much sericitized oligoclase. Graphic intergrowths of quartz and plagioclase and of quartz and potassium feldspar are common. The recognizable accessory minerals include considerable apatite and some sphene. The ratio of normative orthoclase to normative feldspar is 0.39 (table 3), showing that this rock is biotite adamellite, though somewhat less potassic than the granite at the Rion quarry.

ACCESSORY MINERALS

Eight samples of accessory minerals were panned from monazite-bearing rocks in the eastern Piedmont monazite belt of South Carolina at six localities (Mertie, 1978), of which one is in Kershaw County and five are in Fairfield County (pl. 1 and fig. 5). The accessory minerals are listed in table 23.

TABLE 23.—*Accessory minerals and amounts, in percent, in concentrates from 8 samples from the eastern Piedmont monazite belt in 2 counties of South Carolina*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock		Minerals in concentrates						
	Total	Monazite	Magnetite	Ilmenite	Monazite	Epidote	Garnet	Zircon	Quartz and others
Kershaw County									
51 Mt 118	0.18	0.0014	74.5	23.0	0.8	1.5	------	0.2	------
Fairfield County									
51 Mt 105	0.13	0.0078	15.8	75.0	6.0	------	------	0.1	3.1
51 Mt 110	.11	.0025	53.0	41.6	2.2	------	------	.6	2.6
53 Mt 13	.086	.0009	82.2	12.9	1.0	------	Tr.	Tr.	3.9
51 Mt 109	.16	.0037	75.5	20.9	2.4	------	------	.1	1.1
51 Mt 107	.63	.0031	93.8	2.7	.5	------	------	1.5	1.5
51 Mt 140	.1	.0034	40.1	52.6	3.4	2.9	------	.1	.9
53 Mt 15	.11	.0044	48.0	34.0	4.0	------	Tr.	.1	14.0
Mean	0.19	0.0034	60.4	32.8	2.5	0.5	Tr.	0.3	3.4

The total accessory minerals in bedrock as estimated from the concentrates ranges from 0.63 to 0.086 percent and have a mean value of 0.19 percent. This is a greater volume of accessory minerals than is recorded for any other State in any of the three monazite belts, and is 0.12 percent greater than the mean tenor for all the monazite-bearing granitic rocks of the region. In fact, the minimum value of 0.086 given in table 23 is 0.014 percent greater than the regional mean for the monazite-bearing granitic rocks. The cause of these values is the high tenor in iron ores.

The total iron ores in table 23 constitute 0.18 percent of the rocks, of which the tenors in magnetite and ilmenite are respectively 0.14 and 0.04 percent. The corresponding tenors of magnetite and ilmenite in the concentrates are 60.4 percent and 32.8 percent. Both sets of figures show the great predominance of magnetite over ilmenite, but the more significant values are those derived for bedrock. It has earlier been stated that the mean tenors of magnetite and ilmenite in bedrock for all the monazite-bearing rocks of the Southeastern States are respectively 0.017 and 0.029 percent. The bedrock tenors cited above are not only greater than the regional means but are reversed in that the tenor of magnetite is three times as large as that of ilmenite, whereas for the regional bedrock means the tenor of magnetite is little more than half that of ilmenite. These values are interpreted by the writer to mean that the samples in table 23 represent magmatic granites, and that the regional mean values for the total iron ores and for magnetite and ilmenite are caused by a great predominance of metasedimentary over magmatic rocks. Some reduction in the quantity of magnetite during saprolitic weathering is also evident from comparisons between the respective values for magnetite in fresh rock and in saprolite at the two quarries (table 23).

The tenors in monazite shown in table 23 are also significant. The mean tenor in bedrock is 0.0034 percent, which is 0.0013 percent lower than the regional value for monazite-bearing rocks (table 13). Owing to the large volume of accessory minerals, the mean tenor of monazite in the concentrates is much lower than those heretofore recorded. The tenor of monazite in bedrock, however, though lower than the regional tenor, is greater than the mean bedrock tenors recorded for the western Piedmont monazite belt of Virginia and Alabama, and it is also greater than the mean bedrock tenors recorded for the mountain monazite belt in Virginia and North Carolina (table 13). It is thought that the tenors for monazite shown in table 23 indicate a probable southwestward extension of the eastern Piedmont monazite belt in South Carolina beyond the present outline (fig. 5).

Zircon is present in all samples in amounts ranging from 1.5 percent to a trace and has a mean tenor of 0.3 percent. It has already been noted that magmatic monazite-bearing granitic rocks that are not remelts of metasedimentary rocks have generally a low tenor in zircon. Table 23, which is thought to represent solely magmatic rocks, is a excellent example of this generalization. The zircons of these samples, moreover, are homogeneous and unrounded, as might be expected in magmatic rocks.

GEORGIA

The eastern Piedmont monazite belt has not definitely been identified in Georgia (pl. 1 and fig. 6), though considerable exploration has been done in a quadrilateral area bounded at its corners by Thomson, Washington, Greensboro, and Sparta, respectively in McDuffie, Wilkes, Greene, and Hancock Counties, Ga. One monazite-bearing concentrate, 50 Mt 15, from a site about 9 miles N. 65 E. of Thomaston, Upson County (Mertie, 1978), was taken from a pegmatite described by Furcron and Teague (1943, p. 42) and later by Heinrich, Klepper, and Jahns (1953, p. 354–355). This concentrate consisted of 75 percent ilmenite, 19 percent monazite, 1 percent rutile, a trace of zircon, and the remainder quartz. The presence of monazite in this pegmatite was not specifically mentioned by the earlier authors. This locality is too far southeast to be included within the western Piedmont monazite belt, but it may possibly represent a southwestward extension of the eastern Piedmont monazite belt, because a narrow segment of the belt could pass through an unexplored gap about 15 miles northwest of Thomson and Sparta. The mountain monazite belt and the western Piedmont monazite belt are shown in figure 6 to approach closely to one another in the area near La Grange in Troup County, Ga. The eastern Piedmont monazite belt might also converge toward the western Piedmont monazite belt in this general area.

An occurrence of monazite in two pegmatite dikes was recorded by Fortson and Navarre (1959) at a site about 12 miles S. 72° E. of Thomaston, in Crawford County, Ga. This locality is about 9 miles S. 29° W. of the pegmatite in Upson County described above, and similarly it may possibly be interpreted as belonging within the eastern Piedmont monazite belt. Monazite has also been found by V.

J. Hurst (written commun., 1959) in Lamar and Monroe Counties, suggesting the same interpretation.

MOUNTAIN MONAZITE BELT

VIRGINIA

BEDROCK

Monazite has been found in bedrock within the mountain monazite belt of Virginia in Fauquier, Warren, Rappahannock, Culpeper, Madison, Nelson, Rockbridge, Amherst, and Bedford Counties (pl. 1, and fig. 2). Southwest of Bedford County, an unexplored gap extends for 170 miles.

The monazite-bearing rocks of the mountain monazite belt have been found in areas shown on the geologic map of Virginia (Virginia Geological Survey, 1928) as hypersthene granodiorite (in part the Precambrian Pedlar Formation of Bloomer and Werner, 1955), Precambrian Marshall Granite of Jonas (1928), Lovingston Granite Gneiss, Catoctin Greenstone, and the Lower Cambrian Unicoi Quartzite. Of the 25 monazite-bearing concentrates from the mountain monazite belt in Virginia, 17 are from the hypersthene granodiorite, 2 are from the Marshall Granite, 4 are from the Lovingston Granite Gneiss, and one each is from the Catoctin Greenstone and the Unicoi Quartzite. The general trend of this belt is N. 40° E., which likewise is the regional strike of the hypersthene granodiorite. The hypersthene granodiorite southwest of Starkey, in Roanoke and Franklin Counties, has not been sampled; still farther southwest this formation has not been recognized, but the mountain monazite belt, if present, should lie within the basement complex of the Blue Ridge. The southeastern flank of the Precambrian Grayson Granite Gneiss (Virginia Geological Survey, 1928) has been sampled and found to contain no monazite.

An interpretation of the Precambrian geology of the Blue Ridge region in central Virginia has been presented by Bloomer and Werner (1955), who have recognized five subjacent units of rocks, whose relative ages are only partly determinate. The oldest of these is a basement complex of schist and gneiss; the others are the Lovingston Granite Gneiss, the Marshall Granite, the hypersthene granodiorite, and the Precambrian Roseland Anorthosite. Some of these units grade into one another, and none of them is clearly defined. Bloomer and Werner (1955) have concluded that the basement complex consists of metasedimentary rocks and that the Lovingston Granite Gneiss, the Marshall Granite, and the hypersthene granodiorite are migmatitic rocks produced by granitization. With this interpretation the name hypersthene granodiorite was particularly unsatisfactory and Bloomer and Werner (1955) proposed the superior designation of Pedler Formation. The character of the accessory minerals found during the present investigation in these units verifies completely their metasedimentary origin.

The Pedlar Formation is the most important host rock for monazite in the mountain monazite belt of Virginia, and because it is excellently exposed its petrographic character is well known. The monazite-bearing granitic rocks of the Pedlar Formation are characterized mainly by their diversity. They generally are dark gray but some are light gray, and others have dark- and light-gray layers and laminae. Nearly all show planar foliation parallel to mineralogical layering. They range in composition from monzogranite to tonalite, averaging perhaps adamellite or monzotonalite. The alkalifeldspar is microcline, orthoclase, or both, and perthitic intergrowths with quartz are common. Much of the plagioclase is secritized and kaolinized but where determinable appears to have a general composition of An_{30}. All specimens examined contained quartz, but syenitic variants are recorded by Bloomer and Werner (1955). The mafic minerals include hypersthene, biotite, and diopside. About half the 33 thin sections examined by the writer contained hypersthene, most of which is in varying stages of alteration to sericite and chlorite. Biotite occurs either in small amounts with hypersthene or alone as the principal mafic mineral. Diopside is uncommon. The accessory minerals generally recognized in thin section are iron ores, apatite, and zircon, but some of these rocks contain considerable garnet.

The Marshall Granite as shown on the geologic map of Virginia (Virginia Geological Survey, 1928) cannot be described even in generalized terms, because the unit was designated originally by A. J. Stose (oral commun., 1955) as a catchall needed for reconnaissance mapping to include those Precambrian rocks that belonged neither with the hypersthene granodiorite nor with the Lovingston Granite Gneiss. A monazite-bearing variety of the rock mapped (Virginia Geological Survey, 1928) as Marshall Granite was recognized in Culpeper County along the north side of U.S. Route 211 about 2.1 miles by road west of Waterloo (Mertie, 1978). This rock is a medium-gray, granular, faintly banded paragneiss containing rounded grains of feldspar and quartz that were recrystallized on their margins to produce an irregular outline. Interstitial areas were recrystallized to sericite, biotite, and quartz. The dominant feldspar is microcline perthitically intergrown with quartz. Plagioclase is a minor feldspar, and the other essential minerals are quartz and biotite. Few accessory minerals are visible in thin section, but the equivalent saprolite (52 Mt 98) yielded accessory minerals that are mainly zircon, less monazite, and a trace of iron ores.

Another example of a monazite-bearing variant of the Marshall Granite (Virginia Geological Survey, 1928) was recognized in Fauquier County about a mile east of Washington, where a brownish-gray granitic rock having yellowish irregular bands and spots and a distinct gneissic structure is exposed. The essential minerals are microcline, quartz, and biotite, and accessory minerals are secondary sericite, epidote, and iron ores. The microcline is perthitically intergrown with quartz and has a linear structure oblique to the foliation. Plagioclase was not positively identified. The presence of grains of detrital origin and the character of the accessory minerals show that this rock is a paragneiss.

Monazite is absent from the Lovingston Granite Gneiss in its type locality near Lovingston, Nelson County, nor has it been identified southwest or generally northeast of the type locality. At a site about 7 miles west of Culpeper, Culpeper County, monazite occurs in the central part of a rock shown as the Lovingston Granite Gneiss (Virginia Geological Survey, 1928). The genetic character of this monazite-bearing part of the Lovingston Granite Gneiss has not been definitely determined, but the available evidence indicates that it is interbedded quartzite and paragneiss of Precambrian age containing a fossil placer that has a high tenor in monazite. The exposures consist of a radioactive outcrop along the southeast side of County Road 715, and a bulldozed excavation made in 1954 a short distance farther southeast and higher on the hillslope. A line connecting the radioactive zone along the road and the zone of maximum radioactivity in the excavation trends about S. 35° E. This trend is considered probably to be the strike of the sedimentary deposit.

The outcrop in the roadcut is mainly arkosic quartzite about 8 feet thick, bounded on both sides by layers of paragneiss. These rocks are cut by three parallel layers of biotite about 1–8 inches thick which dip vertically, strike S. 20° W., and are cross faulted at several closely spaced intervals. They appear to be unrelated genetically to the metasedimentary rocks.

The arkosic quartzite is composed essentially of grains of quartz and feldspar as much as 0.5 cm in size and present in ratios ranging from 5:1 to 1:1. Nearly all the grains of quartz were originally rounded or subrounded, but in their recrystallized form they have ragged edges and some are assembled in an interlocking fabric. The quartz has undulatory extinction and some grains are ruptured into separate optical fields. The feldspar is in a more advanced stage of recrystallization and shows less evidence of original rounding. Most of the feldspar is kaolinized and sericitized, but the ghosts of twinning lamellae permit the identification of both microcline and sodic plagioclase, the former predominating. Both the feldspar and quartz have borders of sericite, biotite, and secondary quartz, and these secondary minerals occur also as veinlets and clots. The interstitial material is predominantly sericite. The accessory minerals, as determined by panning, are mainly monazite and zircon, in highly variable amounts, but small amounts of ilmenite and garnet are present in some samples.

The arkosic quartzite and adjacent paragneiss in the roadcut contain very small amounts of monazite, but the layers of transecting biotite contain none. The rocks having higher tenors in monazite were found in the excavation farther up the hillslope. This property was sampled in 1954 by Harry Klemic, U.S. Geological Survey. Three of these samples (54 Mt 136, 54 Mt 137, and 59 Mt 3) were found to be much richer in monazite than others from the quartzite or the adjacent paragneiss (fig. 2). The concentrates are mainly monazite, and owing to their unique character and high tenor in monazite, they are not included in the tabular data on accessory minerals given in the section below. Under the microscope the character and size of the grains of quartz, feldspar, and monazite in sample 59 Mt 3 suggest that this rock was derived from some nearby source of pegmatitic material. In general, however, these concentrates show that the host rocks were part of an ancient placer deposit.

Another monazite-bearing gneiss (55 Mt 45) crops out in Fauquier County (pl. 1 and fig. 2) at a few places 1–2 miles east of Markham, within the area shown as Catoctin Greenstone on the geologic map of Virginia (Virginia Geological Survey, 1928). This gneiss is a dark-gray coarse-grained heterogeneous metasedimentary rock that is interpreted to be a granitized phase of greenstone tuff.

Monazite was found in the Unicoi Quartzite of the State map (Virginia Geological Survey, 1928) along the north side of the Blue Ridge Parkway (57

Mt 115) between Bear Hollow and Powell Gaps, Bedford County (fig. 2). The bedrock at this locality is a mixture of tan-colored slate and granitic gneiss, the latter showing some laminae rich in biotite. The bedrock is only partly altered to saprolite, and the sample taken for panning (Mertie, 1978) included both slate and gneiss. Layering of gneiss and slate continues for at least 5 miles to the southwest of this locality. The monazite probably is derived from the gneiss, but the occurrence is cited as the Unicoi Quartzite because it is so designated on the geologic map of Virginia (Virginia Geological Survey), 1928).

ACCESSORY MINERALS

Accessory minerals that include monazite were panned from 25 samples taken at 22 localities within the mountain monazite belt in Fauquier, Warren, Rappahannock, Culpeper, Madison, Nelson, Rockbridge, Amherst, and Bedford Counties (pl. 1 and fig. 2). Data on these concentrates are arranged roughly from northeast to southwest in table 24. All but one of these samples were taken from saprolite; sample 53 Mt 138 represents pulverized hard rock (Mertie, 1978).

The mean tenor of accessory minerals in the mountain monazite belt of Virginia is 0.13 percent,

TABLE 24.—*Accessory minerals and amounts, in percent, in concentrates from 25 samples from the mountain monazite belt in 9 counties in Virginia*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock		Minerals in concentrates							
	Total	Monazite	Magnetite	Ilmenite	Monazite	Garnet	Epidote	Zircon	Rutile	Others
Fauquier County										
55 Mt 45	0.094	0.0001	86.9	0.6	0.1	------	------	12.0	------	0.4
Warren County										
55 Mt 19	.36	.0054	------	87.1	1.5	------	------	1.0	Tr.	10.4
Rappahannock County										
56 Mt 66	.01	.0028	------	37.0	27.0	------	------	20.0	Tr.	16.0
52 Mt 100	.043	.0002	------	85.0	.5	------	------	9.0	------	5.5
55 Mt 47	.051	.0002	------	92.4	.4	------	------	5.0	------	2.2
53 Mt 138	.46	.0046	------	40.0	1.0	39.0	------	4.0	------	16.0
55 Mt 31	.42	.0083	------	90.0	2.0	------	------	3.0	4.0	5.0
55 Mt 28	.15	.0006	------	82.0	.4	------	------	10.0	------	7.6
55 Mt 29	.42	.0008	------	91.0	.2	------	------	4.0	------	4.8
Culpeper County										
52 Mt 98	.0017	.0001	Tr.	7.0	8.0	------	------	85.0	------	------
55 Mt 34	.019	.0001	------	------	.5	------	------	99.0	------	.5
55 Mt 67	.0065	------	------	Tr.	.1	------	------	98.0	------	1.9
55 Mt 68	.025	.0015	------	------	6.0	------	15.0	30.0	------	49.0
59 Mt 1	.011	------	6.7	1.8	.1	------	5.0	70.0	------	16.4
Madison County										
56 Mt 60	.0032	------	------	50.0	.1	------	------	49.0	------	.9
Nelson County										
56 Mt 49	.068	.0031	------	64.8	4.6	------	------	30.0	------	.6
56 Mt 51	.11	.0032	------	86.7	2.8	------	------	8.8	------	1.7
Rockbridge County										
56 Mt 39	.071	.003	------	73.3	4.2	------	------	19.7	------	2.8
Amherst County										
56 Mt 41	.094	.0003	------	86.4	.3	------	------	3.9	------	9.4
56 Mt 55	.14	.0013	5.3	86.2	.9	------	------	6.3	------	1.3
Bedford County										
56 Mt 36	.12	.0022	------	77.5	1.8	------	------	15.4	------	5.3
56 Mt 33	.1	.0005	------	87.2	.5	------	------	8.0	------	4.3
56 Mt 23	.22	.0013	------	90.6	.6	------	------	3.0	------	5.8
56 Mt 19	.15	.0004	------	89.2	.3	------	------	7.5	------	3.0
57 Mt 115	.016	.0022	------	8.0	14.0	------	------	20.0	------	58.0
Mean	0.13	0.0017	3.9	56.6	3.1	1.5	0.8	24.9	0.2	9.1

and maximum and minimum values respectively are 0.46 percent and 0.0017 percent. This mean value is nearly twice that for the monazite-bearing rocks of the Southeastern States (table 13) and is exceeded only by that in the eastern Piedmont monazite belt of South Carolina (table 23). This high tenor, however, is not caused by a large volume of magnetite, as in South Carolina; instead, magnetite is absent except in four samples.

The concentrates consist mainly of ilmenite and zircon. The mean tenor of ilmenite in the concentrates is 56.6 percent, and maximum and minimum values respectively are 92.4 and zero percent; the mean tenor in bedrock is 0.096 percent, and maximum and minimum values are 0.38 and zero percent. The mean tenor of ilmenite in bedrock, which is the significant figure, is 2.4 times greater than that found in the western Piedmont monazite belt of North Carolina and is 3.3 times greater than that of the monazite-bearing rocks of the Southeastern States (table 5).

Monazite constitutes 3.1 percent of the concentrates, and has maximum and minimum values respectively of 27.0 percent and 0.1 percent; the mean tenor in bedrock is 0.0017 percent, and maximum and minimum values are respectively 0.0083 percent and 0.0001 percent. This is next to the lowest recorded mean tenor of monazite in the concentrates of the several belts and States, and, excepting the western Piedmont monazite belt of Alabama and the mountain belt of Georgia, is the lowest recorded tenor in bedrock (table 13). Possibly the ancient Precambrian source rocks of monazite, from which most of the rocks of the mountain monazite belt in Virginia are thought to have been derived, had a distinctly low tenor in monazite.

Zircon constitutes 24.9 percent of the concentrates, and has maximum and minimum values respectively of 99.0 and 1.0 percent; the mean tenor of zircon in bedrock is 0.0094 percent, and maximum and minimum values are respectively 0.036 and zero percent. Zircon is probably present in all samples but in a few can only be expressed as less than 5 parts per 10,000,000. The corresponding mean tenors of zircon for the concentrates and bedrock of the monazite-bearing rocks of the Southeastern States are respectively 11.3 percent (table 5) and 0.0022 percent. Hence, the mean bedrock tenor of zircon for the mountain monazite belt of Virginia is 4.3 times greater than the regional bedrock tenor.

The zircon of these 25 samples occurs almost without exception as partly rounded to well-rounded spherical, spheroidal, or ellipsoidal grains. Most of these grains are light to dark amber in color and are less than 0.5 mm in size, but a few concentrates contain grains as large as 1.0 mm. Some colorless crystals having angular to partly rounded outlines are present in a few concentrates but with these occur also well-rounded amber-colored grains. The grains that are ellipsoidal or are rounded only on their ends have ratios of length to width of 2:1 to 5:1. Some are perceptibly etched.

The high tenor of accessory minerals in these rocks, the extreme paucity of magnetite, and the high tenors in ilmenite and zircon indicate that the monazite-bearing host rocks in the mountain belt of Virginia are metasedimentary granitic rocks. The accessory minerals are thought to have passed through one or more ancient sedimentary cycles resulting in an unusual concentration of the resistant accessory minerals. Some of this detrital concentration may have taken place during the formation of the ancient source rocks for the present hosts, thus long antedating the concentration that occurred in the formation of the present rocks. Regardless of this surmise, however, the metasedimentary character of the host rocks is assured. Inasmuch as almost all these host rocks are part of the Pedler Formation, its sedimentary origin seems certain. Bloomer and Werner (1955), while concurring in this conclusion, also have evidence of later granitization. The accessory minerals neither verify nor deny this hypothesis, but if granitization on a large scale has occurred, a new generation of iron ores and zircon appears not to have been introduced during the process.

Monazite has hitherto not been reported from the cassiterite deposits at Irish Creek, Rockbridge County, but a small amount was found by panning the gravels of that stream, about a mile downstream from the junction of the two headwater forks known as Arch and Painter (Panther) Branches. Two samples were taken, one from the stream gravels and another from the terrace gravels on the southeast side of the stream. The site of panning is about 2 miles west of the Blue Ridge Parkway, where monazite was found in place in samples 56 Mt 49 and 56 Mt 51 (fig. 2) taken from the Pedlar Formation in Nelson County (Mertie, 1978). The drainage from these rocks along this section of the Parkway enters the valley of Irish Creek, and could have tranported monazite to the sampled part of Irish Creek.

The arkosic quartzite exposed in the hillside excavation southeast of County Road 715 in the Precambrian monazite-bearing fossil placer described above in Culpeper County and sampled by Harry

Klemic, U.S. Geological (Mertie, 1978) has a high tenor in monazite but contains only traces of ilmenite and zircon. The monazite of sample 59 Mt 3 (fig. 2) from this deposit consists of fractured grains as much as 2.0 mm in size which evidently were derived from crystals of still larger size. Many of these fragments are intergrown with quartz and have the color and general appearance of monazite of pegmatitic origin. Samples 54 Mt 136 and 54 Mt 137 (fig. 2) were too finely ground during the preparation for panning to permit such characteristics to be observed in the concentrate. The tenors in monazite of concentrates 54 Mt 136, 54 Mt 137, and 59 Mt 3 are respectively 92.6, 98.6, and 90.0 percent; the corresponding tenors in bedrock are 0.012, 0.026, and 0.36 percent. The lowest of these is seven times as great as the mean tenor of monazite in the bedrock of the mountain belt, and more than twice as large as the mean tenor in the bedrock of the Southeastern States (table 5). Rock of the grade of sample 59 Mt 3, which is 70 times as great as the mean tenor of monazite in the bedrock of the Southeastern States, may properly be described as a fossil placer.

Zircon is plentiful in concentrates from the fossil placer and bounding paragneiss in Culpeper County, but only traces are present in the rock exposed in the excavation farther up the hill. All this zircon consists of dark amber to brown grains, essentially similar to those desribed in the other monazite-bearing rocks of the mountain belt. The detrital character of the quartz and feldspar in the fossil placer and the character and amounts of the zircon in the bounding paragneiss indicate with little doubt that all these rocks are of metasedimentary origin.

NORTH CAROLINA

BEDROCK

Monazite has been found in bedrock within the mountain monazite belt in Mitchell, Yancey, Madison, Transylvania, Jackson, and Macon Counties, N.C. (pl. 1 and fig. 3). This belt is believed also to continue northeastward through Avery, Watauga, Ashe, and Alleghany Counties, N.C., but this region has not been explored. Between Madison and Jackson Counties, the belt will probably extend across Haywood County and the western part of Buncombe County. In fact, monazite has been reported in the Carolina Gneiss near Fines Creek about 6 miles north of Crabtree, Haywood County (Carroll and others, 1957, p. 186) and in fluvial gravels of the Horse Cove region of Jackson County about 2 miles east of Highlands (Pratt and Sterrett, 1910, p. 315). The presence of monazite farther to the southwest in Clay County was indicated by Pratt and Sterrett (1910, p. 315–316), but the exact locality was not stated. Probably it was in the eastern part of Clay County.

Monazite occurs in the mountain belt in three general environments, of which two appear to be related. One of these is in the pegmatites of Mitchell, Yancey, and Madison Counties. A second and related environment is as an accessory mineral in the coarse-grained Spruce Pine Alaskite of Hunter and Mattocks (1936) in the Spruce Pine pegmitite district of Mitchell County. The third and unrelated environment is in granitic rocks of sedimentary origin that are interpreted to have been produced through dynamic metamorphism or the melting of metasedimentary rocks and subsequently transformed to orthogneiss, as exemplified by the Paleozoic Whiteside Granite in the vicinity of Highlands, Macon County.

Monazinte and xenotime were found in the Spruce Pine pegmatite district at the Deake mica mine in Yancey County (Pratt, 1916, p. 39). More recently, monazite was found in Yancey County as one of the accessory minerals in quartz-feldspar-mica schist at the Celo kyanite mine (Brannock, 1943). Judd and Hidden (1899, p. 147) enumerated monazite as one of the several accessory minerals that were found in certain gneissic rocks of Macon County about 5 miles north of Franklin.

A well-known occurrence of monazite in pegmatite is at a site about 2.75 miles S. 58° W. of Mars Hill in Madison County where the monazite was in a layer of pegmatite 2½–4 feet thick in Precambrian Cranberry Granite (Pratt, 1916, p. 47–48). Numerous small and some large crystals of monazite were mined from the pegmatite, and one of these, having a length of 16 in. and a weight of 60 pounds, was purchased by B. S. Coburn of Ashville, N.C., and later placed in the mineralogical museum of the University of South Carolina. This crystal was described by Schaller (1933), who was with Mr. Coburn at the time of its purchase from the original owner and producer, the Reverend N. P. M. Corn. The rock adjacent to the pegmatite at one place in the now eroded mine was panned by the writer in 1947 and was found also to contain a little monazite. A few crystalls of monazite have also been found on the old mine dump.

Other occurrences of monazite in Madison County have been recorded by Oriel (1950, p. 29) at four localities which are linearly disposed over a distance of 6 miles in a direction trending north-northeast about 12 miles west-northwest of the monazite-bearing pegmatite near Mars Hill. The monazite is one of several accessory minerals identified in thin sections of mylonitized metasedimentary rocks of arkosic origin that constitute a part of the Snowbird Formation of late Precambrian age (North Carolina Division of Mineral Resources, 1958).

Monazite was found by the writer in 1945 to be a sparsely distributed accessory mineral of the coarse-grained leucogranite of the Spruce Pine district, described on the geologic map of North Carolina (North Carolina Division of Mineral Resources, 1958) as alaskite after the term Spruce Pine Alaskite. This name, however, is not entirely satisfactory, because in its original usage alaskite was described by Spurr (1900) as a fine-grained granular granite consisting mainly of orthoclase, microcline, and albite, and containing practically no mafic minerals. A typical sample of the leucogranite of the Spruce Pine district, taken along the Spruce Pine-Bakersville road about 2 miles from Spruce Pine, was found to consist mainly of oligoclase and microcline, the former predominating, and quartz, a little muscovite, less biotite, and a very small amount of epidote.

The Whiteside Granite was named by Keith (1907a, p. 4–5) for Whiteside Mountain in Jackson County, N.C., and this name was subsequently applied by Keith and Sterrett (1931, p. 6) to a mass of granitic rocks in the Kings Mountain and Gaffney quadrangles in the Piedmont of North Carolina and South Carolina. The Whiteside Granite in the mountains is now known to differ in several important respects from the granitic rocks of the Piedmont 90 miles to the east with which it was correlated. A part of the granitic rocks in the Piedmont formerly considered to be the Whiteside Granite has been separated into units named the Toluca Quartz Monzonite and the Cherryville Quartz Monzonite (Griffitts and Overstreet, 1952).

The Whiteside Granite is described by Keith (1907a, p. 4–5) as dominantly a massive intrusive, but he also states that this rock is locally gneissic or schistose. In areas examined during this investigation, particulary in the vicinity of Looking Glass Rock near Cashiers in Jackson County, and on all sides of Highlands in Macon County, the Whiteside Granite is better described as a granite gneiss. At a locality about 1.3 miles south of Glenville, Jackson County, where sample 57 Mt 105 was taken (Mertie, 1978), an exposure of saprolite is derived from a massive granite, but it is uncertain if this is a part of the Whiteside Granite.

An excellent exposure of the Whiteside Granite is at a small quarry about 0.6 mile north of the center of Highlands in Macon County. The quarry is cut into a high bluff and at its west end has a face about 150 feet high. Along this face the principal granitic rock has a pronounced foliation produced by very thin alternating black and white lamellae, resulting from a planar distribution of the biotite. The lamination is fairly regular and dips gently southwest. Layering is inconspicuous, though a few dark- and light-colored layers a foot thick are present. The principal rock is cut by a myriad of reticulating pegmatitic stringers ranging from a few inches to a foot thick that are irregular in attitude and show a few tight folds of small amplitude which plunge southeastward at angles approximating 30°–50°.

The Whiteside Granite at the localities mentioned is a medium-gray, distinctly gneissic granitic rock, consisting essentially of calcic oligoclase, orthoclase, microcline, biotite, and muscovite. The accessory minerals generally observable under the microscope are iron ores and apatite. Pegmatitic variants, exposed at an old quarry 0.25 mile northwest of Cashiers in Jackson County, and at Highlands, Macon County, are silicic rocks that have a composition close to monzogranite. A chemical analysis of the principal rock at the Highlands quarry (table 1, sample I) gave a ratio of normative orthoclase to normative feldspar of 0.17, which is in the range 0.35–0.05 and clearly indicates the classification of the Whiteside Granite as monzotonalite.

The Whiteside Granite is another example of a granitic formation in which monazite occurs in a narrow belt, whereas the main part of the formation is not monazite bearing. So narrow is this belt that it can readily be missed. Thus, in 1947 the writer took a large concentrate of accessory minerals from the Whiteside Granite about 1.5 miles east of Cashiers, Jackson County, and 10 years later took a second sample 0.4 mile east of Cashiers. Neither sample contained monazite, but later, monazite was found about 2.5 miles west of Cashiers. Similarly, no monazite was found in the Whiteside Granite east of Wagon Gap, Transylvania County, but the mineral was found in the Whiteside Granite about a mile west of this gap.

ACCESSORY MINERALS

Accessory minerals that include monazite were collected at 17 localities in Mitchell, Madison, Tran-

TABLE 25.—*Accessory minerals and amounts (in percent) in concentrates from 17 samples from the mountain monazite belt in 5 counties in North Carolina*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock		Minerals in concentrates								
	Total	Monazite	Magnetite	Ilmenite	Monazite	Xenotime	Garnet	Epidote	Zircon	Rutile	Others
Mitchell County											
45 Mt 285	0.0033	0.0003	1.5	8.7	8.8	0.7	29.8	10.0	1.0	------	39.5
45 Mt 284	.026	.0021	------	1.0	8.0	.5	49.0	------	.1	------	31.4
45 Mt 294	.0015	.0003	30.3	2.0	20.0	------	Tr.	35.0	5.0	Tr.	7.7
Madison County											
45 Mt 251	.011	.0001	------	3.0	.5	------	------	------	77.0	------	19.5
Transylvania County											
57 Mt 112	.01	.0008	------	25.0	8.0	------	8.0	------	50.0	Tr.	9.0
Jackson County											
57 Mt 108	.0027	.0011	------	2.0	42.0	25.0	------	------	12.0	1.0	18.0
57 Mt 105	.0031	.002	------	6.0	65.0	Tr.	15.0	------	5.0	1.0	8.0
57 Mt 83	.0017	.0001	12.0	28.0	4.0	------	6.0	Tr.	30.0	5.0	15.0
Macon County											
57 Mt 86	.012	.0061	2.0	9.0	49.0	------	------	5.0	25.0	tr.	10.0
57 Mt 84	.0051	.0033	1.0	5.0	64.0	------	4.0	------	19.0	2.0	5.0
57 Mt 85	.0031	.0026	Tr.	3.0	83.0	------	1.0	------	6.0	1.0	6.0
57 Mt 87	.011	.0072	1.0	4.0	67.0	------	1.0	------	7.0	tr.	20.0
57 Mt 98	.038	.0017	5.6	40.8	4.5	------	5.0	7.0	1.0	18.0	18.1
57 Mt 99	.0041	.0025	tr.	10.0	62.0	------	4.0	------	16.0	2.0	6.0
57 Mt 100	.023	.0063	51.0	9.0	28.0	------	.5	------	8.0	Tr.	3.5
57 Mt 101	.046	.0027	23.0	60.0	6.0	------	------	------	5.0	------	6.0
57 Mt 103	.0094	.0049	tr.	12.0	52.0	------	------	15.0	4.0	Tr.	17.0
Mean	0.012	0.0026	7.5	13.4	33.6	1.5	7.3	4.2	15.9	1.8	14.1

sylvania, Jackson, and Macon Counties, N.C. (pl. 1 and fig. 3). Descriptions of these concentrates are arranged roughly from northeast to southwest in table 25. All but one of these samples were taken from saprolite. One (57 Mt 98) was panned from rock powder and fragments available under the crusher at the quarry close to Highlands, Macon County (Mertie, 1978). Thirteen of these samples were taken from the Whiteside Granite and related rocks; thus, this formation dominates in the mean values that are derived.

The mean tenor of accessory minerals in the mountain monazite belt of North Carolina is 0.012 percent, and maximum and minimum values are respectively 0.046 and 0.0015 percent (table 25). This mean value is only a little greater than the low mean value recorded for the western Piedmont monazite belt of Alabama (table 20), and it is about one-sixth of the regional tenor for the monazite-bearing rocks of the Southeastern States (table 5). The meaning of this low concentration of accessory minerals is not clear, but the writer believes that it indicates a sedimentary cycle in the geologic history of these granitic rocks.

The tenor of monazite in the concentrates is relatively high at 33.6 percent, and maximum and minimum values are respectively 83.0 and 0.5 percent (table 25). However, due to the low overall tenor of accessory minerals, the tenor of monazite in bedrock is only 0.0026 percent, and maximum and minimum values are respectively 0.0072 and 0.0001 percent. This mean tenor is 0.0009 percent greater than the tenor of monazite in the mountain monazite belt of Virginia (table 24), but it is only about half the regional tenor for all monazite-bearing rocks (table 5). Still smaller mean tenors have been recorded for the western Piedmont monazite belt of Virginia (table 15) and Alabama (table 20).

The iron ores in monazite-bearing concentrates from the mountain monazite belt of North Carolina constitute 21 percent of the accessory minerals; ilmenite in the concentrates is twice as plentiful as magnetite (table 25). The mean tenor of magnetite in bedrock is 0.0009 percent, and maximum and minimum values are respectively 0.01 and zero; the correspanding percentages for ilmenite are 0.0019, 0.027, and zero. Hence, the ratio of magnetite:ilmenite in bedrock is 1:2. These values should be compared with the average tenor of magnetite and ilmenite in the monazite-bearing rocks of the Southeastern States, respectively 0.017 and 0.029, and the resulting ratio 1:1.7 (table 5). The total iron ores in bedrock are only three-fifths as great as the regional average, but the magnetite:ilmenite ratio has the same general order of magnitude.

The character and amounts of the accessory minerals in the Whiteside Granite are interpreted by the writer to indicate that the granite originated by the complete melting of sediments in which the iron ores were depleted. In this earlier sedimentary cycle, the magnetite may have been nearly or completely eliminated by weathering, erosion, and sedimentation, but more magnetite is thought to have formed from ilmenite during the subsequent fusion, with a liberation of TiO_2 to other minerals. Thus a magnetite:ilmenite ratio was attained that approaches the general ratio characteristic of magmatic granitic rocks. A further genetic indicator is that all the zircons observed in the Whiteside Granite are unrounded. Further study will be required to determine whether the gneissic structure is primary, resulting from flowage at the time of emplacement, or whether it is a later phenomenon, caused by dynamic metamorphism. The evidence so far available indicates that the Whiteside Granite, where foliation appears, is a primary gneiss.

GEORGIA

BEDROCK

Monazite-bearing bedrock has been identified within the mountain monazite belt of Georgia in Rabun, Hall, DeKalb, Fayette, Coweta, and Heard Counties (pl. 1 and fig. 6), having been found first in saprolite by the writer in Coweta County in 1949 and in Fayette County in 1950. Alluvial monazite has also been recorded in Habersham County (Teague and Furcron, 1948) and in White County (Zodac, 1952, p. 56–57). Monazite probably occurs in Gwinnett and Clayton Counties (pl. 1), but exploration for monazite in White, Gwinnett, and Clayton Counties is incomplete.

The mountain monazite belt crosses at least five granitic formations shown on the geologic map of Georgia (Georgia Division of Mines, Mining, and Geology, 1939). From the boundary between Georgia and North Carolina nearly to the south end of Hall County, and from the southwestern end of Gwinnett County nearly to the western end of Coweta County, the rock along this belt is described as biotite gneiss and schist, including injection gneiss. Other formations across which the mountain monazite belt passes are described (Georgia Division of Mines, Mining, and Geology, 1939) as biotite and muscovite granite (Stone Mountain type), porphyritic granite of late Paleozoic(?) age (Palmetto type), granite gneiss (Lithonia type), and porphyritic granite gneiss (porphyritic phase of Lithonia Granite Gneiss).

In Rabun County, outcrops of unweathered rock were not seen along the mountain monazite belt, but the monazite-bearing saprolite appears to be similar to the gneissic granite described in North Carolina as the Whiteside Granite, though it may well be an older gneiss that is part of the Carolina Gneiss of former usage.

Alluvial monazite was found at two places in White County by S. P. Cronheim in 1952 (Zodac, 1953, p. 56–57). One is in the lower valley of Dukes Creek; the other is in the Chattahoochee River Valley below the mouth of Dukes Creek. The concentrates in which the monazite was identified were recovered in connection with gold placer mining. The bedrock sources were not identified. Sterrett (1907, p. 1196) also recorded the occurrence of alluvial monazite in Rabun County, Ga., and A. S. Furcron (oral commun., 1949) reported the occurrence of alluvial monazite in Habersham County.

Alluvial monazite was found on Flat Creek in Hall County near the settlement called The Glades during the early days of gold placer mining on that stream. The Glades, now abandoned, was on Stockeneter Branch, one of the four headwater tributaries of Flat Creek, about halfway between Lula and Clermont. An unpaved road leads down Stockeneter Branch of Flat Creek, and thence westward to U.S. Route 129, the main road between Gainesville and Clermont. Both saprolite and unweathered rock crop out along this road east and west of Flat Creek, and both are monazite bearing. The bedrock consists of intricately crenulated granitic gneiss, coarse-grained granite which somewhat resembles that near Spruce Pine, N.C., and pegmatitic dikes. The coarse-grained granite was found to consist of orthoclase and some microcline, sericitized plagioclase, and a little biotite and muscovite. The biotite is altered to chlorite containing clots of iron ores. This rock is classified as a pegmatitic adamellite.

Another locality in this general vicinity where alluvial monazite has been found is near Gillsville, about 10 miles east of Gainesville in Hall County, but this locality lies between the mountain monazite belt and the western Piedmont monazite belt.

Stone Mountain in DeKalb County is an elongate granitic dome of elliptic plan rising nearly 700 feet above the surrounding country. This monadnock is essentially a dome-shaped pavement of massive granite. The same rock extends eastward for miles as a saprolitic blanket. The petrographic character of the Stone Mountain type granite has been stated in considerable detail by Herrmann (1954, p. 29–32), and two analyses were published by Watson (1902, p. 117). The essential modal minerals are quartz, microcline, plagioclase, and muscovite, though at a few sites south of Stone Mountain some biotite is also present. Small light-colored tourmaline-bearing aureoles of indefinite outline and leached borders are common and represent a late hydrothermal phase. The mean of six modal analyses by Herrman (1954) shows 30.8 percent quartz, 27.7 percent potassium feldspar, and 31.1 percent plagioclase; the corresponding normative tenors computed from the chemical analyses published by Watson (1902) are 21.8, 30.2, and 44.6 percent. The mean ratio of potassium feldspar to total feldspar is 0.47 for the modes, and 0.4 for the norms. The modal composition of the plagioclase is given as An_{10-11}; the mean normative composition is An_9. All these numerical data agree in the appellation of muscovite adamellite to this rock. Herrman recorded the presence of the accessory minerals epidote, garnet, apatite, zircon, pyrite, rutile, and sericite, but excepting apatite, which commonly does not survive saprolitization, zircon is the principal accessory mineral. By panning a large sample of the saprolite from the northeast side of Stone Mountain, the writer also established the presence of ilmenite, monazite, and xenotime in this rock.

Monazite has been found in Fayette County in an igneous formation that is designated on the geologic map of Georgia as porphyritic granite of the Palmetto type (Georgia Division of Mines, Mining, and Geology, 1939). Several bodies of this rock are known, and about a mile south of Tyrone is a large quarry owned by the Tyrone Rock Products Co. The rock at the quarry is a massive, very coarse grained, generally porphyritic, medium-gray granite having many phenocrysts of feldspar. Dikes are scarce, but there are numerous xenoliths of hornblende and biotite schist. The rock is nongneissic, but a subhorizontal sheeting, 4–10 feet thick, is well developed. This granite consists of microcline, more or less sericitized plagioclase, quartz, biotite, muscovite, apatite, sphene, iron ores, and other accessory minerals, including a very small amount of monazite, that were revealed by panning. A chemical analysis of this rock is given as sample P in table 1. The plagioclase, judging from the norm, is at the boundary between andesine and labradorite. Both the mode and the norm indicate that this granitic rock is a mica adamellite. The other granitic intrusives of this type exposed elsewhere in Fayette County and in Fulton County are not known to be monazite bearing.

The bedrock of Coweta County that lies within the mountain monazite belt consists mainly of biotite gneiss and schist that include injection gneiss, but at one locality about 6 miles west of Sharpsburg a massive monazite-bearing granitic rock and its saprolite are exposed along the north side of State Route 16 (Mertie, 1978). This is a fine-grained cream-colored rock that weathers to a red saprolite and a red soil. The rock consists essentially of plagioclase, quartz, biotite, muscovite, and epidote. The plagioclase, which is close to andesine, is considerably kaolinized. The rock is classified as a mica tonalite.

Two igneous formations are shown on the geologic map of Georgia (Georgia Division of Mines, Mining, and Geology, 1939) in Heard County. One of these in which monazite is present is granite gneiss of Lithonia type. The other, in which monazite probably occurs, is the porphyritic phase of the Lithonia type. The granite gneiss of Lithonia type in the vicinity of Franklin, Heard County, is a light- to medium-gray rock having a well-developed foliation. It consists essentially of microcline, plagioclase, quartz, biotite, and muscovite. The plagioclase generally lacks twinning and is greatly kaolinized. Accessory garnet is visible in thin secitons, and epidote is locally present. The potassium feldspar is so much more plentiful than the plagioclase that the rock is classified as a mica monzogranite. The porphyritic phase of the Lithonia Granite Gneiss in the vicinity of Texas, Heard County, was not sampled.

Five types of granitic rocks have been recognized in the mountain monazite belt of Georgia as host rocks for monazite. These range from massive intrusive rocks to the most gneissoid rocks of Georgia. It therefore is evident here, as elsewhere in the Southeastern States, that neither petrographic character nor metamorphic rank are the principal determinative factors in the localization of a monazite belt. It must also be stressed that the cited granitic host rocks are not everywhere monazite bearing but may become so where they lie within one of the monazite belts.

ACCESSORY MINERALS

Accessory minerals that include monazite were panned from 14 samples taken from saprolite in Rabun, Hall, DeKalb, Fayette, Coweta, and Heard Counties, within the mountain monazite belt of Georgia (pl. 1 and fig. 6) but the net of samples is incomplete and leaves many unexplored gaps along this belt. These concentrates are arranged in table 26 approximately from northeast to southwest. The accessory minerals differ considerably in their total and individual proportions because the monazite-bearing rocks in this belt are not closely related petrographically and genetically. This fact must be remembered in the evaluation of mean tenors.

The mean tenor of accessory minerals in bedrock in the mountain monazite belt of Georgia is 0.023 percent, and maximum and minimum values are respectively 0.17 and 0.0009 (table 26). The mean value is only one-third that of the monazite-bearing rocks of the Southeastern States (table 5), but it is larger than the means for the western Piedmont monazite belt of Alabama (table 20) and the mountain monazite belt of North Carolina (table 25). Sample 50 Mt 68, however, has an unusually high tenor of accessory minerals, of which the iron ores constitute 90.5 percent of the concentrates and 0.16 percent of the bedrock. The latter value is 3½ times that of the mean tenor of iron ores for the monazite-bearing rocks of the Southeastern States. This sample clearly represents a magmatic granitic rock, even though the magnetite:ilmenite ratio is only 1:2.8. Omitting sample 50 Mt 68 from the tabulation, the mean tenor of accessory minerals is almost as low as the lowest mean tenor recorded for the Southeastern States (table 13). The minimum tenor of accessory minerals for the mountain monazite belt, 0.0009 percent, is found in sample 50 Mt 56 from granite gneiss, (Mertie, 1978). The only lower tenors than this in the granitic rocks of the Southeastern States are several recorded in the western Piedmont monazite belt of Alabama (table 20).

The accessory minerals of the Stone Mountain type granite deserve particular mention. A sample (45 Mt 23) of 680 pounds of saprolite from Stone Mountain, DeKalb County, was panned, yielding 3.3 grams of concentrate, that sufficed for mineralogical and spectrographic examination. The minerals that constituted this concentrate are zircon, ilmenite, monazite, xenotime, garnet, and tourmaline, of which ilmenite, monazite, and xenotime had not heretofore been reported.

Zircon occurs in the Stone Mountain type granite as small amber-colored prisms 0.05–0.2 mm long having a ratio of length to width of 2:1 and 4:1. They are unrounded and do not suggest an alluvial origin, but the high concentration of zircon compared with the other accessory minerals suggests an

TABLE 26.—*Accessory minerals and amounts, in percent, in concentrates from 14 samples from the mountain monazite belt in 6 counties in Georgia*

[Tr., trace; leaders (---), absent]

Field No.	Minerals in bedrock			Minerals in concentrates								
	Total	Monazite	Xenotime	Magnetite	Ilmenite	Monazite	Xenotime	Epidote	Garnet	Zircon	Rutile	Others
Rabun County												
57 Mt 111	0.0023	0.0016	---	---	4.0	68.0	1.0	---	0.5	3.0	Tr.	23.5
57 Mt 110	.011	.0001	---	9.6	64.8	.5	---	---	---	7.0	Tr.	18.1
57 Mt 109	.013	.0001	---	11.0	70.0	1.0	---	---	---	10.0	0.1	7.9
Hall County												
50 Mt 106	0.015	0.0092	---	2.2	1.0	59.8	---	---	0.5	7.0	---	29.5
50 Mt 107	.034	.0019	---	5.8	55.6	5.6	---	---	---	12.0	---	21.0
50 Mt 108	.0088	.003	---	---	18.2	34.1	---	---	---	25.0	tr.	22.7
DeKalb County												
45 Mt 23	0.0011	0.0002	0.0001	---	10.0	20.0	6.0	---	3.5	40.0	---	20.5
Fayette County												
50 Mt 68	0.17	0.0003	---	23.7	66.8	0.2	---	0.5	1.0	2.0	---	7.3
Coweta County												
49 Mt 50	0.0044	0.0006	---	1.9	48.2	12.5	---	---	---	1.2	---	36.2
Heard County												
50 Mt 44	0.016	0.0016	---	34.0	1.0	10.0	3.0	30.0	---	10.0	1.0	11.0
50 Mt 45	.0015	.0001	0.0007	---	4.0	10.0	50.0	---	---	30.0	---	6.0
50 Mt 56	.0009	---	---	Tr.	30.0	2.0	3.0	10.0	2.0	30.0	---	23.0
50 Mt 55	.044	.0022	---	55.1	20.0	5.0	---	---	8.0	2.0	---	9.9
50 Mt 52	.0059	.0003	.0009	8.0	38.0	5.0	15.0	---	10.0	7.0	---	17.0
Mean	0.023	0.0015	0.0001	10.8	30.8	16.7	5.6	2.9	1.8	13.3	0.1	18.1

antecedent sedimentary cycle in the history of this rock.

The Stone Mountain type granite has a very low tenor in iron ores. Ilmenite constitutes only 0.0001 percent of the rock, whereas the regional tenor for monazite-bearing rocks is 0.029 percent. Magnetite is absent, whereas the regional tenor for monazite-bearing rocks is 0.017 percent. It therefore appears that the iron ores of the granite at Stone Mountain have a ratio of 1:460 to the regional tenor for monazite-bearing rocks.

Monazite and xenotime constitute about a fourth of the concentrates recovered from the Stone Mountain type granite, and have a ratio to one another of about 3.3:1. In terms of bedrock, however, their tenors are low. Thus the percentages of monazite in this rock is only 0.0002 percent, as compared with the regional average for monazite-bearing rocks of 0.0047 percent. The monazite occurs both as faced yellow crystals and fractured grains in sizes as large as 1.0 mm. Some of the grains are partly covered with a thin veneer of the white secondary mineral heretofore described. The xenotime occurs as minute pale greenish bipyramids in sizes as large as 0.1 mm. Some of these crystals are fractured. Garnet forms grains larger than the other accessory minerals, but the mineral is relatively scarce in the saprolite.

The tenors of total accessory minerals and of the individual accessory minerals in the Stone Mountain type are anomalous. For reasons stated above, it seems likely that this rock has passed through an ancient sedimentary cycle, but no sedimentary features are evident. It is concluded that the granite was originally a sedimentary or metasedimentary rock which was totally melted and injected into its present site as a magmatic granitic rock. The presence of tourmaline-bearing aureoles and of associated pegmatite suggest hydrothermal activity in the later history of its emplacement.

The iron ores in concentrates from granitic rocks in the mountain monazite belt of Georgia are generally low (table 26). The mean tenors in magnetite and ilmenite in bedrock are respectively 0.0047 and 0.009 percent, as compared with the regional tenors for the monazite-bearing rocks of 0.017 and 0.029 percent (table 5). The magnetite:ilmenite ratio of 1:1.9 compares closely with the regional ratio of 1:1.7. The mean magnetite:ilmenite ratio derived from the concentrates is about 1:2.9. On the basis of the contained iron ores, few of these rocks qualify as magmatic granite; most of them are best interpreted as melted sedimentary or metasedimentary rocks.

The zircon in these concentrates adds little to a genetic interpretation. Most of the zircon occurs as unrounded grains, though in some samples it is heterogeneous and appears to be partly rounded on the ends of the prisms. Sample 50 Mt 107 from Hall County (Mertie, 1978) is the only one that contains well-rounded grains of zircon.

ORIGIN OF THE MONAZITE BELTS

GENERAL CONSIDERATIONS

Many data are available relating not merely to the occurrence of monazite and xenotime but also to other accessory minerals that bear upon the origin of the monazite belts. This information is susceptible to different genetic interpretations (Overstreet, 1967, p. 11–26, 184–189; Overstreet and others, 1968; Theobald, Overstreet and Thompson, 1967). The habitat of monazite and xenotime in granitic rocks of necessity makes the geologic history of the host rocks a primary chapter in the history of the accessory minerals. Conversely, the occurrence and history of the accessory minerals is fundamental in any interpretation of the genesis of the granitic rocks. Little mineralogical data regarding the accessory minerals can be gleaned from conventional petrographic studies or chemical analyses of the granitic rocks because such minerals are too sparsely distributed. The investigation described in this paper has therefore been pursued unconventionally in the reverse order, from the history of the separated accessory minerals to the history of their host rocks.

The investigated granitic host rocks for monazite in the Southeastern States include magmatic intrusive bodies, either massive or primarily gneissic; secondarily gneissic orthogneiss and paragneiss; and other secondary gneissic rocks produced by pressure and heat, partial melting, migmatitization, or combinations of these processes. Pematite bodies are granitic rocks, but they are too scarce and insecurely related to large bodies of granitic rocks to yield much genetic information of the kind sought in this investigation; therefore, scant attention has been given to pegmatite bodies and their contained accessory minerals in the present investigation.

The history of monazite and xenotime in the granitic rocks is a long one which is thought by the writer to have started with the formation of the upper or granitic part of the sial in the primitive crust of the earth. It is inferred that monazite and xenotime were formed in the crystallization of these rocks, and that other elements having nearly the same ionic radii replaced a part of the rare earths and phosphorus at the time of the formation of monazite and xenotime. Among these were thorium and uranium, which substituted for the rare earths, and silicon, which substituted for phosphorus. Not all of the available rare earths or their common substitutes entered into the formation of monazite and xenotime, even where sufficient phosphorus and oxygen was available. Instead part of these elements were dispersed in other minerals having elements of nearly the same ionic radii, both in rocks that contain monazite and xenotime and others that do not (Overstreet, 1967, p. 29; Tugarinov and Vainshtein, 1959, p. 20–35). The cause of this partition of the rare earths and associated elements into two categories is not known, but it is believed to have existed from the time of the formation of the crustal granite, though not necessarily in constant proportions. The divergence in the analyses of Precambrian granites, and particularly the existence of petrographic provinces, suggests that the granitic crust of the earth was inhomogeneous and that parts of the upper sial had a high, and other parts a low, tenor in the rare earths and phosphorus.

The history of monazite and xenotime in granitic rocks is concerned with the degree of mutation in the environment of the rare earths, thorium, and phosphorus from the time of crystallization of the sial to the time when the rocks came into existence that are now visible at the earth's surface. Such rocks may possibly include remelts of the earth's crust, but more probably the magmatic rocks now visible are melts of sediments or metasediments derived from more primitive granitic rocks. Any melting or partial melting of an antecedent granite may possibly result in differences in the character and proportions of the resultant minerals. No question can exist that the melting of sediments or rocks of sedimentary origin must produce proportions of monazite and xenotime different from those that existed in an antecedent granite. Questions do arise, however, concerning the causes of the original uneven distribution of elements in the earth's granitic crust, including the rare earths and thorium; concerning the affiinity of cations for phosphorus in the primitive melts; and concerning the possibility that monazite and xenotime may be partly or wholly destroyed and their cations dispersed in other minerals during the evolution of gneisses and schists of certain metamorphic facies (Overstreet, 1967, p. 11–26). The first two questions are too speculative for positive answers. The third question implies that cations and anions may migrate in dynamically metamorphosed rocks. If this could be verified, it might partly explain the presence of monazite and xenotime in some rocks and their absence in others.

The rare earths are so widespread in dispersed form that traces of them may be found in rocks of almost every description. This fact is not necessarily related to the origin of monazite and xenotime in the monazite-bearing rocks nor to the absence of these minerals in other rocks. In other words, the localization of monazite and xenotime in certain rocks and the presence of dispersed rare earths and thorium in others are not necessarily problems that are fundamentally dependent upon metamorphic processes. The diversity of rocks that contain these two minerals appears clearly to deny their restriction to rocks of a suitable metamorphic facies. The origin and history of monazite and xenotime appear to be solvable geologic problems, and the methods for studying the distribution of monazite and xenotime demonstrated in this investigation afford a means to solve the problem.

GEOLOGIC ENVIRONMENT OF MONAZITE IN THE SOUTHEASTERN STATES

The oldest granitic rocks of the Southeastern States were formerly designated the Carolina Gneiss, an inclusive term which is being subdivided by current research. The Carolina Gneiss has been repeatedly shown to include both metasedimentary and metaigneous rocks (Keith and Darton, 1901, p. 2; Keith, 1903, p. 2; 1904, p. 2–3; 1905, p. 2; 1907a, p. 2–3; 1907b, p. 2–3; 1907c, p. 2–3; Keith and Sterrett, 1931, p. 3). The criteria developed in this paper indicate that most of these rocks are paragneiss, though some have been migmatized. Monazite occurs in the Southeastern States in many different rocks of the Carolina Gneiss, regardless of their petrographic character and degree of metamorphism, provided only that these rocks lie within the zones designated as monazite belts.

The eastern Piedmont monazite belt of Virginia lies within Precambrian formations mapped (Virginia Geological Survey, 1928) as Baltimore(?) Gneiss, Wissahickon Schist, and Wissahickon Granitized Gneiss. All three of these units are metasedimentary rocks, of which the last named is strongly migmatized. In addition, this belt lies partly within an unnamed granite of northern Virginia and within the Petersburg Granite, which is an unmetamorphosed intrusive rock much younger than the Precambrian rocks. Monazite occurs in parts of all these formations, as well as in the Cartersville Granite a foliated granitic gneiss of uncertain origin and age.

The western Piedmont monazite belt of Virginia lies within parts of the Wissahickon Granitized Gneiss, the Wissahickon Schist, hornblende gneiss and white granite intruded into the Wissahickon Schist, an unnamed granite, and possibly the Leatherwood Granite.

The mountain monazite belt of Virginia crosses and lies within parts of the four principal series of the basement complex, which, named from oldest to youngest, are the undivided fraction of the basement complex, the Pedlar Formation, the Marshall Granite, and the Lovingston Granite Gneiss. All these formations are believed by Bloomer and Werner (1955, p. 581–582) to consist of granitized metasedimentary rocks that grade into one another. Certainly the origin of each of them is mixed. Monazite occurs in parts of all of them.

The units mentioned above include a large part of the metamorphic and igneous granitic rocks of Virginia. They range from the oldest rocks of the basement complex to the youngest Precambrian rocks to granitic intrusive bodies that are generally assigned a Paleozoic age. The petrographic character, degree of metamorphism, and migmatism appear to have no influence upon the sites of monazite.

The two units in which the eastern Piedmont monazite belt is located in North Carolina are shown on the geologic map of that State (North Carolina Division of Mineral Resources, 1958) as an unnamed granite described as a massive to weakly foliated, even-grained to porphyritic rock, and a mica gneiss that includes mica schist and a wide variety of gneiss and schist. The unnamed granite contains a narrow belt of monazite-bearing rock in Wake County and Franklin County, and the monazite found in Warren County is partly in the unnamed granite and partly in the gneissic rocks. These gneissic rocks continue northward into Virginia, where they are shown (Virginia Geological Survey, 1928) as the Wissahickon Granitized Gneiss. Southward from Wake County, the granite and gneiss are overlapped by the Cretaceous sediments of the Coastal Plain. Thus the monazite-bearing rocks of the eastern Piedmont monazite belt in North Carolina are partly ancient Precambrian rocks and partly granite of Paleozoic age.

The western Piedmont monazite belt of North Carolina has been found in a variety of rock units shown on the State geologic map (North Carolina Division of Mineral Resources, 1958). These are mica gneiss, including a wide variety of gneiss and schist; mica schist, likewise including many types of gneiss and schist; a granite gneiss complex and an unnamed granite. In Cleveland and Rutherford Counties in the western Piedmont monazite belt, monazite has been reported in biotite schist, biotite gneiss, sillimanite gneiss, hornblende gneiss, the Toluca Quartz Monzonite, and pegmatite of two types (Overstreet, Yates, and Griffitts, 1963a).

The mountain monazite belt of North Carolina has not been traced continuously across the State but is known to occur in two unrelated classes of granitic rocks. One of these is the Spruce Pine Alaskite of Hunter and Mattocks (1936) and related pegmatite. The other is the Whiteside Granite, a gneissic granite that occurs mainly in Transylvania, Jackson, and Macon Counties. The Whiteside Granite is petrographically different from the Spruce Pine Alaskite.

The eastern Piedmont monazite belt of South Carolina is not well defined, but monazite has been found in a body of granite gneiss in Kershaw County and in massive granite at a number of sites in Fairfield County. Monazite-bearing saprolite in the western Piedmont monazite belt of South Carolina includes gneiss and schist, granitic dikes, pegmatite, and gneissic granite. The mountain monazite belt passes to the west of South Carolina.

The eastern Piedmont monazite belt has not been traced into Georgia, but the western Piedmont monazite belt of Georgia is found in granitic rocks of three general types called (Georgia Division of Mines, Mining, and Geology, 1939) biotite gneiss and schist including injection gneiss, granite gneiss of the Lithonia type, and biotite and muscovite granite of the Stone Mountain type, not including the actual granite at Stone Mountain. In Hart County, monazite occurs also in sillimanite-mica schist, biotite-graphite schist, biotite-plagioclase gneiss, muscovite granodiorite, and biotite granodiorite gneiss (Grant, 1958). In Madison County most of the monazite was found in granitic gneiss of the first type. Monazite was also identified in massive granite in Elbert County, Madison County, and Oglethorpe County. Southwestward in Clarke, Walton, Newton, Spalding, Pike, Meriwether, and Troup Counties, the western monazite belt lies in all three units and also in particular granites, such as those near Athens and Zetella and in the Snelson Granite.

The mountain monazite belt of Georgia lies within five notably different rock units (Georgia Division of Mines, Mining, and Geology, 1939) : biotite gneiss and schist, including injection gneiss, biotite and muscovite granite of the Stone Mountain type, porphyritic granite of the Palmetto type, granite gneiss and a porphyritic phase of the Lithonia type. One of these is probably a southwestward continuation of the Whiteside Granite into Rabun County. A second comprises the granitic gneiss and associated pegmatite of Hall County. A third is the unique Stone Mountain type granite that is duplicated at no other site in Georgia. A fourth is the coarse-grained porphyritic granite near Tyrone in Fayette County. The last comprises the gneissic rocks near Franklin and possibly the associated granite near Texas.

Only the western Piedmont monazite belt has been identified in Alabama. This belt crosses a number of mapped formations (Alabama Geological Survey, 1926), but monazite has been identified only in a schist and gneiss of igneous origin, in biotite augen gneiss, and in the Pinckneyville Granite.

This brief summary of the localization of the three monazite belts in Virginia, North Carolina, South Carolina, Georgia, and Alabama shows the great diversity of granitic rocks in which monazite and xenotime occur. This assemblage includes parts of many of the oldest to the youngest crystalline rocks represented on the geologic maps of these five States, and parts of the most metamorphosed to the least metamorphosed crystalline rocks. Most of the gneissic rocks are of metasedimentary origin but included also are metaigneous and migmatitic gneiss. The assemblage also includes some magmatic igneous rocks, mainly massive but in part orthogneissic rocks. The petrographic character, mode of origin, and degree of metamorphism do not appear to be exclusive determinative factors in the localization of monazite and xenotime. Conversely, the character and amounts of these and other accessory minerals are critical factors in deciphering the genetic history of the host rocks.

OTHER GENETIC FACTORS

The monazite belts suggest what may be called a rare-earths and thorium petrographic or mineralogical province in the Southeastern States. The southeastern and northwestern limits of this province, however, are not known and cannot be determined because the crystalline rocks are covered in those directions by younger formations. Thus to the southeast, the sedimentary deposits of the Coastal Plain (pl. 1) overlap the crystalline rocks. All these sedimentary deposits, ranging in age from Late Cretaceous to Holocene, contain at favored localities detrital monazite that was derived from one or more of the monazite belts, though the oldest of these sediments may also have received monazite from crystalline rocks that lie east of the eastern Piedmont monazite belt and that are now wholly or partly overlapped.

Monazite-bearing crystalline rocks may underlie the Paleozoic rocks that bound on the west the crystalline rocks of the Piedmont and Blue Ridge provinces. Monazite has been found in sedimentary rocks west of the mountain monazite belt, but the original source rocks are unknown. The writer identified zircon and monazite among the accessory minerals from a fossiliferous Devonian or Mississippian sandstone in the vicinity of Marlinton, Pocohontas County, W. Va. Another locality has been recorded by Carroll, Neuman, and Jaffé (1957, p. 185) who found monazite in a boulder bed that constitutes a part of the Precambrian Ocoee Supergroup of Blount County, Tenn. Detrital monazite is present at many localities west of the Allegheny Mountains (Overstreet, 1967, p. 162–163, 167, 230, 262, 270).

Monazite and xenotime are shown on plate 1 to occur in bedrock within three fairly distinct belts the boundaries of which are approximate as the exigencies of reconnaissance work do not permit precision. Enough sampling between the belts has been done, however, to verify the existence of the belts and the essential absence of monazite between the belts. A few exceptions to this areal limitation were shown by the presence of monazite in the Cartersville Granite, Goochland County, Va.; in gneissic granite in the central part of Person County, N.C.; in granite gneiss in the extreme northeastern corner of Lincoln County, N.C.; but its presence in a pegmatite in Upson County, Ga., together with other occurrences in Lamar and Monroe Counties, Ga. (V. J. Hurst, written commun., 1959), may mark the extension of the eastern Piedmont monazite belt into Georgia.

Monazite and xenotime are in the stated geologic formations and groups of formations within the monazite belts, but outside the monazite belts the same units do not contain these minerals. Hence there is no such formation as a monazite-bearing granite or a monazite-bearing gneiss, and the presence of monazite and xenotime at favored sites cannot be taken as a characteristic feature in defining a formation or group of formations. Moreover, the occurrence of monazite and xenotime within the monazite belts is erratic. Certain rocks that contain these minerals at specified sites will not contain them at other places within the belts, either across or along their strikes. In other words, the width of a belt in passing across a uniform geological formation, such as the Whiteside Granite, may be very narrow. Within such a narrow belt, monazite may be present either continuously, or at widely spaced intervals. In other areas, as for example in Cleveland County, N.C., monazite is so generally prevalent that it is in almost all geological formations of granite, gneiss, and schist. Examples of all these erratic factors of distribution have already been cited in the description of the three belts, and of the occurrence and amount of monazite and xenotime within the belts.

It is here thought that the existence of the monazite belts cannot be explained as a direct function of the petrographic character or degree of metamorphism of the monazite-bearing rocks within the belts. The geologic histories of these rocks, however, are the best clues in deciphering the formation of the belts. The plenitude, character, ratios, and morphology of the accessory minerals are the most significant available data bearing on the history. To these physical characteristics should be added a comparison of the chemical composition of the accessory minerals from the various rock units, like that done for detrital minerals in the western Piedmont monazite belt (Theobald and others, 1967; Overstreet, Warr, and White, 1969; 1970), but appropriate analyses have not been made. Utilizing the physical aspects of the accessory minerals here, it has been shown that most of the monazite-bearing granitic rocks are paragneiss and paraschist, having indications at some places of migmatitic modifications. The percentages of massive granite and orthogeniss are comparatively small. Moreover, omitting the pegmatites, scant evidence exists of any widespread hydrothermal emplacement of monazite, though this origin has been recorded in the literature of monazite (Pratt, 1916). Any explanation of the monazite belts must therefore be predicated upon original sedimentation, which in this region means Precambrian and lower Paleozoic sedimentation.

ORIGIN OF THE BELTS

The general distribution of the monazite-bearing belts as a whole suggests that distinctly elongate monazitic petrographic provinces exist in which some parts are more enriched in monazite than others. The writer infers that during some epoch or epochs in the long history of the Precambrian, detrital granitic materials derived directly from the earth's crust were transported and deposited in favored sites that were generally concordant with the present trends of the monazite belts. The nature of these earliest sites of sedimentary deposition are unknown, as such deposits have probably been eroded to form later deposits. Sometime within the Precambrian, however, the sites of the present monazite belts were outlined. Probably the beginnings of these sites of sedimentary deposition were not contemporaneous, and it is possible that one site of linear sedimentation originated long before the second, and the second long before the third. Eventually these deposits, sequential or contemporaneous, were buried, indurated, metamorphosed with or without igneous activity, elevated, and again bared to erosion. If not contemporaneous, one deposit may have acted as a source rock for a later deposit. Such formation of monazite belts did not entirely cease when the crystalline rocks of the Southeastern States became a positive crustal element, because detrital monazite is present in sedimentary rocks throughout the length of the Atlantic Coastal Plain.

In the hypothesis outlined above, the nature and genesis of the postulated curvilinear basins of sedimentation now marked as monazite belts remains to be resolved. An interpretation of these loci of sedimentation as marine or estuarine beaches is not attractive because it would be expected that monazite would have been widespread over a considerable area southeast or northwest of the present belts, owing to advancing or retreating shorelines, as in the present Atlantic Coastal Plain. If such bordering deposits were subsequently narrowed by erosion, the sediments of the innermost shoreline should also have been eroded, because sediments of restricted thickness could not well survive the long interval during which the southeastern crystalline rocks have existed as a positive element. The same argument may also be advanced against an interpretation of the monazite belts as ordinary Precambrian fluvial deposits, because such deposits would be comparatively thin and readily eroded. A process is needed which, regardless of the loci of sedimentation, operated to preserve the monazite-bearing sediments after their deposition.

Sinking basins of deposition produced either by lateral compression or faulting appear to offer the necessary preservation of the sediments. Whether such basins, coextensive with the monazite belts, consisted of only slightly folded rocks that later were dynamically metamorphosed, or whether these basins were geosynclines in which subsidence, folding, and recrystallization were concurrent, are questions that remain to be answered. Another question is whether these basins were contemporaneous or sequential, but their occurrence close together seems to indicate that they were not contemporaneous. Three sinking basins of sedimentation are therefore inferred, which may have been taphrogeosynclines (Kay, 1951), and which appear to have developed sequentially during three different times in the Precambrian. The relative ages of these basins are unknown.

A final speculative question is the nature of the postulated basins of sedimentation. Were the original sediments marine, estuarine, or fluvial? The morphology of the accessory minerals offers the best available evidence on this matter. Zircon, more than any other of the accessory minerals, is hard, tough, and practically immune to the effects of weathering. It also is little affected by dynamic metamorphism and preserves to a remarkable degree its original detrital surfaces. If deposited along any strand line, all or most of the grains of zircon would be expected to show rounding in various degrees, depending upon the distance of the sediments from bedrock sources. It has been mentioned in the preceding descriptions that rounded grains of zircon do occur in many of the metasedimentary gneisses, but the degree of rounding and the prevalence of this morphology are less than what is found in the beach deposits of Florida. The writer therefore favors the interpretation that the monazite-bearing deposits were formed under conditions of fluvial deposition.

A considerable proportion of the monazite-bearing granite and orthogneiss, though admittedly of magmatic origin, have characteristics that relate them to sedimentary rocks. Such characteristics are abnormal tenors in accessory minerals, generally much below the regional mean value; low tenors in iron ores; and low magnetite:ilmenite ratios. All these factors favor the interpfretation that such magmatic rocks are melts from ancient sedimentary rocks. The granitic materials that caused the granitization or migmatitization of other rocks, mainly of metasedimentary origin, are presumed also to have originated from the melting of ancient sediments or metasediments. Such granitic materials may either have been injected into the host rocks or may represent extensive rheomorphism.

Normal monazite-bearing granitic rocks that have large or average tenors in the accessory minerals and magnetite:ilmenite ratios ranging from 1:2 and 2:1 are unusual but have been described in the preceding pages. These may have originated as secondary remelts of the earth's crust, or more probably as melts of metasedimentary rocks that had unusual concentrations of heavy minerals. Such primitive sediments may also have accumulated under climatic conditions that did not tend to destroy the iron ores nor particularly to eliminate magnetite. Also, under long-continued magmatism, a new generation of magnetite may have evolved from rocks that contained originally only ilmenite, and excess TiO_2 formed other magmatic minerals.

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