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GEOLOGICAL SURVEY CIRCULAR 237

MONAZITE DEPOSITS OF THE SOUTHEASTERN ATLANTIC STATES

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By John B. Mertie, Jr.

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CONTENTS

ILLUSTRATIONS

ABSTRACT

Monazite, a phosphate of the rare earths, is the principal mineral from which the cerium earths and thorium are obtained. Fluviatile monazite placers were mined in the Piedmont province of North and South Carolina from 1887 to 1911, and again intermittently from 1915 to 1917; but the principal sources in recent years have been the beach placers of India and Brazil. In 1946, an embargo was placed on the exportation of Indian monazite, and the Brazilian production has not increased materially to replace this loss. Accordingly monazite in recent years has become a scarce commodity.

The principal domestic sources from which monazite may be recovered commercially are in Idaho and in the Piedmont province of the southeastern States. Some monazite is now being produced in Idaho, and a small output is being recovered as a byproduct of heavy mineral mining in Florida. The southeastern placers were not exhausted by the earlier mining and new deposits have been discovered; but production from this region awaits adequate exploration.

The country rock of the southeastern Piedmont province is a complex assemblage of metamorphic and igneous rocks. The monazite occurs in two belts. A western belt has been traced from east-central Virginia for 600 miles southwestward into Alabama; and an eastern belt has been traced from the vicinity of Fredericksburg, Va., south-southwestward for 200 miles into North Carolina. Monazite-bearing rocks near Rion, S. C., appear to indicate a southwestward continuation of the eastern belt.

The western, or principal belt, includes the placers that were formerly mined in North and South Carolina. These placers were sampled, and the monazite was separated from the best of the samples, for mineralogical and chemical analysis. The tabulated results show a mean tenor, in the headwater placers of highest grade, of 8.4 pounds of monazite to the cubic yard. Farther downstream where mining must be done to obtain larger yardages, the tenor will be much lower. The mean contents of ThO_2 and U_3O_8 in the placer monazite are shown to be respectively about 5.7 and 0.4 percents.

The western monazite belt was explored northeastward and southwestward from the sites of earlier mining by sampling the weathered bedrock; and the eastern monazite belt was discovered and sampled by the same technique. The principal source-rocks are certain types of granitic intrusives, granitized and pegmatitized country rock, and certain granitic gneisses

of the Carolina gneiss. Some of the associated pegmatites also contain high percentages of monazite. Most of the monazite-bearing granitic intrusives are quartz monzonite or closely related rocks. The mean tenor of monazite in bedrock is about 0.006 percent. No search has yet been made for workable placers in these belts beyond the original sites of mining.

Monazite derived from bedrock sources in the piedmont has been found in small quantities in all of the Coastal Plain formations, but the tenor is too low to warrant mining for this mineral alone. At favored localities, however, commercial deposits of heavy minerals may be found, similar to those now being mined in Florida, that may yield monazite as a by-product. Small fluviatile deposits of heavy minerals, including monazite, that were reconcentrated from detrital deposits of Cretaceous age, have recently been found in Georgia and South Carolina, along the inner margin of the Coastal Plain.

The monazite belts are conceived to be the sites of early pre-Cambrian valleys, wherein detrital monazite derived from an earlier pre-Cambrian granite, was distributed. These ancient fluviatile deposits were later reconstituted into gneisses of Carolina age, and parts of the latter were remelted to form monazite-bearing granitic intrusives. Some of the monazite-bearing granites may also have originated by the remelting of earlier pre-Cambrian intrusives. The distribution of iron ores in the monazite-bearing rocks appears to accord with this hypothesis.

INTRODUCTION

Monazite is the principal mineral from which the rare earths and thorium are obtained, but it also contains small amounts of uranium and numerous other elements. Years ago monazite was mined mainly for its content of thorium, which was used in the manufacture of Welsbach gas mantles; but in recent years it has been sought chiefly for the contained rare earths, which are becoming progressively important in industrial applications. A part of the thorium present in monazite is still used commercially, but a large part of it is being stockpiled in unused tailings. Thorium has great potential importance in the future production of nuclear power. The uranium contained in monazite is available as a valuable byproduct.

Monazite placers were mined commercially in North and South Carolina from 1887 to 1911, and again on a smaller scale from 1915 to 1917; but, other deposits were discovered in Brazil in 1905, and in India in 1909, and competition with these foreign sources proved unprofitable. In 1946, an embargo was imposed on the exportation of Indian monazite, and the Brazilian output has not increased materially to compensate for this loss. Accordingly monazite, which a few years ago sold for 3 cents a pound or less, is quoted nominally, as of October, 1952, at 16½ to 19 cents a pound, depending upon the content of total rare earths plus ThO_2. The placers of the Carolinas, however, were not exhausted by the earlier mining; and the partially worked and unworked placers, together with others that were unknown during the era of mining, now constitute one of the principal reserves of this mineral in the United States.

The importance of monazite, both for its rare earths and for the contained thorium and uranium, was recognized by the Geological Survey during World War II. Most of the sites in Idaho, where monazite was known to exist, were visited by the writer in 1944; and the placers of North and South Carolina were examined and sampled in 1945. The latter work, however, soon led to a study of the bedrock sources of monazite, and ultimately to a general study of all the granitic rocks of the southeastern States. The Shelby, N. C., quadrangle, in the heart of the monazite placer district, was selected for detailed geologic mapping; and Robert G. Yates and William C. Overstreet, beginning in 1948, and Wallace R. Griffitts, starting in 1949, carried this work to completion in 1951. Meanwhile the writer continued his study of the granitic rocks, with special reference to the bedrock sources of monazite; and the present paper outlines the results of this work in the five states of Virginia, North Carolina, South Carolina, Georgia, and Alabama. Collateral investigations relating to the occurrence of monazite in the formations of the Coastal Plain have also been made.

GEOGRAPHY AND GEOLOGY

General features

The Piedmont province in northern Virginia has a width of about 40 miles, increasing southwestward to a maximum width of 125 miles in North Carolina, and decreasing thereafter as the crystalline rocks of South Carolina, Georgia, and Alabama are overlapped progressively by the sediments of the Coastal Plain. The maximum width of the Coastal Plain is about 225 miles in Georgia, decreasing northeastward and westward. The altitude of the Piedmont province, excepting isolated hills or groups of hills, ranges from 1,200 feet at the southeastern flank of the Blue Ridge to 400 feet at the northwestern limit of the Coastal Plain. Numerous large streams that head in or northwest of the Blue Ridge flow southeastward and southward, draining both the Piedmont and the Coastal Plain. Most of these rivers and their tributaries are shown in plate 1.

The general geology of the crystalline rocks of the southeastern Piedmont province is imperfectly known, as little detailed geologic mapping has yet been done, and even the reconnaissance surveys are incomplete. Geologic maps of Virginia, Georgia, and Alabama, on a scale of 1:500,000, were published respectively in 1928, 1939, and 1926, but no comparable maps of the crystalline rocks are available for North and South Carolina. The country rock of the Piedmont comprises a complex assemblage of metamorphic and igneous rocks, together with some unmetamorphosed or little-metamorphosed sedimentary rocks. The metamorphic rocks include mica and hornblende gneisses, amphibolite, and schists of several kinds; the igneous rocks include granitic and dioritic rocks, pegmatites, rhyolitic rocks with associated pyroclastics, gabbro, diabase, and ultrabasic rocks. Many of the igneous rocks are partially sheared, gneissoid, or recrystallized.

The general distribution of the igneous and metamorphic rocks is fairly well shown on the State geologic maps, but the limits of these rocks are only approximately given. The Carolina and Roan gneisses, a complex assemblage of metamorphic rocks, constitute the country rock over a large part of the southeastern Piedmont province. The Carolina gneiss includes granitic gneisses of sedimentary origin, some gneisses of eruptive origin, and a variety of schistose rocks. The Roan gneiss includes all the metamorphosed basic and ultrabasic rocks. These two groups of rocks are too generalized for satisfactory geologic mapping, and locally have been subdivided into several series and formations; but these smaller units have not generally been adequately defined, so that their limits, ages, and correlation are more speculative than factual.

The terms "granite" and "granitic intrusive" are used in this paper in a generic sense to include all intrusive igneous rocks with a granitic texture and composition. These terms therefore include granite, monzogranite, quartz monzonite, granodiorite, quartz diorite, and their quartz-free equivalents. Gneisses having the same range in composition are called "granitic gneiss," regardless of their origin. The terms "granitic rock" and "granitic saprolite" are used where the character of the material, commonly saprolite, is not clear; but it is also used, when convenient, to describe a group of intrusive and metamorphic rocks having a granitic composition, as above defined. Some of the granites and granitic gneisses shown on the geologic maps of Virginia, Georgia, and Alabama have been given formational names; and similarly the Carolina gneiss has locally been subdivided into smaller units. These formational names are used in the following pages merely as convenient descriptive designations, to refer observations or collections to published maps. They are not necessarily used to imply ages or correlations that may be inferred from such maps.

Plate 1 and figure 1, which accompany this report, are not to be construed as geologic maps. They show merely the positions of the two monazite belts, and the localities within and without the belts where sampling has been done. The rocks within the monazite belts are heterogeneous. Some are monazite-bearing but many, and probably most, are not. It is believed that many of the localities are isolated, and it is reasonably sure that some gaps of considerable length exist, along which monazite-bearing rocks do not exist. Nevertheless the localities where monazite has been found have a linear collocation that warrants their collective designation as belts.

The boundary between the crystalline rocks and the formations of the Coastal Plain is shown on plate 1 as it is drawn on the geologic maps of Virginia, North and South Carolina, Georgia, and Alabama; but at many places the formations of Cretaceous and younger age extend much farther inland than mapped. The pre-Pleistocene stratigraphic column varies from state to state, but the subdivisions of the Pleistocene are fairly well standardized. Eight Pleistocene formations have been recognized, which named from oldest to youngest are the Brandywine, Coharie, Sunderland, Okefenokee, Wicomico, Penholoway, Talbot, and Pamlico. All the formations of the Coastal Plain have been found to contain small amounts of monazite, derived obviously from bedrock sources within the monazite belts.

Special features

Geologic study and mapping of the crystalline rocks in the southeastern Piedmont has all the difficulties that prevail in other regions where such rocks occur. But geologic work is further complicated by deep residual weathering, so that few outcrops of unaltered bedrock are present. The country, in fact, is mantled by a considerable thickness of decomposed, earthy but untransported bedrock, known as saprolite. The principal characteristic of saprolite is that the feldspars are completely or nearly completely altered to clayey products, though the original structure of the rock may still be visible. The essential characteristics of the crystalline rocks are thus obscured or rendered indeterminate, making it impossible to determine their true petrographic character. Chemical data are similarly vitiated.

Saprolite, however, has some remarkable advantages in the study and mapping of granitic rocks. It can readily be cut along any desired plane, thus making it possible to measure structural features in the most advantageous sections. But its principal asset is that it may be picked, shoveled, and panned, with the acquisition of representative samples of the contained heavy minerals, most of which are resistant to weathering. These suites of heavy minerals serve two principal purposes. Their total and relative percentages in the granitic rocks are commonly more distinctive than the character and amounts of the feldspars, so that they afford an effective substitute for the latter in the local correlation of such rocks. The heavy minerals are also useful because they are the sources of most of the radioactivity of the rocks; and some of them, notably zircon and monazite, are most useful in the determination, by radiometric and spectrographic measurements, of the absolute and relative ages of the granitic rocks.

Saprolite, because it can readily be panned, is also a great asset in evaluating rocks for heavy minerals of economic value, such as monazite. The investigation of the occurrence of monazite in the southeastern states was done by the use of a gold pan, and could not otherwise have been accomplished. Panning also gives approximately the total percentage of the feldspars in granitic rocks, as the clay representing the feldspars is removed by washing, leaving a residue of nonfeldspathic minerals to be panned, whose volume may readily be estimated. If only the plagioclase feldspar is completely altered to clay, and the potash feldspar is unaltered, the percentage of the former may similarly be estimated. The technique of panning saprolite was stressed by Orville A. Derby in Brazil before 1890, and for many years thereafter, but geologists are not yet generally aware of its potentialities.

References are made in the following pages to what are described by the writer as "pavements." A pavement is the upper surface of a dome-shaped mass of crystalline rock, commonly of granitic character, from which erosion has partially removed the overlying mantle of saprolite, producing a level or nearly level hardrock floor. If the erosion has been more extensive, a large volume of the crystalline rock may be bared, creating a prominent bedrock dome. An outstanding example of a large pavement is the outcrop of granite on which is located the quarry at Mt. Airy,

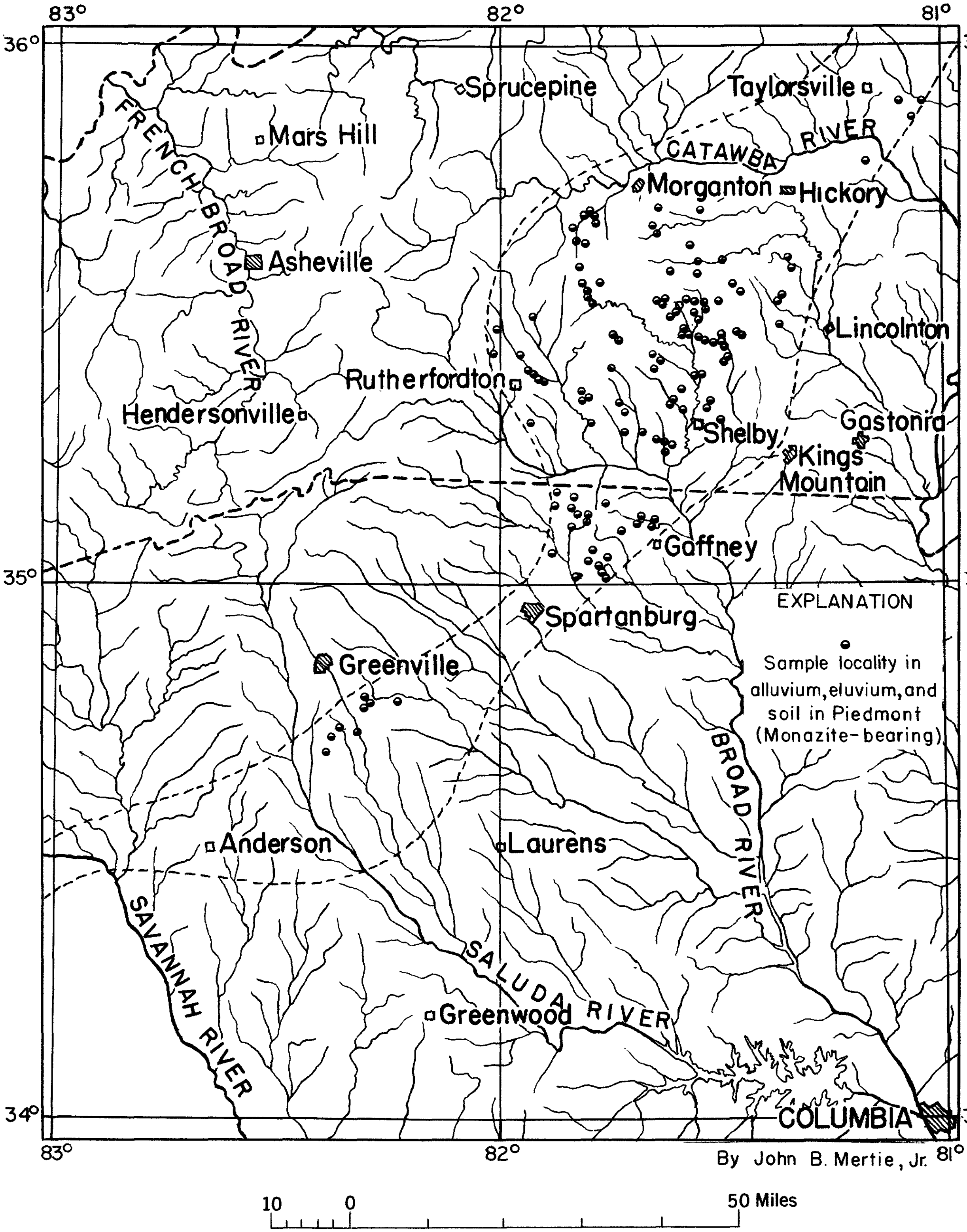

Figure 1. —Monazite placers of North and South Carolina.

Surry County, N. C. A prominent bedrock dome produced by extensive removal of the saprolite is exemplified by Stone Mountain, about 14 miles east-northeast of Atlanta, Ga. Practically all granite quarries in the southeastern states are located on pavements or domes.

The boundary between saprolite and the underlying hardrock is at some places transitional, at others very abrupt, and appears to represent either a variable or sharp lower limit of the zone of weathering. This boundary is now exposed at the surface at many places, thus leading to the interpretation that most of the saprolite in this region was formed in an earlier physiographic cycle, and probably under climatic conditions different from those which prevail at the present time. The saprolite is therefore regarded as a relic of an earlier zone of weathering that is now being bared to erosion.

Outcrops of saprolite are much more plentiful than outcrops of hardrock, and rarely is it possible to find saprolite in such a relation to hardrock, that the two are unmistakably equivalent. Quarries are the best sites for this purpose, because they are located on pavements, above which may be uneroded remnants of saprolite. Collections made at such favored localities, from both saprolite and hardrock, serve to determine the stability of rock-forming minerals under the influence of the climatic conditions that produced the saprolite.

ECONOMIC GEOLOGY

Properties of monazite

Monazite is essentially an ortho-phosphate of the rare earths, with the formula RPO_4, where R represents mainly lanthanum, cerium, praseodymium, neodymium, and samarium, though smaller quantities of the terbium and yttrium earths may also be present. Gadolinium, one of the terbium earths, is particularly prevalent in monazite, commonly constituting 1 percent or more of the rare earths present. Xenotime may likewise be represented by the same general formula, where R represents mainly the yttrium earths. Silicon is a common constituent of monazite, ranging in content from 1 to 10 percent, and proxying for phosphorous; at least a dozen other nonradioactive elements in small quantities have been identified.

Monazite contains commonly from 2 to 10 percent of thorium, and much smaller amounts of uranium. These two super-rare earths proxy for the cerium earths. Owing mainly to its content of thorium, monazite is a highly radioactive mineral, though this property is accentuated by the contained uranium, to a minor degree by the contained samarium, and by lutetium, if present. The radiogenic elements resulting from the decomposition of thorium, uranium, and samarium are necessarily present.

Both monazite and xenotime are electromagnetic, but xenotime is more strongly magnetic than monazite, approaching the magnetism of ilmenite. All the elements of the rare earths have high paramagnetism, and gadolinium is known to be ferromagnetic at room temperature. The atomic susceptibilities of these elements, however, are no criteria for predicting the magnetic properties of the rare earth minerals, but they do serve to explain that the high magnetic susceptibilities of monazite and xenotime, approaching ferromagnetism, are inherent properties of these minerals, and are not caused by ferromagnetic inclusions.

Monazite is distinctly brittle with a hardness of about 5, and a specific gravity of about 5.1. The small grains found in granitic rocks are honey-yellow to greenish-yellow and resinous, but the larger crystals found in pegmatites are more commonly reddish brown and opaque. This mineral is highly resistant to alteration by weathering, for which reason the grains found on ocean beaches do not differ materially, except for size and shape, from those recovered directly from saprolite. Monazite is a poor electrical conductor, and this property is utilized in its commercial separation from ilmenite and rutile, which are good conductors.

Monazite, if it contains neodymium, can invariably be identified in the field by examining it in reflected sunlight with a hand spectroscope. A broad absorption band will be seen in the yellow, centering at 578 millimicrons, and a faint and narrow absorption band may also be seen in the green, centering at 521 millimicrons. This test will work on concentrates in which the percentage of monazite is as low as 5 percent. The absorption band in the yellow can also be seen in diffused daylight, and almost equally well by the use of an ordinary Mazda light. Lower concentrations of monazite can be rendered amenable to this test by the removal of minerals that are more magnetic than monazite. The sample may be further concentrated by spreading in on a piece of paper, which is gently tapped on one edge. By either or both of these methods, monazite may be recognized with the hand spectroscope in samples containing only a small fraction of 1 percent.

The writer has discovered that xenotime can similarly be determined in the field by recognition of one or two absorption bands in the green, centering at 521 and 539 millimicrons, caused by the presence respectively of erbium and holmium. No absorption band shows in the yellow. This test is much more effective if a hand spectroscope with an iris diaphragm is used, so that the absorption may be viewed through a small aperture. The test is made possible by the fact that xenotime may be separated from a mixture of xenotime and monazite by the use of an Alnico magnet of the proper power.

Occurrence and production

Small percentages of monazite are common in certain granitic rocks, including pegmatites, and concentrations occur in derived detrital deposits; and this mineral has been described from many localities throughout the world. Deposits of heavy minerals that include monazite are known in India, Burma, Ceylon, Netherland Indies, Malaya, Korea, Formosa, Australia, Tasmania, Nigeria, French West Africa, Uganda, Kenya, Nyasaland, Egypt, Madagascar, Norway, Brazil, and other countries. These, except for the monazite of Norway, are detrital deposits that contain ilmenite, leucoxene, magnetite, zircon, monazite, xenotime, rutile, garnet, staurolite, and other heavy and semi-heavy minerals, in widely varying proportions. Monazite, therefore, is only one of the minerals recovered from such placers. The principal commercial sources in recent years have been the beach placers of India and Brazil.

Monazite has been reported at many localities in the United States. It is known to occur in many of the eastern states from New England to Florida; in the Black Hills; in Arkansas and Texas; and in a number of the Cordilleran states, notably in Idaho. The principal commercial sources of monazite in this country are in Idaho and in the southeastern states. The deposits of the southeastern states are not being mined at present, although a small byproduct output is coming from the mining of heavy minerals in Florida. Monazite was not saved in the earlier gold placer mining operations in Idaho, but significant quantities are known in the Boise basin, the Warren-Burgdorf district, the Dixie district, the Florence district, and others. Old tailings will have to be reworked to recover the monazite lost in this earlier mining, but some monazite is now being recovered in present gold-mining operations. Recently, moreover, three dredges have started to operate near Cascade, Idaho, mining monazite placers that contain little or no gold.

The principal commercial sources of monazite, since 1910, have been the province of Travancore, in India, and Brazil. The production in India has come mainly from monazite-bearing littoral sands, that occur intermittently from Cape Comorin northwestward for more than 100 miles to Trikunnapuzha, though deposits of lower grade are found east of Cape Comorin in the Tinnevelly district and also near Walthair in Vizagapatam. The primary sources are granitic rocks that occur inland, though a secondary source is the Warkalay formation, of late Tertiary age. The monazite deposits of Brazil occur intermittently along the Atlantic beaches of Bahia, Espirito Santo, Rio de Janeiro, and Sao Paulo, though monazite also has been found in the Barreiras (Tertiary) formation, on elevated beaches, and along the bars of streams close to the ocean. The Brazilian placers have been concentrated from monazite-bearing granitic rocks, mainly gneisses, that crop out along and close to the beaches, and from the alluvial sources mentioned. A small production has come from Ceylon, Netherland Indies, Australia, and elsewhere.

The production of monazite from India and Brazil is no longer being reported, and Brazil has limited its annual exports to 3,000 tons. The production of monazite in the United States, Brazil, and India, so far as known to the writer, is given in the following tabulation. The data on Brazil, from 1911 to 1929, have been taken from Houk's figures (Houk, 1943, pp. 11-12). The other data have been taken from published reports and official information.

Monazite production in United States, Brazil and India
(Short tons)

Year	U. S.	Brazil	India	Year	U. S.	Brazil	India
1887	10	---	----	1922	---	127	140
1893	65	---	---	1923	---	---	276
1894	273	---	---	1924	---	---	697
1895	786	3,307	---	1925	---	22	---
1896	15	192	---	1926	---	221	72
1897	22	249	---	1927	---	224	314
1898	125	2,149	---	1928	---	112	115
1899	175	2,932	---	1929	---	99	202
1900	454	1,633	---	1930	---	17	16
1901	374	1,811	---	1931	---	---	101
1902	401	1,328	---	1932	---	331	732
1903	431	3,636	---	1933	---	449	156
1904	373	5,357	---	1934	---	---	1,130
1905	676	4,891	---	1935	---	---	4,277
1906	423	4,797	---	1936	---	---	2,943
1907	274	4,891	---	1937	---	460	3,451
1908	211	5,473	---	1938	---	356	5,848
1909	271	7,121	---	1939	---	53	
1910	50	5,994	---	1940	---	198	
1911	19	4,064	932	1941	---	941	
1912	---	3,746	1,271	1942	---	1,576	4,480
1913	---	1,584	1,382	1943	---	1,709	(Average)
1914	---	661	1,328	1944	---	3	
1915	18	484	1,241	1945	---	1,135	
1916	19	---	1,447	1946	---	1,378	
1917	11	1,252	2,173	1947	---	1,930	
1918	---	551	2,371	1948	---	2,205	2,258
1919	---	161	2,266	1949	---	[1]2,381	Not reported
1920	---	1,270	1,838				
1921	---	366	1,411	Total	5,476	85,827	80,708

[1] Exports.

Southeastern placers

Piedmont province

Distribution.—Certain granitic intrusives and granitic gneisses that occur in the Piedmont province of Virginia, North Carolina, South Carolina, Georgia, and Alabama are the principal bedrock sources of monazite in the southeastern states, but other rocks into which granitic material has been introduced are also important hardrock sources. Certain monazite-bearing schists are also known, in which the monazite may be either detrital or secondary. The principal monazite placers so far developed lie in an area between Shelby, Rutherfordton, and Morganton, N. C., that extends southwestward through Spartanburg, and Greenville, S. C. This area is shown in figure 1. Monazite in bedrock, however, is now known to occur in two belts that cross five states, as shown in plate 1. A little monazite also has been found west of the Blue Ridge, and in isolated localities outside the two principal belts. No placer exploration has yet been done in these extended fields, but it is possible that new fluviatile placers will later be found in the Piedmont province.

The monazite deposits of the southeastern states were not seriously depleted by the earlier mining, because only the stream placers in the extreme headwater stretches of the valleys were worked, and many of these by extremely crude methods. There remain the deposits in or close to the stream channels in the lower valleys, the deposits of the valley floors, other deposits that were known but had not been developed by 1911, and still others that were not known at that time. Since the era of mining, the monazite-bearing gravels in the headwater stretches of streams have been rejuvenated, because the soil nearby is permeated with monazite, and every torrential rain delivers a large quantity of this mineral to the stream channels.

Some of the placer concentrates have been found to contain significant quantities of xenotime. Thus a sample from Grassy Creek, in the Shelby quadrangle, contains about 8 percent of xenotime; and smaller amounts were detected in other placer samples. In the earlier placer mining operations in North and South Carolina, all separatory work was done with an electromagnet; and owing to its magnetic susceptibility, xenotime was probably separated and discarded with the ilmenite. In present operations, where a high tension separator first removes the ilmenite and rutile, some xenotime will doubtless be recovered with the monazite. The net effect is commercially negligible, being merely to increase slightly the percentage of yttrium earths at the expense of the cerium earths.

Valuation.—The placers, at the sites of earlier mining, were sampled by the writer in 1945. Placers of any kind can be sampled accurately only by open cutting, by sinking shafts with or without drifting, or by drilling with casing. A favored method in Alaska utilizes a Keystone drill, or some modification thereof, and 6-inch casing. The writer, working alone, was unable to use any of these methods, but panned instead the gravel riffles in those headwater stream channels, where mining had formerly been done. Such work necessarily could not give the true tenors of the placers, but gave instead a set of approximate values, that differ from the true tenors according to local conditions. The results served, nevertheless, to compare the tenors of different streams, and to obtain samples of adequate size for mineralogical and chemical analysis.

Samples of this kind were taken at 104 localities, mainly from stream gravels, but also from eluvium and soils. The total volume handled by panning was about 3.2 cubic yards, or roughly the same number of tons. About half of these samples, mainly those of highest tenor, were selected for measurement of the contained monazite, and chemical analysis of the same. The localities of these selected samples are given below.

Localities of monazite placer samples

North Carolina

45 Mt 110. Hickory Creek, at the old L. U. Campbell mine, which was also the site of mining for the British Monazite Co., about 2½ miles northeast of Shelby, Cleveland County, N. C.

45 Mt 117. Head of Little Hickory Creek, on ground of W. M. Spake, about 2-3/4 miles N. 75° E. of Shelby, Cleveland County, N. C.

45 Mt 124. East fork of Knob Creek, about 7/8 mile N. 30° W. of Tuluca, Cleveland County, N. C.

45 Mt 126. West fork of Knob Creek, about 1-3/4 miles N. 69° W. of Tuluca, Cleveland County, N. C.

45 Mt 128. Branch of Crooked Run, about 1¼ miles S. 15° E. of Casar, Cleveland County, N. C.

45 Mt 141. Fork of Brushy Creek, about 4 miles S. 37° W. of Double Shoals, Cleveland County, N. C.

45 Mt 154. Fork of Brushy Creek, about 2½ miles S. 57° W. of Double Shoals, Cleveland County, N. C.

45 Mt 154-a Branch of Buffalo Creek, about 1 mile N. 30° E. of Fallston, Cleveland County, N. C.

45 Mt 155-a Long Branch, a west tributary of Buffalo Creek, about 1-3/4 miles S. 13° E. of Fallston, Cleveland County, N. C.

North Carolina--Continued

45 Mt 157. West branch of Buffalo Creek, about $1\frac{1}{2}$ miles S. 47° E. of Fallston, Cleveland County, N. C.

45 Mt 160. West branch of Little Knob Creek, about 3 miles N. 85° E. of Eakers Corners, Cleveland County, N. C.

45 Mt 162. Headwater fork of Sandy Run Creek, about 1-1/8 miles N. 12° W. of Hopewell, Rutherford, N. C. Site of mining by old German-American Monazite Co.

45 Mt 163. Old Louisa Smart property, on Webb Creek, about $2\frac{1}{2}$ miles S. 68° E. of Bostic, Rutherford County, N. C.

45 Mt 164. Same general site as 45 Mt 163, but from a small south-flowing branch of Webb Creek, about 2-5/8 miles S. 75° E. of Bostic, Rutherford County, N. C.

45 Mt 165. Monazite Branch, about 2-3/8 miles N. 74° E. of Ellenboro, Rutherford County, N. C.

45 Mt 169. Southwest branch of Duncans Creek, about 1-7/8 miles N. 5° E. of Hollis, Rutherford County, N. C.

45 Mt 171. Southwest branch of Duncans Creek, about $2\frac{1}{2}$ miles north of Hollis, Rutherford County, N. C.

45 Mt 172. East branch of Second Broad River, about 2-3/4 miles S. 37° W. of Ellenboro, Rutherford County, N. C.

45 Mt 175. Henderson Branch of Hollands Creek, about $2\frac{1}{4}$ miles N. 63° E. of Rutherfordton, Rutherford County, N. C.

45 Mt 178. Chunk Creek, a south branch of Hollands Creek, about 2-3/8 miles N. 75° E. of Rutherfordton, Rutherford County, N. C.

45 Mt 184. West branch of Sandy Run Creek, about 1-3/8 miles N. 22° W. of Mooresboro, Cleveland County, N. C.

45 Mt 185. Same general locality as 45 Mt 184, but from a small tributary.

45 Mt 186. West branch of Sandy Run Creek, about 7/8 mile S. 43° W. of Mooresboro, Cleveland County, N.C.

45 Mt 189. South branch of Silver Creek, about $2\frac{1}{2}$ miles S. 10° E. of Glen Alpine, Burke County, N. C.

45 Mt 192. Grassy Creek, about 3/4 mile S. 50° E. of Polkville, Cleveland County, N. C.

45 Mt 193. Rock Creek, about 7/8 mile N. 80° E. of Pleasant Grove, Burke County, N. C.

45 Mt 209. West branch of Buffalo Creek, about $2\frac{1}{4}$ miles N. 6° E. of Fallston, Cleveland County, N. C.

45 Mt 213. Head of Maple Creek, about 1 mile south of Belwood, Cleveland County, N. C.

45 Mt 215. Alexander Creek, tributary of Muddy Creek, about 2-3/8 miles N. 29° W. of Dysortsville, McDowell County, N. C.

45 Mt 221. Camp Creek, about 1 mile S. 47° E. of Ramsey, Burke County, N. C.

45 Mt 229. Beaverdam Creek, about 2 miles east of Boiling Springs, Cleveland County, N. C.

45 Mt 230. Bald Knob Creek, about 1-3/8 miles S. 73° E. of Casar, Cleveland County, N. C.

45 Mt 233. Branch of Knob Creek, about 1-3/8 miles S. 65° W. of Belwood, Cleveland County, N. C.

45 Mt 234. Wellman Branch of Knob Creek, about 2 miles S. 61° W. of Belwood, Cleveland County, N. C.

45 Mt 235. Original site of Millholland Mill, on Third Creek, about 2-5/8 miles S. 30° E. of Hiddenite, Alexander County, N. C.

45 Mt 244. East branch of Crooked Run Creek, about $3\frac{1}{2}$ miles N. 25° W. of Lawndale, Cleveland County, N. C.

Localities of monazite placer samples--Continued

South Carolina

45 Mt 29. Little Cherokee Creek, about $3\frac{1}{4}$ miles north of Gaffney, Cherokee County, S. C.

45 Mt 36. The old Swofford mine, on Pole Bridge Branch of Cherokee Creek, about 0.8 mile S. 25° W. of Grassy Pond, Cherokee County, S. C.

45 Mt 38. The old Lemmon mine, on a small branch of Cherokee Creek (flowing N. 15° E.) about 2 miles S. 35° W. of Grassy Pond, Cherokee County, S.C.

45 Mt 40. The old Jonas Blanton mine, on N. Fork of Beaverdam (Irene) Creek, about 4 miles N. 68° W. of Gaffney, Cherokee County, S. C.

45 Mt 50. Floyd Branch of Island Creek, about $1\frac{1}{2}$ miles south of Cowpens Battleground Monument, Cherokee County, S. C.

45 Mt 55. Cudds Creek, about 1-3/4 miles N. 83° W. of Cowpens Battleground Monument, Cherokee County, S. C.

45 Mt 59. Bill Martin Creek, about 1 mile S. 35° E. of Cowpens Battleground Monument, Cherokee County, S. C.

45 Mt 60. Joe Welchel Creek, a southeast-flowing tributary of the N. Fork of Beaverdam Creek, adjoining the old Jonas Blanton mine, Cherokee County, S. C.

45 Mt 65. Cherokee Creek, about 2 miles north of Gaffney, Cherokee County, S. C.

45 Mt 66. Double Branch (Melon) Creek, about 3 miles S. 30° E. of Chesnee, Spartanburg County, S. C.

45 Mt 73. South branch of Macedonia Creek, about 5 miles N. 51° W. of Thicketty, Cherokee County, S. C.

45 Mt 74. Little Thicketty Creek, about 4-3/4 miles N. 69° W. of Thicketty, Cherokee County, S. C.

45 Mt 81. South-flowing branch on the old Waldrop farm, about 3-3/4 miles S. 69° E. of Piedmont, Greenville County, S. C.

45 Mt 98. Branch of Gillard Creek, about 1 mile N. 17° E. of Mauldin, Greenville, S. C.

45 Mt 101. South-flowing branch of Reedy Creek, on the old Charles Brooks farm, about 7/8 mile south of Mauldin, Greenville County, S. C.

45 Mt 105. Small north-flowing branch, about 4-3/8 miles N. 78° E. of Piedmont, Greenville, S. C.

Georgia

49 Mt 18. Small stream, about 7 miles S. 87° W. of Griffin, Spalding County, Ga.

The following tabulation gives the results of this sampling, which was done with a 16-inch gold pan. About 130 heaped pans are considered to be equivalent to a cubic yard, but in this work most of the larger cobbles were thrown out and replaced by finer material, for which reason only 80 pans were taken as the equivalent of a cubic yard.

Placer monazite, southeastern Atlantic States

Sample no.	Number of pans	Heavies (grams)	Monazite percent	Heavies[1]	Monazite[1]	Sample no.	Number of pans	Heavies (grams)	Monazite percent	Heavies[1]	Monazite[1]
45 Mt 29	6	350.1	30	10.3	3.1	45 Mt 162	5	1251.3	60	44.1	26.5
45 Mt 36	7	274.2	26	6.9	1.8	45 Mt 163	3	239.1	61	14.1	8.6
45 Mt 38	5	240.9	41	8.5	3.5	45 Mt 164	1	195.9	70	34.6	24.2
45 Mt 40	3	120.9	17	7.1	1.2	45 Mt 165	4	423.0	68	18.7	12.7
45 Mt 50	3	135.6	39	8.0	3.1	45 Mt 169	3	187.2	59	11.0	6.5
45 Mt 55	1	120.8	37	21.3	7.9	45 Mt 171	3	150.4	60	8.8	5.3
45 Mt 59	1	109.7	33	19.3	6.4	45 Mt 172	2	84.4	68	7.4	5.1
45 Mt 60	3	127.4	48	7.5	3.6	45 Mt 175	5	575.6	31	20.3	6.3
45 Mt 65	4	94.3	34	4.2	1.4	45 Mt 178	4	918.5	57	40.5	23.1
45 Mt 66	3	69.2	43	4.1	1.7	45 Mt 184	3	174.5	54	10.3	5.5
45 Mt 73	2	276.0	30	24.3	7.3	45 Mt 185	2	207.1	70	18.3	12.8
45 Mt 74	1	74.1	30	13.1	3.9	45 Mt 186	3	136.3	56	8.0	4.5
45 Mt 81	2	257.6	38	22.7	8.6	45 Mt 189	3	144.3	47	8.5	4.0
45 Mt 98	4	248.6	35	11.0	3.8	45 Mt 192	8	661.7	65	14.6	9.5
45 Mt 101	6	271.8	47	8.0	3.8	45 Mt 193	4	370.2	43	16.3	7.0
45 Mt 105	3	1455.4	49	85.6	41.9	45 Mt 209	3	168.8	61	9.9	6.1
45 Mt 110	8	236.6	58	5.2	3.0	45 Mt 213	2	855.7	32	75.5	24.1
45 Mt 117	4	196.8	45	8.7	3.9	45 Mt 215	3	485.0	19	28.5	5.4
45 Mt 124	8	277.6	50	6.1	3.1	45 Mt 221	3	289.2	42	17.0	7.1
45 Mt 126	8	395.9	56	8.7	4.9	45 Mt 229	1	103.0	49	18.2	8.9
45 Mt 128	5	249.2	37	8.8	3.3	45 Mt 230	2	175.7	30	15.5	4.6
45 Mt 141	2	548.0	22	48.3	10.6	45 Mt 233	1	189.7	75	33.5	25.1
45 Mt 154	5	424.5	24	15.0	3.6	45 Mt 234	1	205.3	84	36.2	30.4
45 Mt 154-a	5	248.0	33	8.7	2.9	45 Mt 235	3	352.4	13	20.7	2.7
45 Mt 155-a	5	89.4	58	3.1	1.8	45 Mt 244	4	359.9	66	15.9	10.5
45 Mt 157	4	84.2	60	3.7	2.2						
45 Mt 160	3	158.2	84	9.3	7.8	Mean			47	18.0	8.4

[1]In pounds per cubic yard.

The mean content of these samples is 8.4 pounds of monazite to the cubic yard, but the tenors range upward to five times this value. The nominal price of monazite, as of October 1952, was 19 cents a pound for a product containing 65 percent of rare earths and ThO_2. Analyses of 19 of the preceding samples, made in the chemical laboratory of the U. S. Geological Survey, show an average tenor of 68.87 percent in the rare earths plus ThO_2. These figures suggest the presence of some high-grade placers, but it should be emphasized that these samples were taken in headwater stretches of the streams where no great volume of alluvial material is available. In order to obtain yardage, mining must be carried on farther downstream where the valleys open out to alluvial floors of some width. Necessarily the tenors will decrease downstream, owing partly to the addition of alluvium from tributaries that carry little or no monazite, and partly to other factors. One unfavorable condition results from the specific gravity of monazite, together with the omnipresence of saprolite. Monazite is only one-third as dense as ordinary placer gold, and therefore does not gravitate toward bedrock to the same degree as gold. Instead it tends to migrate downstream, unless retained by beds of gravel; but gravel, in a region characterized by saprolite, is replaced in large measure by sand and silt. William C. Overstreet, in drilling the fluviatile deposits within the western monazite belt, has found that such conditions are generally prevalent, resulting in the production of placers of lower grade than might be expected from headwater panning. A large movement of monazite downstream is further corroborated by its presence in all the formations of the Coastal Plain, many miles from the bedrock sources. It is improbable, however, that placer mining is at all possible in the valleys of master streams like the Broad and Saluda Rivers, except as a byproduct in the recovery of other products, such as sand and gravel; and in the Coastal Plain, monazite is more likely to be recovered as a byproduct of heavy mineral mining.

Other factors must be considered in placer mining downstream from these headwater stretches. The lack of a marked concentration of monazite near bedrock, and the presence of much overlying sand and silt with a low tenor, will require the processing of all the overburden above the basal gravels, if a high recovery is to be obtained. But this requirement is opposed, in a farming country where the land is privately owned, by laws which forbid the discharge downstream of a large volume of fine sediments, and may require the replacement of soil after mining is ended.

Another deterrent to the domestic mining of monazite is the uncertainty regarding its future value. The present high price results from an artificial scarcity, caused by the removal of Indian monazite from the market, and by a limited Brazilian output. These conditions could change suddenly. Moreover, if a large volume of rare earth minerals should be produced from the southeastern States, from Idaho, or from other domestic or foreign sources, competition would quickly lower the market price. Mining men who understand these conditions are understandably cautious in attempting to mine domestic monazite on a large scale.

Extensive placer mining in the southeastern States will have to be preceded by exploration, either by private concerns or by governmental agencies; and such work, preferably by drilling, should also give heed to other heavy and semi-heavy minerals contained in the placers. Starting in November 1951, the Geological Survey began to block out fluviatile deposits in the western monazite belt that should be drilled; and the Bureau of Mines has already started such drilling. In the mining of fluviatile monazite placers in the Piedmont province, ilmenite, rutile, and zircon should constitute saleable byproducts. Garnet, kyanite, sillimanite, staurolite, and other semi-heavy minerals might also be of interest if they could be economically separated from one another.

The situation regarding placer monazite mining in the southeastern States may be summarized as follows. At present only the high-grade deposits, lying in or not far downstream from the headwater stretches of the streams, offer quick and profitable returns. Such mining will require many plants, consisting probably of small power shovels and mobile concentrating equipment. Deposits of larger volume may be discovered by the underground exploration now in progress. A vast volume of monazite, however, is present, if one considers the total content of the fluviatile deposits, the saprolites, and the formations of the Coastal Plain. In a period of future emergency, when the motive of profit might temporarily be inoperative, the monazite of the southeastern States could be invaluable.

Content of thorium and uranium. — The thorium contained in monazite was formerly used in the manufacture of Welsbach gas mantles, but it now is used in limited quantities for other purposes. Its potential use in the future is as a substitute for uranium in the production of nuclear power. Thus U^{233} can be produced from Th^{232} by means of a breeder reaction exactly analogous to that being used to produce Pu^{239} from U^{238}; and U^{233}, in its susceptibility to nuclear fission, is intermediate between U^{235} and Pu^{239}. The content of uranium in monazite, though small, is also significant.

The monazite from 53 samples of placer concentrates was analyzed for the contents of ThO_2 and U_3O_8. Acknowledgment for this work is gratefully made to John C. Rabbitt, Chief of the Trace Elements Laboratory of the Geological Survey; and to Frank C. Grimaldi and his co-workers, who did the analytical work. The results are shown in the following tabulation:

Content, in percent, of ThO_2 and U_3O_8 in placer monazite

Sample no.	ThO_2	U_3O_8	$\frac{U_3O_8}{ThO_2}$	Sample no.	ThO_2	U_3O_8	$\frac{U_3O_8}{ThO_2}$
45 Mt 29	4.90	0.45	0.092	45 Mt 162	4.58	0.33	0.072
45 Mt 36	6.45	.23	.036	45 Mt 163	5.76	.40	.069
45 Mt 38	6.21	.22	.035	45 Mt 164	4.47	.34	.076
45 Mt 40	5.91	.22	.037	45 Mt 165	5.80	.28	.048
45 Mt 50	4.95	.55	.111	45 Mt 169	5.28	.33	.062
45 Mt 55	4.84	.58	.120	45 Mt 171	5.02	.28	.056
45 Mt 59	4.91	.58	.118	45 Mt 172	4.74	.64	.135
45 Mt 60	6.44	.24	.037	45 Mt 175	5.49	.25	.046
45 Mt 65	5.87	.49	.083	45 Mt 178	5.27	.22	.042
45 Mt 66	5.47	.36	.066	45 Mt 184	5.52	.31	.056
45 Mt 73	6.76	.18	.027	45 Mt 185	5.86	.28	.048
45 Mt 74	6.59	.19	.029	45 Mt 186	5.58	.33	.059
45 Mt 81	5.08	.24	.047	45 Mt 189	2.48	.28	.113
45 Mt 98	5.56	.55	.099	45 Mt 192	5.31	.49	.092
45 Mt 101	5.05	.47	.093	45 Mt 193	4.94	.58	.117
45 Mt 105	4.85	.32	.066	45 Mt 209	6.46	.41	.063
45 Mt 110	7.72	.33	.043	45 Mt 213	7.22	.28	.039
45 Mt 117	5.77	.98	.170	45 Mt 215	3.60	.27	.075
45 Mt 124	6.80	.39	.057	45 Mt 221	6.20	.45	.073
45 Mt 126	7.00	.29	.041	45 Mt 229	5.08	.54	.106
45 Mt 128	6.45	.32	.050	45 Mt 230	5.66	.36	.064
45 Mt 141	4.62	.55	.119	45 Mt 233	5.08	.40	.079
45 Mt 154	5.06	.53	.105	45 Mt 234	7.06	.34	.048
45 Mt 154-a	6.34	.45	.071	45 Mt 235	5.19	.36	.069
45 Mt 155-a	6.13	.38	.062	45 Mt 244	7.54	.37	.049
45 Mt 157	7.38	.31	.024	49 Mt 18	4.42	.26	.059
45 Mt 160	7.84	.35	.045	Mean	5.67	.38	.070

The contents of thorium and uranium are not so related that a high content of thorium necessarily implies a high content of uranium. This is shown in the following tabulation, where the analyses are arranged in seven groups, according to their contents of ThO_2.

Number of samples	Range in ThO_2	Range in $\frac{U_3O_8}{ThO_2}$	Mean value of $\frac{U_3O_8}{ThO_2}$
7	7.84-7.00	0.039-0.049	0.044
3	6.99-6.50	.027- .057	.038
8	6.49-6.00	.035- .073	.053
10	5.99-5.50	.037- .170	.073
12	5.49-5.00	.042- .106	.072
9	4.99-4.50	.072- .135	.106
[1]15	4.49-2.48	.043- .113	.073

[1]Includes one sample from saprolite not given in preceding tabulation.

This arrangement indicates that the largest content of U_3O_8 in the southeastern monazite is to be expected in samples that contain from $4\frac{1}{2}$ to 5 percent ThO_2, and that the tenor in uranium decreases in both directions from this optimum value. This relationship appears not to be the result of any particular geographic distribution or localization, as the samples were taken from all parts of the placer mining area of North and South Carolina.

Coastal Plain

Monazite, unlike gold, is transported for long distances from its bedrock sources, and therefore it occurs also in small quantities in all of the formations of the Coastal Plain. These deposits, in turn, may function as secondary or proximate bedrock sources, from which other placers may be concentrated. In addition to monazite, however, many other heavy and semiheavy minerals are present in the Coastal Plain deposits derived from all the crystalline rocks of the Piedmont. In general, neither the monazite nor the other heavy minerals occur in sufficient quantities in this environment to constitute workable deposits, but under favorable conditions they may be reconcentrated to produce fluviatile and littoral placers of heavy minerals.

Fluviatile placers.—Streams that head in the monazite belts of the Piedmont may contain commercial deposits of monazite in their headwaters and possibly for moderate distances downstream. Still farther downstream, however, the monazite-bearing alluvium becomes mixed with a large volume of detrital materials from other streams that do not head in monazite-bearing bedrock. Therefore the valley floors of master streams, such as the Broad and Saluda Rivers, are unlikely to contain workable deposits either of monazite or of other heavy minerals; and downstream from the Piedmont, within the Coastal Plain, the presence of such placers may be regarded as highly improbable. This generalization, however, recognizes the possibility that monazite and other heavy minerals may be recovered from the valleys of master streams, either within the Piedmont or the Coastal Plain, as a byproduct of other mining operations, such as the recovery of sand and gravel.

Fluviatile placers of heavy minerals, however, may occur in streams that head within the Coastal Plain, where the source-rocks are the various formations of the Coastal Plain. Such smaller streams are generally too sluggish to be favorable sites for the concentration of heavy minerals, except close to the Piedmont, where the stream gradients are higher. At such sites the streams are small, even if they head back a short distance in the Piedmont. It follows, therefore, that fluviatile placers of heavy minerals in the Coastal Plain are most likely to occur in the valleys of small streams that head either within this province or at no great distance back in the piedmont. Such placers, moreover, will probably be localized near the inner margin of the Coastal Plain, and most of them are likely to be of small volume, though unusual physiographic conditions may result in the development of larger placers. It also follows, because the formations of the Coastal Plain are the proximate sources of the heavy minerals, that any such deposits will be heavy mineral placers, rather than placers that might be worked for their content of monazite alone.

Two such placers of low grade were discovered by the writer in the spring of 1951. One of these occurs on a small branch of Sweetwater Creek, about 3 miles east of Thomson, McDuffie County, Ga. The tenor at this site, as gaged by panning on the riffles, is about $1\frac{1}{2}$ pounds of monazite to the cubic yard. The source-rock was found to be the Tuscaloosa formation, of Late Cretaceous age, which in this vicinity contains a very small percentage of monazite. The second deposit was discovered on Rocky Creek, about 5 miles west-northwest of Lexington, Lexington County, S. C. The tenor of this deposit is only about $\frac{1}{2}$ pound of monazite to the cubic yard. Rocky Creek is a small tributary of Saluda River that heads and flows in the Coastal Plain. Some granite has been bared to erosion in its drainage basin, but this was found not to be monazite-bearing. Therefore the source of the monazite is believed to be the basal formations of the Coastal Plain.

Neither of these deposits has any commercial significance, but they show that fluviatile placers can exist within the Coastal Plain; and it is possible under favorable physiographic conditions that placers of higher grade and larger volume may exist in this environment. Similar placers were in fact found later in the summer of 1951, near Aiken, Aiken County, S.C., about midway between the two deposits mentioned above. The valleys of Horse and Holley Creeks, in this vicinity, were drilled by the U. S. Bureau of Mines between December 1951 and March 1952.

Beach placers.—The occurrence of beach placers of heavy minerals is closely related to the geologic history of the Coastal Plain, and particularly to the depositional history of the Pleistocene formations. An adequate discussion of these topics would far exceed the bounds of this paper, and the best that can be done is to present a few terse statements of the guiding principles.

Most of the sediments of the Pleistocene formations are believed by the writer to be of deltaic and estuarine origin, particularly those in the vicinity of the large rivers that drain the Piedmont province; and it is further believed that these deposits were not generally reworked by the sea, although obviously strand lines existed throughout the Pleistocene. Oscillations of the shorelines during the Pleistocene were produced unquestionably by the storage and release of ice in successive glacial and interglacial stages; and if changes in the strandline had been produced by this process alone, the deposits of the Coastal Plain would largely have been reworked by waves and shore currents. But concurrently, throughout the Pleistocene, a general lowering of the base level of erosion was superposed on these glacial oscillations, such that the sediments of each stage were deposited generally farther offshore than those of the preceding stage, and new terrigenous sediments were deposited above those that had been reworked by the sea. Thus the wave-worked beaches were buried by later deltaic deposits, which owing to epeirogenic uplift were not generally reached by the sea, and therefore remained in their primitive condition. This regimen was less effective in southeastern Georgia and Florida, owing to the absence of large rivers that would produce the deltaic sediments; and therefore in this part of the eastern Coastal Plain a greater percentage of the sediments at or near the surface show signs of littoral reconcentration.

A larger volume of heavy minerals was transported from the Piedmont to the Coastal Plain during the interglacial stages of the Pleistocene than during the glacial stages, owing to warmer, and possibly more humid, climates and more active weathering and erosion. More over each of the interglacial stages was much longer than post-Wisconsin time. The upper limits of the Pleistocene formations, at the altitudes heretofore mentioned represent the uppermost base levels that prevailed at each of the interglacial stages, so that the surficial sediments now exposed are mainly of deltaic or estuarine origin, whereas the marine sediments of both the interglacial and glacial stages are either buried by terrigenous deposits or are actually offshore beyond the present strand line. The net result of these conditions is that any marine terrace deposits that may be found are much more likely to be the sites of commercial deposits of heavy minerals than are the Recent sediments.

These conclusions were reached partly from theoretical considerations and partly as a result of panning 56 samples from the Coastal Plain. The localities at which these samples were taken are in southeastern South Carolina and in southeastern Georgia,

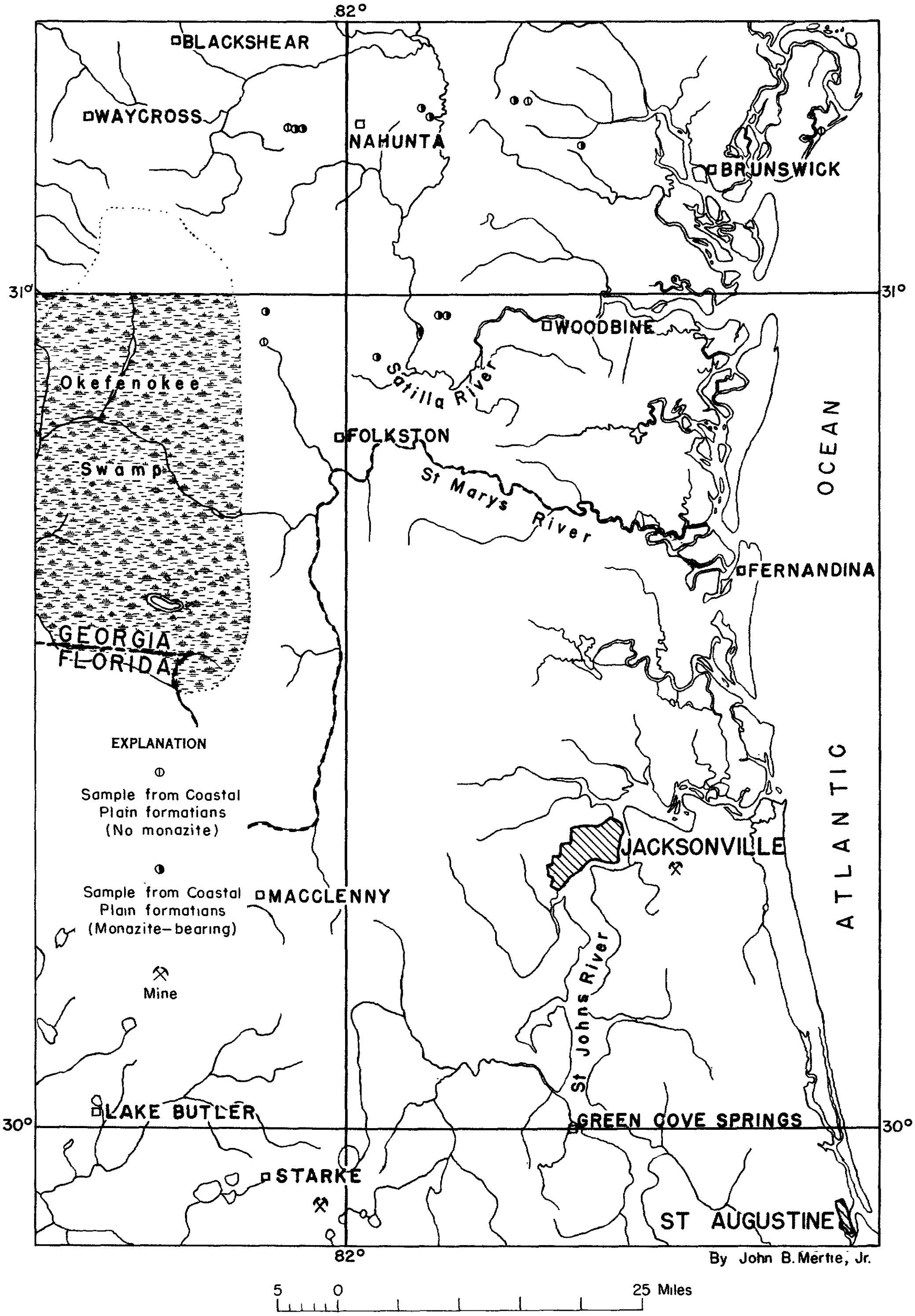

Figure 2. —Samples and mines in coastal plain of southeastern Georgia and northeastern Florida.

and are shown in plate 1 and figure 2. Southeastern South Carolina was selected as one site of exploration because of its proximity to the Santee River, whose headwater tributaries drain the most important part of the western monazite belt. Southeastern Georgia was selected as the other site because of its proximity to Florida, where deposits of heavy minerals are now being mined.

The net results of these theoretical conclusions and actual exploration follow. Heavy mineral concentrations were nowhere found, at the sites charted, that attain the minimum commercial grade, which is between 3 and 4 percent of the sand. But the concentration in southeastern Georgia is greater than in southeastern South Carolina; and at a few places along the eastern margin of the Okefenokee Swamp, the concentration of several feet of sediments at the surface was found to attain one percent. As the commercial deposits of Florida lie mainly below the surface, a concentration of one percent at the surface is significant, and suggests that the region just east of the Okefenokee Swamp is worth prospecting.

The amount of monazite found in the formations of the Coastal Plain of South Carolina and Georgia ranged from less than 1 to 9 percent of the heavies, but as the heavies in general constitute only 0.01 to 0.1 percent of the sediments, it follows that no placers are present in which monazite is of primary importance. Monazite, however, may be recovered as a byproduct in the mining of heavy mineral placers, if it occurs in amounts sufficiently large to be saved. Thus, two large plants in Florida are now engaged in the mining of the ilmenite, leucoxene, rutile, zircon, and staurolite. One of these plants, owned by the National Lead Co. and operating east of Jacksonville in the Penholoway terrace, is working sand that contains about 5 percent of heavies, whereas the tenor of the sand in monazite is only about 0.03 percent. This low percentage of monazite nevertheless makes possible in a large scale operation the production of a small but significant output of this mineral. The other plant, owned by E. I. du Pont de Nemours & Co. and operating in the Sunderland and Coharie terraces southeast of Starke, produces no monazite because the tenor of the sand in this mineral is a mere trace.

Bedrock sources

Monazite belts

The monazite placers of the Piedmont, up to 1948, were known to extend for about 100 miles in North and South Carolina, with a general northeasterly trend. This stretch, now called the western monazite belt, was subsequently traced by the writer northeastward into Virginia, and across that State for 170 miles. Southwestward, it was traced through North and South Carolina, Georgia, and Alabama for 430 miles, to a point where it finally is overlapped by the southern Coastal Plain. Hence the total length of the western monazite belt is now known to be about 600 miles. In 1949, however, monazite was discovered by the writer in bedrock about 15 miles northeast of Raleigh, N. C., and thence was traced for 200 miles north-northeastward to the vicinity of Fredericksburg, Va. These occurrences were designated as the eastern monazite belt. Recently the writer discovered monazite in bedrock about 20 miles north of Columbia, S.C., at a site that may constitute a southwestern continuation of the eastern monazite belt. These two belts, shown in plate 1, appear to join each other at an angle of about 45 degrees, in the vicinity of Manakin, Goochland County, Va.

The study of the southeastern granitic rocks, including those that contain monazite, has required a great deal of panning. A total of 516 samples of saprolite, aggregating about 45,200 pounds, have been collected and processed by the writer, of which 175 samples, weighing about 18,400 pounds, were found to contain monazite. The localities where these samples were collected are charted on plate 1, but owing to the small scale of this map, the symbols greatly exaggerate the size of the sites. To compensate for this shortcoming, the actual localities of the monazite-bearing samples, with which this paper is primarily concerned, are given herewith.

Localities of monazite-bearing saprolite and hardrock

Virginia

50 Mt 172 Saprolite of granitic gneiss from north side of Route 103, 0.9 mile by road west of Route 663 (entering 103 from south), and 7.4 miles S. 54° W. of Stuart, Patrick County, Va.

50 Mt 178 Saprolite of granitic gneiss from southeast side of Route 57, just southwest of junction of 57 with Route 647 from south, and about ½ mile southwest of Mountain Valley, Henry County, Va.

50 Mt 179 Saprolite of aplitic granite from northwest side of Route 57, just southwest of junction of 57 with Route 647 from south, and about ½ mile southwest of Mountain Valley, Henry County, Va.

50 Mt 196 Granitic saprolite from east side of Route 663, about 1.3 miles by road south of Route 103, and 1.6 miles by road north of Virginia-North Carolina line, in Patrick County, Va.

50 Mt 202 Granitic saprolite from southeast side of Route 626, about 4.3 miles by road north-northeast of intersection of Routes 626 and 58, and 7.3 miles N. 86° E. of Stuart, Patrick County, Va.

50 Mt 204 Saprolite of granitic dike in sheared gneiss, from east side of Route 626, about 5.3 miles by road south-southeast of junction of Routes 626 and 687, and 10.1 miles N. 75° E. of Stuart, Patrick County, Va.

Virginia--Continued

50 Mt 205 Saprolite of banded granitic gneiss from west side of Route 626, about 5.0 miles by road south-southeast of junction of Routes 626 and 687, and 10.3 miles N. 72 1/2° E. of Stuart, Patrick County, Va.

50 Mt 222 Granitic saprolite from northeast side of Route 38, about 150 yards northwest of junction of Routes 38 and 153, and 7.4 miles S. 57° E. of Amelia, Amelia County, Va.

50 Mt 233 Saprolite of granitic gneiss from south side of Route 460, 0.8 mile east of the Nottoway-Dinwiddie County line, and 1.4 miles S. 64° W. of Wilson, Dinwiddie County, Va.

50 Mt 234 Saprolite of granitic gneiss from east side of Route 46, about 200 yards north of Nottoway River, and 6.1 miles S. 20° E. of Blackstone, Nottoway County, Va.

50 Mt 235 Saprolite of granitic gneiss from northwest side of US 1, 0.3 mile west-southwest of the Mecklenburg-Brunswick County line, and 6.3 miles N. 60° E. of South Hill, Mecklenburg County, Va.

50 Mt 251 Saprolite of granitic gneiss, from east side, of Route 51, about 2.4 miles by road north-northwest of Little River, and about 0.4 mile north-northeast of Trinity Church, Hanover County, Va.

50 Mt 264 Saprolite of granitic gneiss, from north side of Route 606, and 0.1 mile by road east-southeast of Post Oak, Spotsylvania County, Va.

50 Mt 267 Saprolite of granitic gneiss, from south side of Route 3, about 5.3 miles by road west of the intersection of Routes 3 and 1-A, and about 1.3 miles by road west of Five Mile, Spotsylvania County, Va.

50 Mt 268 Saprolite of granitic gneiss, from south side of State Route 3, and about 7.0 miles by road west of the intersection of State Route 3 and US 1-A, Spotsylvania County, Va.

50 Mt 269 Saprolite of Petersburg granite(?), from northeast side of Route 33, about 3.8 miles by road northwest of Chickahominy River, and about 0.4 mile by road southeast of the intersection of Routes 33 and 623, Hanover County, Va.

50 Mt 271 Saprolite of granitic gneiss, from east side of Route 621-623, and about 0.8 mile by road north of the intersection of this road with Route 6, Goochland County, Va.

50 Mt 272 Saprolite of granitic gneiss, from southwest side of Route 6, and about 1.0 mile by road west of the intersection of Route 621-623 with Route 6, Goochland County, Va.

52 Mt 57 Granitic saprolite from north side of Route 615, about 2.5 miles by road west of the junction of Routes 615 and 47, and 2.8 miles airline S. 78° W. of Madisonville, Charlotte County, Va.

52 Mt 61 Saprolite of granitic rock from northeast side of Route 26, about 3.5 miles by road southeast of Red House, Charlotte County, Va.

52 Mt 73 Saprolite of granite gneiss from north side of Route 658, about 2.9 miles by road east-northeast of the junction of Routes 658 and 650; and 0.3 mile by road east of Buffalo Creek, Prince Edward County, Va.

52 Mt 74 Saprolite of cream-colored gneiss, from south side of Route 460, about 1.7 miles by road west of the western junction of Routes 460 and 15, Prince Edward County, Va.

52 Mt 75 Saprolite of cream-colored gneiss, from east side of Route 45, just north of the city limits of Farmville, Cumberland County, Va.

52 Mt 84 Saprolite of granitic gneiss from northeast side of Route 640, and about 100 yards northwest of the junction of Routes 640 and 670, and within sight of the schoolhouse at Renan, Pittsylvania County, Va.

52 Mt 89 Saprolite of white granite gneiss, from north side of Route 13, about 0.3 mile by road west of Macon, Powhatan County, Va.

52 Mt 91 Saprolite of white pegmatitic gneiss, from west side of Route 38, about 0.4 mile by road north of Appomattox River, Powhatan County, Va.

52 Mt 97 Granitic saprolite from west side of Route 15, about 1.6 miles by road north-northwest of west junction of Routes 460 and 15, and 0.3 mile south-southeast of Appomattox River, Prince Edward County, Va.

North Carolina

45 Mt 112	Saprolite of pegmatized gneiss, from the bedrock excavation of the British Monazite Co., on east side of Hickory Creek, 2 1/2 miles N. 47° E. of Shelby, Cleveland County, N. C.
45 Mt 119	Saprolite of pegmatite dike, on north side of Route 74, about 5.6 miles east of Buffalo Creek, Cleveland County, N. C.
45 Mt 125	Saprolite of the gneissoid granite near Toluca, from east side of an unpaved road, and 1.5 miles N. 11° W. of Toluca, Cleveland County, N. C.
45 Mt 136	Saprolite of the granite near Toluca, from east side of Route 18, and about 0.6 mile by road north of Fallston, Cleveland County, N. C.
45 Mt 137	Saprolite of the granite near Toluca, from east side of Lawndale-Casar road, and about 2.4 miles by road S. 35° E. of Casar, Cleveland County, N. C.
45 Mt 138	Granitic saprolite, from east side of Route 18, and about 2.8 miles by road north of Jacob Fork River, Burke County, N. C.
45 Mt 139	Granitic saprolite from east bank of small south-flowing branch of Brushy Creek, about 4 1/2 miles northwest of Shelby, Cleveland County, N. C.
45 Mt 152	Granitic saprolite from south side of unpaved road, about 2.1 miles by road east of Fallston, Cleveland County, N. C.
45 Mt 155	Saprolite of granitic bedrock in branch on farm of Cliff C. Blanton, about 5.3 miles N. 32° W. of Shelby, Cleveland County, N. C.
45 Mt 158	Saprolite of granitic material in schist, in bank of a short northeast-flowing branch of Buffalo Creek, about 1.7 miles S. 43° E. of Fallston, Cleveland County, N. C.
45 Mt 161	Saprolite of gneissoid granite, in bank of small branch of Little Knob Creek, about 3.7 miles S. 40° E. of Casar, Cleveland County, N. C.
45 Mt 173	Granitic saprolite from north side of Route 74, under the Southern Railway bridge, and about 0.8 mile by road east of Mooresboro, Cleveland County, N. C.
45 Mt 177	Granitic saprolite from east side of Route 221, about 1.0 mile by road north of Gilkey, Rutherford County, N. C.
45 Mt 179	Saprolite of granitized schist from west side of an unpaved road, about 1.3 miles northeast of Spindale, Rutherford County, N. C.
45 Mt 180	Saprolite of slightly granitized schist from west side of an unpaved road, about 1.3 miles northeast of Spindale, Rutherford County, N. C.
45 Mt 182	Granitic saprolite from south side of Route 74, in a soil erosion gulch, about 5.2 miles S. 88° W. of Shelby, Cleveland County, N. C.
45 Mt 194	Saprolite of granite of the type found near Toluca, from south side of an unpaved road, and 0.8 mile S. 80° W. of Pleasant Grove, Burke County, N. C.
45 Mt 210	Saprolite of granitized schist, from bank of a small tributary of Buffalo Creek, and 2.4 miles N. 6° E. of Fallston, Cleveland County, N. C.
45 Mt 218	Crushed building stone from the Winthrow quarry, about 1-1/2 miles west of Hollis, Rutherford County, N. C.
45 Mt 225	Saprolite of granitic gneiss, from north side of Route 64 and 70, just west of the Burke-McDowell County line, in McDowell County, N. C.
45 Mt 232	Saprolite from the granite near Toluca, from banks of a small branch of Knob Creek, and 3.4 miles N. 30° W. of Fallston, Cleveland County, N. C.
45 Mt 236	Excavated material from dump of Hiddenite mine, near Hiddenite, Alexander County, N. C.

North Carolina--Continued

45 Mt 243 Crushed granitic intrusive rock, from dump of Hiddenite mine, near Hiddenite, Alexander County, N.C.

45 Mt 245 Saprolite of granite of the type found near Toluca, from banks of a small branch of Crooked Run Creek; and 3.5 miles N. 23° W. of Lawndale, Cleveland County, N. C.

45 Mt 251 Saprolite of pegmatite and country rock at the site where a 16-inch crystal of monazite was recovered years ago (the Mars Hill pegmatite), about 2-3/4 miles S. 58° W. of Mars Hill, Madison County, N.C.

45 Mt 279 Saprolite of pegmatite, from a narrow gulch tributary to Hickory Creek from east, about 300 yards upstream from the site of an old dam built by the British Monazite Co., Cleveland County, N.C.

45 Mt 284 Granitic saprolite from northeast side of Spruce Pine-Bakersville road, about 4.2 miles by road northwest of the bridge at Spruce Pine, and 3.4 miles N. 52° W. of Spruce Pine, Mitchell County, N.C.

45 Mt 285 Saprolite of coarse-grained pegmatitic granite, from an old quarry on the northeast side of the Spruce Pine-Bakersville road, about 1.7 miles by road northwest of the bridge at Spruce Pine, Mitchell County, N. C.

45 Mt 294 Saprolite of coarse-grained pegmatitic granite, from north side of Route 19-E, about 5.2 miles by road west of the bridge at Spruce Pine, Mitchell County, N. C.

45 Mt 296 Saprolite of the granite near Mt. Airy, from both sides of Route 89, about 3 miles by road west of Mt. Airy, Surry County, N. C.

47 Mt 57 Crushed Toluca quartz monzonite from Acre Rock, about 0.7 mile S. 45° W. of Toluca, Cleveland County, N. C.

47 Mt 71 Saprolite of granite of the type found near Toluca, from west side of Route 18, about 2.5 miles by road north-northwest of Jacob Fork River, and 3.1 miles N. 20° W. of Ramsey, Burke County, N.C.

47 Mt 73 Saprolite of gneissic granite of the type found near Toluca, from east side of an unpaved road; and 0.8 mile N. 11° W. of Toluca, Cleveland County, N. C.

48 Mt 2 Saprolite of granitized gneiss from east bank of small south-flowing branch of Brushy Creek, about 4 1/2 miles northwest of Shelby, Cleveland County, N. C.

48 Mt 7 Saprolite of granitized schist or gneiss, from southeast bank of Webbs Creek, at site of old Louisa Smart monazite placers, where trail from house of T. W. Smart meets the creek. Also 2 1/2 miles S. 68° E. of Bostic, Rutherford County, N. C.

48 Mt 28 Saprolite of granitized gneiss, from west side of Polkville-Casar road (Route 10), and about 3.7 miles by road north of Eakers Corners, Cleveland County, N. C.

48 Mt 29 Saprolite of granite of the type found near Toluca, from west side of an unpaved road, about 0.7 mile S. 22° W. of Ramsey, Burke County, N. C.

48 Mt 43 Saprolite of the granite found at Mt. Airy, from west side of Route 601, and about 1 1/2 miles by road south of center of Mt. Airy, Surry County, N. C.

48 Mt 45 Saprolite of granitized country rock, from northeast side of Route 18, and 0.4 mile S. 38° E. of Ramsey, Burke County, N. C.

49 Mt 136 Saprolite of granitized gneiss, from soil erosion gulch on south side of a dirt road, and 2.7 miles N. 5° E. of Fallston, Cleveland County, N. C.

49 Mt 182 Granitic saprolite from west side of a paved road, and 1 1/4 miles S. 22° E. of Rolesville, Wake County, N. C.

50 Mt 192 Saprolite of banded granitic gneiss, from north side of Route 421, about 5.9 miles by road east of junction of Routes 421 and 115, Wilkes County, N. C.

50 Mt 274 Granitic saprolite from south side of a cut along Seaboard Airline Railroad, and 0.5 mile east of Norlina, Warren County, N. C.

50 Mt 275 Granitic saprolite from southwest side of Route 158, and 2.2 miles S. 38° E. of Norlina, Warren County, N. C.

Localities of monazite-bearing saprolite and hardrock--Continued

North Carolina--Continued

50 Mt 276 Granitic saprolite from southwest side of Route 158, and 3.6 miles S. 38° E. of Norlina; also 0.9 mile by road northwest of the center of Warrenton, Warren County, N. C.

50 Mt 278 Granitic saprolite from west side of Route 58, about 8.0 miles by road S. 29° W. of the center of Warrenton, Warren County, N. C.

50 Mt 282 Granitic saprolite from north side of Route 64, and 1.2 miles by road west of the Neuse River, Wake County, N. C.

50 Mt 284 Granitic saprolite from south side of Route 64, and 0.8 mile by road east of the Neuse River, Wake County, N. C.

50 Mt 290 Granitic saprolite from south side of Route 56, and 2.6 miles S. 62° W. of Louisburg, Franklin County, N. C.

50 Mt 295 Granitic saprolite from north side of Route 56, and south side of cut along Seaboard Airline Railroad; also 1.2 miles S. 49° W. of Louisburg, Franklin County, N. C. (Trace of monazite)

50 Mt 296 Granitic saprolite from south side of Route 56, and 1 3/4 miles S. 60° W. of Louisburg, Franklin County, N. C.

52 Mt 37 Saprolite of granitic rock, from west side of an unpaved road, and 1.1 miles airline S. 42° W. of Garner, Wake County, N. C.

52 Mt 76 Saprolite of granite at Mt. Airy, from north side of Route 103, about 1.0 mile by road east of Ararat River, and 0.4 mile east of entrance to quarry of North Carolina Granite Corp., Surry County, N. C.

52 Mt 77 Saprolite of peripheral phase of granite at Mt. Airy, from southwest side of Route 52, and about 0.9 mile by road northwest of the junction of Routes 52 and 104, Surry County, N. C.

52 Mt 79 Saprolite of granite at Mt. Airy, from north side of Route 89, and 1.7 miles by road west of Lovills Creek; also 2.3 miles by road west of the junction of Routes 89 and 52, in center of Mt. Airy, Surry County, N. C.

52 Mt 81 Saprolite of fine-grained white granite gneiss, from west side of Route 601, about 4.7 miles by road south of Dobson, and 0.6 mile by road north of the junction of Routes 601 and 268, Surry County, N.C.

South Carolina

45 Mt 34 Granitic saprolite, in part pegmatitic, in stringer and pockets, from east side of an unpaved road a short distance northeast of Route 150, and 3 1/4 miles N. 50° W. of Gaffney, Cherokee County, S.C.

45 Mt 37 Pegmatitic saprolite, a thin stringer in schist, from southwest bank of Pole Bridge Branch of Cherokee Creek, and 0.9 mile S. 25° W. of Grassy Pond, Cherokee County, S. C.

45 Mt 39 Saprolite of schist impregnated with granitic material, from small headwater tributary of Cherokee Creek, northeast of Route 11, and 3 3/4 miles N. 45° W. of Gaffney, Cherokee County, S. C.

45 Mt 52 Pegmatitic saprolite in lenses and pockets, from bank of Floyd Branch of Island Creek, about 1.0 mile south of Cowpens Battleground Monument, Cherokee County, S,C.

45 Mt 62 Saprolite of pegmatized schist, from west bank of Joe Welchel Creek, a tributary of Beaverdam Creek, and 2.0 miles west of Gaffney, Cherokee County, S. C.

45 Mt 67 Pegmatitic saprolite in bank of Double Branch Creek, about 4.0 miles S. 23° E. of Chesnee, Spartanburg County, S. C.

45 Mt 89 Saprolite of gneissoid granite in east bank of Rock Ford Creek, and 2.2 miles N. 57° E. of Moonville, Greenville County, S. C.

45 Mt 95 Saprolite of pegmatized gneiss, from south side of paved road leading east from Greenville airfield, and 1 3/4 miles S. 32° E. of Conestee, Greenville County, S. C.

45 Mt 96 Aplitic saprolite, from south side of paved road leading east from Greenville airfield, and 1-3/4 miles S. 32° E. of Conestee, Greenville County, S. C.

Localities of monazite-bearing saprolite and hardrock--Continued

South Carolina--Continued

49 Mt 45 Saprolite of granite of the type found near Toluca, N. C., from east side of Route 29, about 1.1 miles by road north of the Saluda River, Greenville County, S. C.

50 Mt 119 Saprolite of granitic gneiss from northwest side of Route 76, and 1.3 miles by road northeast of Honea Path, Anderson County, S. C.

50 Mt 120 Saprolite of granitic dike from southeast side of Route 76, and 2.0 miles by road northeast of Honea Path, Anderson County, S. C.

50 Mt 122 Saprolite of granitic gneiss from south side of Route 76, about 1/4 mile west of Reedy River, and 3.5 miles N. 81° E. of Princeton, Laurens County, S. C.

50 Mt 123 Saprolite of muscovite granite gneiss, from north side of Route 101, and 150 yards west of the city limits of Gray Court, Laurens County, S. C.

50 Mt 124 Saprolite of coarse-grained granitic gneiss, from north side of Mauldin-Conestee road, and 0.7 mile N. 53° E. of Conestee, Greenville County, S. C.

50 Mt 126 Granitic saprolite from southeast side of the paved road that connects Simpsonville and Pelzer, and 2.3 miles N. 39° W. of Woodville, Greenville County, S. C.

50 Mt 127 Granitic saprolite from northwest side of the paved road that connects Simpsonville and Pelzer, and 2.6 miles N. 58° W. of Woodville, Greenville County, S. C.

50 Mt 145 Granitic saprolite from southeast side of Route 221, and 1.1 miles by road northeast of Pacolet River; also 0.3 mile by road southwest of Mayo, Spartanburg County, S. C.

50 Mt 149 Granitic saprolite from west side of Route 221, about 0.4 mile northeast of the junction of Routes 221 and 9-43, and just north of the city limits of Spartanburg, Spartanburg County, S. C.

50 Mt 160 Granitic saprolite from southeast side of Route 296, and 1.9 miles N. 67° E. of Reidville, Spartanburg County, S. C.

50 Mt 161 Saprolite of pegmatized gneiss, from northeast side of Route 49, and 3 3/4 miles S. 9° W. of Batesville, Greenville County, S. C.

50 Mt 163 Saprolite of granitic gneiss, from east side of a paved road, 3.5 miles S. 73° E. of Simpsonville, Greenville County, S.C.

51 Mt 105 Granitic saprolite from north side of Route S-20-19, leading from Route 29 to Rion, just west of the track of the Rockton-Rion R. R. Also 5.5 miles S. 22° W. of Winnsboro, Fairfield County, S. C.

51 Mt 107 Saprolite of coarse-grained granite, from west side of Route 269, and 9.5 miles S. 24° W. of Winnsboro, Fairfield, County, S. C.

51 Mt 109 Granitic saprolite from west side of Route 269, and 6.7 miles S. 24° W. of Winnsboro, Fairfield County, S. C.

51 Mt 110 Granitic saprolite at entrance to quarry of Rion Crush Stone Corp., 6.1 miles S. 27° W. of Winnsboro, Fairfield County, S. C.

51 Mt 140 Granitic saprolite behind shop at the Blair quarry, about 1/2 mile east-southeast of Blair station on the Southern Railway, Fairfield County, S. C.

Georgia

49 Mt 14 Saprolite of granite near Zetella, from north side of Route 16, and 1.3 miles east of Zetella, Spalding County, Ga.

49 Mt 15 Saprolite of granite near Zetella, from both sides of an unpaved road that leads south-southeast from Zetella, and 2.2 miles by road from Zetella, Spalding County, Ga.

49 Mt 35 Granitic saprolite from south side of unpaved road that connects Covington with Pace (the old Covington-McDonough road), and 3.5 miles S. 71 1/2° W. of Covington, Newton County, Ga.

Localities of monazite-bearing saprolite and hardrock--Continued

Georgia--Continued

49 Mt 40	Saprolite of granitized schist, from north side of an unpaved road (the old Porterdale-McDonough road), and 10.0 miles S. 66½° W. of Covington, Newton County, Ga.
49 Mt 41	Saprolite of granitized gneiss, from north side of an unpaved road (the old Porterdale-McDonough road), and 9.0 miles S. 66° W. of Covington, Newton County, Ga.
49 Mt 42	Saprolite of granitized gneiss, from north side of an unpaved road (the old Porterdale-McDonough road), and 7.8 miles S. 64° W. of Covington, Newton County, Ga.
49 Mt 43	Saprolite of granitized gneiss, from north side of an unpaved road (the old Porterdale-McDonough road), and 6.5 miles S. 58° W. of Covington, Newton County, Ga.
49 Mt 46	Saprolite of granite similar to that near Zetella, from northwest side of US 29, and 0.7 mile N. 20° E. of Athens, Clarke County, Ga.
50 Mt 50	Saprolite of massive granite, from north side of Route 16, about 3¼ miles west of Sharpsburg, Coweta County, Ga.
49 Mt 59	Granitic saprolite along south side of Route 18, and 3.7 miles S. 68° E. of Greenville, Meriwether County, Ga.
50 Mt 15	Saprolite of a granite stringer in augen gneiss, from a point just east of an old shaft in pegmatite, which is 3.5 miles N. 55° W. of Yatesville, and 2.0 miles N. 25° W. of Tobler Mill, Upson County, Ga. (Sample donated by Georgia Geological Survey.)
50 Mt 17	Saprolite of banded granitic gneiss, from west side of Route 85, and 3.4 miles S. 27° E. of Gay, Meriwether County, Ga.
50 Mt 33	Saprolite of Snelson granite, from west side of Route 18-41, and about 0.5 mile by road north of Harris, Meriwether County, Ga.
50 Mt 36	Saprolite of granitic gneiss, from southwest side of Route 18, and 1.8 miles by road S. 76° E. of Greenville, Meriwether County, Ga.
50 Mt 40	Sun-baked reddish-brown saprolite of Carolina gneiss, from north side of Route 18, and 0.8 mile by road west of Woodbury, Meriwether County, Ga.
50 Mt 44	Saprolite of granitic gneiss, from northeast side of Route 27, and 1.7 miles S. 55° E. of Franklin, Heard County, Ga.
50 Mt 45	Saprolite of granitic gneiss, from northeast side of Route 27, about ¼ mile southeast of Franklin, Heard County, Ga. This locality is on an unpaved (abandoned) road, in sight of Route 27.
50 Mt 52	Saprolite of granitic gneiss, from north side of Route 34, and 1.7 miles by road east-northeast of Texas, Heard County, Ga.
50 Mt 70	Granitic saprolite from northwest side of Route 14, about 4.0 miles by road west-southwest of La Grange, and 1.4 miles by road west-southwest of railroad crossing, Troup County, Ga. In 1951, this locality was obliterated by a grader that cut away this bank, but equivalent material crops out on southeast side of road.
50 Mt 75	Granitic saprolite from northwest side of Route 14, about 2 3/4 miles by road west-southwest of La Grange, and 0.15 mile by road west-southwest of railroad crossing, Troup County, Ga.
50 Mt 76	Granitic saprolite from northwest side of Route 14, about 75 yards west of the road that leads southwest of Gallaway Field, and 3.15 miles by road west-southwest of La Grange, Troup County, Ga.
50 Mt 80	Saprolite of granitic gneiss, from northwest side of Route 14, about 5.9 miles by road west-southwest of La Grange, and 3.3 miles by road west-southwest of railroad crossing, Troup County, Ga.
50 Mt 106	Saprolite of coarse-grained crenulated white granite, from northwest side of an unpaved road, 0.2 mile northeast of Flat Creek, and 4.2 miles S. 32° E. of Clermont, Hall County, Ga.
50 Mt 107	Granitic saprolite along southeast side of an unpaved road, 0.3 mile southwest of Flat Creek, and 4.5 miles S. 28° E. of Clermont, Hall County, Ga.

Georgia--Continued

50 Mt 108 Saprolite of pegmatitic stringer in schist, from north side of an unpaved road, 0.4 mile west of a north-south road, and 4.4 miles S. 3° E. of Clermont, Hall County, Ga.

50 Mt 114 Saprolite of granitic gneiss, from west side of US 29, about 200 yards south of Little Bluestone Creek, and 3.1 miles N. 21° E. of Danielsville, Madison County, Ga.

50 Mt 115 Saprolite of white residual (pegmatitic) clay, along east side of a small gulch tributary to Shoal Creek, south of Route 51, and 1.0 mile S. 58° E. of Bowersville, Hart County, Ga.

50 Mt 116 Saprolite of granitic gneiss, on south side of Route 51, and 1.1 miles S. 67° E. of Bowersville, Hart County, Ga.

50 Mt 117 Saprolite of a mixture of pegmatite and schist, along east side of Shoal Creek, just north of Route 51, and 1.2 miles S. 74° E. of Bowersville, Hart County, Ga.

50 Mt 139 Saprolite of granitic gneiss on north side of an unpaved road, 1.0 mile by road east of Route 59, and 6.1 miles N. 17° E. of Bowersville, Hart County, Ga.

51 Mt 204 Saprolite of red granitic gneiss, from west side of Route 29, and 2.7 miles N. 19° E. of the junction of Routes 29 and 18, in West Point, Troup County, Ga.

51 Mt 205 Saprolite of Snelson granite, from southeast side of Route 18, and 0.6 mile by road east-northeast of the railroad station at Durand; also 1.1 miles by road south-southwest of Crowders, Meriwether County, Ga.

51 Mt 206 Saprolite of Snelson granite, from east side of Route 41, and 2.6 miles N. 18° W. of center of Warm Springs, Meriwether County, Ga.

51 Mt 212 Saprolite of granitized gneiss, from north side of Route 238, about 0.1 mile east-southeast of bridge across Chattahoochee River; and 8.6 miles S. 76° W. of center of La Grange, Troup County, Ga.

51 Mt 216 Saprolite of a thin seam of very coarse grained biotite granite, from north side of Route 238, and 7.2 miles S. 69° W. of center of La Grange, Troup County, Ga.

51 Mt 217 Saprolite of granitized gneiss, from south side of Route 238, and 7.0 miles S. 67° W. of center of La Grange, Troup County, Ga.

51 Mt 218 Saprolite of granitized gneiss, from west side of Route 29, and 6.9 miles S. 54° W. of center of La Grange, Troup County, Ga.

52 Mt 154 Saprolite of granite from west side of Liberty (Parker Hunt Co.) quarry, about 11.65 miles N. 49½° E. of Lexington, Oglethorpe County, Ga.

52 Mt 160 Saprolite of granite gneiss (interbanded with schist) from east side of Route 22, and 6.6 miles by road south of junction of Routes 72 and 22; also 7.8 miles by road north of junction of Routes 78 and 22; in Oglethorpe County, Ga.

52 Mt 163 Saprolite of granite from southeast side of Route 72, and 1 3/4 miles northeast of Carlton; also 1.0 mile by road southwest of Broad River, Madison County, Ga.

52 Mt 164 Saprolite of coarse-grained (pegmatitic) gneiss, from east side of Route 77, about 3.2 miles by road south-southeast of center of Hartwell, Hart County, Ga.

52 Mt 165 Saprolite of granite from east side of Route 172, about 6.1 miles by road south-southwest of center of Hartwell; also 0.5 mile north-northeast of Coldwater Creek; in Hart County, Ga.

52 Mt 167 Saprolite of banded gneiss, from northwest side of Route 78-10, about 3.7 miles by road southwest of Walton-Oconee county line, Walton County, Ga.

52 Mt 169 Saprolite of granitic stringer in schist, from east side of Route 129, and about 0.3 mile by road north-northeast of Barber Creek, Clarke County, Ga.

52 Mt 170 Saprolite of granite from east side of Route 129, about 0.9 mile by road north-northeast of Barber Creek, in Princeton, Clarke County, Ga.

Georgia--Continued

52 Mt 172 Saprolite of gneiss with granitic stringers, from north side of Route 29-82, about 3/4 mile by road west of the railroad station at Colbert, Madison County, Ga.

52 Mt 173 Saprolite of coarse-grained granitic dike, from east side of a newly paved road, about 2.5 miles by this road southwest of Dewy Rose, Elbert County, Ga.

52 Mt 174 Saprolite of a granitic dike, from northeast side of Route 17, about 3.0 miles by road southeast of center of Royston, Hart County, Ga.

52 Mt 175 Saprolite of a coarse-grained pegmatite, from southeast side of Route 17, about 1.9 miles by road northeast of the Madison-Clarke County line, in Madison County, Ga.

Alabama

51 Mt 161 Saprolite of granitic gneiss, from north side of paved road that connects Foster with Penton; and 1.0 mile N. 70° E. of Foster, Chambers County, Ala.

51 Mt 165 Saprolite of Pinckneyville "granite," from southwest side of the Route 241 bypass southwest of Alexander City; and 2.1 miles S. 31° E. of center of Alexander City, Tallapoosa County, Ala.

51 Mt 166 Saprolite of Pinckneyville "granite," from south side of Route 241, and 0.8 mile S. 40° E. of center of Kelleyton, Coosa County, Ala.

51 Mt 167 Saprolite of Pinckneyville "granite," from west side of Route 115, and 2.7 miles S. 33° W. of center of Kelleyton, Coosa County, Ala.

51 Mt 171 Saprolite of strongly biotitic Pinckneyville "granite," from west side of Route 9, and 4.7 miles S. 31° W. of center of Kelleyton, Coosa County, Ala.

51 Mt 172 Saprolite of Pinckneyville "granite," from east side of Route 9, and 2.6 miles N. 17° W. of Equality, Coosa County, Ala.

51 Mt 173 Saprolite of Pinckneyville "granite," from northwest side of Route 22, and 4.8 miles S. 53° W. of center of Alexander City, Coosa County, Ala.

51 Mt 175 Saprolite of gneissic Pinckneyville "granite," from west side of Route 63, and 3.3 miles S. 7° W. of center of Alexander City, Tallapoosa County, Ala.

51 Mt 184 Saprolite of Pinckneyville "granite," from west side of Route 11, and 6.6 miles S. 8° W. of Rockford, Coosa County, Ala.

51 Mt 185 Saprolite of Pinckneyville "granite," from north side of Route 22, and 5.1 miles S. 82° E. of Rockford, Coosa County, Ala.

51 Mt 190 Saprolite of Pinckneyville "granite," from west side of paved road that connects Alexander City with Hackneyville, Tallapoosa County, Ala.

51 Mt 192 Saprolite of Pinckneyville "granite," from southwest side of paved road that connects Alexander City with Hackneyville, and 3.1 miles N. 14° E. of center of Alexander City, Tallapoosa County, Ala.

51 Mt 201 Saprolite of granitic gneiss, from east side of the unpaved road that connects Hickory Flat with Finley, and 2.7 miles N. 83° E. of Stroud, Chambers County, Ala.

51 Mt 220 Saprolite of granitic gneiss, from northeast side of a paved road that connects Five Points with Fredonia, and 2.4 miles S. 55° E. of Five Points, Chambers County, Ala.

51 Mt 222 Saprolite of granitic gneiss from east side of an unpaved road that runs parallel and close to the Alabama-Georgia boundary line, and 4.2 miles N. 75° E. of Fredonia, Chambers County, Ala.

51 Mt 224 Saprolite of granitic gneiss, from east side of an unpaved road that connects Buffalo with Chapel Hill, and 1.6 miles N. 21° W. of Buffalo, Chambers County, Ala.

51 Mt 225 Saprolite of gneissic granite, from east side of an unpaved road that connects Chapel Hill with Albany, and 5.2 miles N. 21° W. of Buffalo; also 1.6 miles N. 5° W. of Chapel Hill, Chambers County, Ala.

The bedrock source of monazite was first recognized in 1948 in Cleveland County, N. C., in the heart of what is now called the western monazite belt. One of the areas in which a great deal of placer mining was done in earlier years includes the valleys of Knob Creek and its tributaries, which head in and around a prominent granitic hill called Carpenter Knob, that lies about 17½ miles north of Shelby. About 2 miles south-southeast of Carpenter Knob is one of the pavements of granitic rocks earlier mentioned, known locally as Acre Rock. A small opening has been made at this site, and rough building stone has been quarried there for many years. Sampling of the placers in the vicinity of Carpenter Knob and Acre Rock led to the belief that the granitic rocks exposed at these two sites are the principal sources of the placer monazite in this vicinity. This conclusion was fortified by the discovery of monazite in the soil adjacent to Acre Rock; but as the residual character of this soil was uncertain, it was necessary also to sample the unweathered bedrock. Accordingly two samples, aggregating 760 pounds, were crushed, rolled, and panned, and these likewise were found to contain monazite.

The monazite-bearing rocks are now known to consist mainly of granitic intrusives, older granitic gneisses of the Carolina gneiss, and country rock of various kinds into which granitic materials have been introduced. It is stated by William C. Overstreet, in an oral communication, that about one-fifth of the samples collected in the Shelby quadrangle comprise monazite-bearing schists, that have no proven granitic affinity. The granitic intrusives are generally massive rocks that have not been rendered gneissoid by regional metamorphism, but locally have a primary foliation of magmatic origin. The monazite-bearing rocks of the Carolina gneiss are largely granitic gneisses, most of which are probably of sedimentary origin, and are therefore to be designated as paragneiss. Other granitic gneisses of the Carolina gneiss that are monazite-bearing are probably ancient intrusives, that properly may be called orthogneiss. Rocks into which granitic minerals of normal size have been introduced, either in seams or lamillae of discernible size, or in more intimate association, are said to be granitized; and where the introduced material comprises minerals of large size, the term pegmatitization is used. The monazite in the schists cited by Overstreet may either have been derived from detrital grains that were a part of the original sediments from which these rocks were formed, or it may be of secondary origin. In either case, such schists are proximate rather than original sources of monazite.

The gneiss adjacent to the Toluca quartz monzonite in the Shelby quadrangle was found by Yates and Overstreet[1] to be granitized close to the intrusive by thin seams of granitic material which gave place farther from the contact to granitic lamellae, that still farther from the intrusive became megascopically indistinguishable from the gneiss itself. Dikelike processes of granitization and pegmatitization were found to be more prevalent in the biotite and sillimanite schists; but pegmatitic impregnation has been observed by the writer in both massive and schistose types of country rock. Granitization and pegmatitization are specially prevalent in the Shelby area, but also have been observed to constitute important processes in South Carolina, particularly in the area southeast of Greenville. At most places in the monazite belts, however, where monazite occurs in granitic gneisses, later granitic materials appear not to have been introduced secondarily.

Granites, pegmatites, and granitic orthogneisses are thus the original bedrock sources of monazite; the monazite-bearing paragneisses and schists, in the absence of evidence to the contrary, are interpreted as metamorphosed detrital rocks that contained monazite at the time of their deposition. Such rocks and also those into which granitic material has been introduced may be called proximate bedrock sources of monazite. Ortho and paragneisses are difficult to differentiate, and in fact are generally indistinguishable in roadside exposures of saprolite; similarly the introduction of granitic material into the country rock is not strikingly self-evident. Most southern geologists believe, however, that the granitic gneisses of the Carolina gneiss are dominantly of sedimentary origin, and it therefore is probably true that most of the bedrock sources of monazite in the Carolina gneiss are proximate sources. The field evidence so far accumulated indicates that granitic intrusives and the granitic gneisses of the Carolina gneiss, regardless of origin, are the principal sources of the monazite; and that the ratio of original to proximate bedrock sources varies greatly from one area to another.

Some of the granitic rocks within the monazite belts that have received formational names, and others of unusual significance, will now be mentioned. General geologic maps of North and South Carolina have not been made, so that formational names for the igneous and metamorphic rocks have not been generally applied. The name Whiteside granite was applied originally by Keith (1907, p. 4) to the granite at Whiteside Mountain, Jackson County, N. C.; and later this name was used (Keith and Sterrett, 1931, p. 6) to designate certain granitic rocks east of the Blue Ridge, in the Kings Mountain, N. C., and Gaffney, S. C., quadrangles. The use of this formational name at a distance of more than 100 miles from the type locality, across the regional strike, was unwarranted, and the correlation is now believed to be erroneous. A part of this so-called Whiteside granite, that lies within and adjacent to the Shelby quadrangle, North Carolina, was found by the writer to be monazite-bearing; and later the name Toluca quartz monzonite was applied by Griffitts and Overstreet (1952, pp. 777-789) to this monazite-bearing rock. This formational name, however, was defined only for a small area, so that it can not properly be applied to similar rocks to the northeast or southwest. The specialized designation of quartz monzonite also limits its areal extension; the name Toluca granite would have been better. Finally the Toluca quartz monzonite is defined as monazite-bearing; but judging by experience elsewhere in the Piedmont, the same rock will probably be found not to contain monazite outside the western monazite belt.

One of the larger bodies of monazite-bearing granite found in the western belt occupies an area surrounding Mt. Airy, Surry County, N. C. This is well exposed at the quarry of the North Carolina Granite Corp., originally a large pavement called The Rock, where quarrying has been in progress since 1889. The central part of this mass is characterized by exposures

[1] Yates, Robert G., and Overstreet, William C. Geology of the Shelby quadrangle, North Carolina, in preparation.

along the highways of partly decomposed bedrock and of saprolite, that are monazite-bearing. The peripheral part of the intrusive, however, is somewhat finer grained, and crops out commonly as a clayey saprolite, which contains little or no monazite.

Between the Shelby and Mt. Airy districts, a few localities of monazite-bearing saprolite are shown on plate 1, but in general this stretch has been little explored. The monazite that has been known for many years at Hiddenite, Alexander County, occurs in pegmatite and in granitized country rock. The localities east of North Wilkesboro, Wilkes County, and south of Dobson, Surry County, are the sites of monazite-bearing granitic gneiss.

Northeast of Mt. Airy, N. C., in Virginia, is a formation described on the geologic map of Virginia as the Leatherwood granite (Pegau, 1932), which is crossed by the western monazite belt. Monazite has been found in the vicinity of Pegau's Leatherwood granite, but not actually within the areas mapped as such. Owing to possible inaccuracies of charting on the geologic map, it can not be said with assurance that monazite is absent from the so-called Leatherwood granite, but certainly it is not present in most of this formation. The geologic map of Virginia also delineates three other formations of granitic rocks that lie athwart or close to the western monazite belt. These are the Shelton granite gneiss, an unnamed granite shown near Redhouse, in Charlotte County, and the Redoak granite (Laney, 1917). None of these has been found to contain monazite. Instead, the monazite of the western belt in Virginia has been found largely in gneissic horizons of the three mapped divisions of the Wissahickon. These are the schist, the granitized gneiss, and intrusives in the schist all of the Wissahickon formation. West of Farmville, in Prince Edward County, monazite was found in massive granite that is undifferentiated on the map, but may be regarded as a part of the intrusives in the schist of the Wissahickon.

Granitic saprolites containing monazite have been recognized at numerous localities in South Carolina, all of which are shown on plate 1. One granitic saprolite of a type high in ilmenite, is exposed in the northern suburbs of Spartanburg. Numerous monazite-bearing granitic intrusives and gneisses were sampled southeast of Greenville, in Greenville County, and others still farther southeast in Anderson and Laurens Counties. Some of those southeast of Greenville are pegmatized rocks that have a high tenor in monazite. The sizes and shapes of the host-rocks are not known. The localization of the western monazite belt across South Carolina is determined partly by the sites of monazite placers that were formerly mined in Cherokee and Greenville Counties, and partly by discoveries in bedrock.

Three principal formations are shown on the geologic map of Georgia that constitute most of the granitic bedrock lying within the western monazite belt. These are: first, granite of the type of Lester's Stone Mountain (Lester, 1938); second, granite gneiss of the type of his Lithonia; and third, the old Carolina gneiss. The granite at Stone Mountain, east-northeast of Atlanta, is a muscovite granite that is not monazite-bearing, and is characterized by an extraordinarily low content of heavy minerals, mainly zircon. At Zetella, Spalding County, Ga., however, is a mass of granite, occupying an area of about 90 square miles, that is correlated on the geologic map with the Stone Mountain type; and southwest of this is a smaller body of the same type. Both these masses are biotite granite, actually quartz monzonite, that are monazite-bearing and are characterized by heavy minerals that are largely ilmenite, although the tenor in monazite is not less than in most of the granitic rocks of North and South Carolina.

A body of granite with a major elongation of N. 35° E. extends for 40 miles through Elberton and Lexington, Ga. This, though correlated on the geologic map of Georgia with the granite at Stone Mountain, is a biotitic rock and includes the monumental stones of Elbert and Oglethorpe Counties. This monumental stone is not generally monazite-bearing, but along the northwestern edge of the intrusives, specifically at the Liberty quarry (sample 52 Mt 154), it was found to contain monazite. This site is along the southeastern margin of the western monazite belt. Thus is displayed a feature that has been observed at other places in the southeastern States; a rock, which is not ordinarily monazite-bearing, becomes so where it extends into the monazite belt.

The typical granite gneiss at Lithonia, De Kalb County, Georgia is likewise not monazite-bearing, but granitic rocks that are mapped as the Lithonia type have been found to be monazite-bearing at Athens and Princeton, in Clarke County, in the vicinity of Greenville, Meriwether County, and west of La Grange, Troup County. The rock near Athens is a biotite quartz monzonite, as are some of those near Greenville. In the area west of La Grange, is a complex assemblage of granitic rocks, that include a monazite-bearing intrusive characterized by a high content of ilmenite, like that near Zetella, and also monazite-bearing gneisses. These rocks will only be distinguished by detailed geologic mapping.

The Carolina gneiss of Georgia, though not generally monazite-bearing, has been found to contain monazite near Bowersville, Hartwell, and Royston, in Hart County; near Danielsville, Colbert, and at other places in Madison County; in Clarke, Oconee, and Walton Counties; southeast of Covington, in Newton County; west of Sharpsburg, in Coweta County; and at other localities. Further exploration is needed in the country between Athens and La Grange.

A detailed geologic map has been made by the U. S. Geological Survey (Hewett and Crickmay, 1937, pl. 1), of the Warm Springs quadrangle, lying in Meriwether, Harris, and Talbot Counties, Georgia, Four granitic formations are shown on this map, namely, the Snelson and Cunningham granites, the Woodland gneiss, and the undivided Carolina gneiss. Four samples taken of the Snelson granite prove it to be generally monazite-bearing; and one of these, collected just east of Durand, in Meriwether County, contains about 0.02 percent of monazite, which is as high as any found in North Carolina, excepting pegmatite or pegmatized schist. The Carolina gneiss, just west of Woodbury, in Meriwether County, was also found to be monazite-bearing.

The Pinckneyville granite, the principal granitic rock of the crystalline rocks of Alabama, has been found to be weakly monazite-bearing, Farther east, in Tallapoosa and Chambers Counties, the country rock that is shown on the geologic map of Alabama as Archean schist and gneiss has also been found to be monazite-bearing within a narrow belt. These occurrences are collinear with the similar belt west of La Grange, in Troup County, Ga.

The eastern monazite belt is shown in plate 1 to extend from a point 6 miles south of Raleigh north-northeastward for 200 miles to a point a short distance west of Fredericksburg, Va. The original discovery of an eastern monazite belt was made about $1\frac{1}{4}$ miles south-southeast of Rolesville, Wake County, where a granitic intrusive and its altered saprolite crop out close together. The few localities to the southwest are granitic gneisses. North-northeast of Rolesville, the eastern belt, though distinguishable, is nowhere strongly defined until it reaches the Norlina-Warrenton area, where a monazite-bearing granite is well developed.

South of Raleigh the eastern monazite belt appears to be overlapped by the formations of the Coastal Plain, but it may reappear farther to the southwest. Evidence tending to confirm this idea was recently obtained near Rion, Fairfield County, S. C., where monazite was found to be present in granitic saprolite at the quarry of the Rion Crush Stone Corp., and elsewhere in that vicinity. It was also found in granitic saprolite at the Blair quarry, near Blair station on the Southern Railway, in Fairfield County.

The monazite-bearing rocks of the eastern belt in Virginia are heterogeneous. The principal host-rock is the granitized Wissahickon gneiss in which monazite is fairly plentiful. Five samples from this source were taken in Dinwiddie, Nottoway, Mecklenburg, and Goochland Counties. Three samples were taken in Spotsylvania County from a gneissic granite that continues north-northeastward toward the District of Columbia. One sample was taken in Hanover County from rocks mapped as Baltimore gneiss; and another, likewise from Hanover County, was taken from rocks mapped as Petersburg granite, though this formation is known not to be generally monazite-bearing. Finally, one sample was taken at a site southeast of Amelia, in Amelia County, from a small body of granitic saprolite, resembling somewhat the saprolite of Laney's Redoak granite (Laney, 1917). The latter however, is not monazite-bearing, and its heavies include considerable epidote, whereas the monazite-bearing granite southeast of Amelia contains no epidote.

Outlying localities

Monazite has been found at a number of localities that lie outside of the two monazite belts. Most of the granitic rocks at these sites are either pegmatite, or coarse-grained granitic rocks with a pegmatitic habit. A few monazite-bearing granites have been found, however, that do not fit into these categories.

Monazite has been known for years as a rare mineral in some of the pegmatites in the Spruce Pine district, of western North Carolina. Recently however, the writer has discovered that the coarse-grained granite of this area, though generally barren of monazite, contains some of this mineral at a few places. The largest amount of monazite was found at a site along the northeast side of the Spruce Pine-Bakersville road, about 4.2 miles by road from Spruce Pine. A horse or slice of schist, bounded on both sides by granite, crops out here; and monazite is present in the granite on both sides of the schist. Some of this monazite is coarse-grained, the larger grains ranging upward to 1/8 inch in size. At a few other sites, smaller amounts of monazite were recognized in the granite near Spruce Pine.

Another occurrence in this part of western North Carolina is a small dike of pegmatite about 2 3/4 miles west-southwest of Mars Hill, in Madison County. A 16-inch crystal of monazite, which was recovered at this locality years ago, is now a part of the mineral collection of the University of South Carolina, at Columbia.

A third locality is at and near "The Glades," in Hall County, Ga. This place was repeatedly mentioned in the older literature on monazite in the southeastern states, but various writers, quoting one another, gave no details. The writer recently visited this place, and found "The Glades" to be an abandoned town site, which was formerly the center of an old gold-placer mining camp. Monazite evidently was found in the concentrates recovered with the gold, but apparently was not mined, except possibly as a small by-product. Exploration revealed that some of the local bedrock is a coarse-grained monazite-bearing granite, not unlike the granite near Spruce Pine. The monazite is coarse-grained. In an oral communication, A. S. Furcron, assistant State Geologist of Georgia, reported monazite northeast of The Glades, in Habersham and Rabun Counties. This would suggest the presence in this part of Georgia of a narrow subsidiary belt of monazite-bearing rocks, about 30 miles northwest of the main western belt. Another locality in this general area where alluvial monazite has been found is near Gillsville, about 10 miles east of Gainesville, in Hall County.

A fourth locality is in Upson County, Ga., about halfway between Yatesville and The Rock. This also is an occurrence of monazite in pegmatite. A sample was furnished to the writer by Dr. Furcron.

Other localities have been found where the source-rock is not pegmatitic. One of these, lying northwest of the western monazite belt, is the site of a red saprolite derived from massive granite, about $3\frac{1}{4}$ miles west of Sharpsburg, Coweta County, Ga. Three other localities where monazite-bearing granites occur, have also been found in the general vicinity of Franklin, Heard County, Ga. Sporadic occurrences of monazite outside the two monazite belts are to be expected, particularly in pegmatite.

Doubt has been expressed by some geologists regarding the reality of the two principal monazite belts. The existence of monazite at 176 localities is admitted, but it is suggested that the other 340 sites, where monazite is proven to be absent, are insufficient to establish the localization of monazite shown in plate 1. Some knowledge of the geology of the southeastern Piedmont region, coupled with a critical examination of the localities where monazite is absent, will reveal that a large percentage of the granitic rocks of this region have already been sampled, though not at very close intervals. But many of these more prominent bodies of granite and granitic gneiss are remarkably similar along their major elongations, both petrographically and with regard to their contained heavy minerals. Therefore 340 scattered localities have more significance than may be realized by the casual reader.

No claim to finality, however, can be made for conclusions that are based upon reconnaissance work, though it seems reasonably certain, from the work so far done, that monazite is not universally distributed in the southeastern Piedmont region. It has already been stated that most of the rocks within the monazite belts are not monazite-bearing; and that the two belts represent merely the limits within which most of the southeastern monazite is likely to be found. It should also be emphasized that parts of the monazite belts are imperfectly explored, even for the standard of reconnaissance work, and may be found to be wider than shown in plate 1. It is envisaged that detailed geologic mapping, if done with the aid of the gold pan, will reveal the presence of many thin and unconnected horizons of monazite-bearing rocks, as well as isolated spots where such rocks occur, both within and without the two principal belts. Thus the three localities east of Anderson, S. C., may possibly constitute part of a narrow subsidiary belt that is not a part of the main western belt; and the same is true of the five localities shown between Athens and Elberton, Ga. Attention has already been called to the definitely outlying localities near Spruce Pine, N. C., the area extending northeastward from The Glades, Ga., and the Franklin-Texas area, Ga. It is hoped that the reconnaissance work recorded in this paper will stimulate other geologists to familiarize themselves with the use of the gold pan, so that more detailed results can eventually be obtained.

Petrographic character of rocks

The monazite-bearing source rocks enumerated in the preceding pages have been described generically as granite, pegmatite, granite gneiss, or merely as granitic rocks; and only a few of them can be more accurately designated. The reason for this nomenclature is that petrographic names can be given only from a study of hardrock samples; and outcrops of hardrock are rare at critical localities. In order to correlate saprolite with hardrock, the two must be found either in contact, or so close together that no doubt can exist of their equivalence. Granite quarries are the best sites for this correlation, but only a few quarries have been developed in monazite-bearing granitic rocks, and even at such sites saprolite does not necessarily overlie the hardrock. It therefore is much easier to discover monazite-bearing saprolite than it is to identify its hardrock equivalent.

Most of the granitic rocks that contain monazite, excepting the pegmatites, are biotitic. The granites in the Shelby area, and at Mt. Airy, N. C., are known to be quartz monzonites. The granites near Zetella, Spaulding County, and at Athens, Clarke County, Ga., likewise are biotite-quartz monzonites. The Snelson granite, of the Warm Springs area, exposed at an old quarry a short distance east of Harris, Meriwether County, Ga., is a gneissoid granite, which is classified as a biotite monzogranite. The monazite-bearing rocks of western Georgia and of Alabama have not yet been studied. In the eastern monazite belt, the granite near Rolesville, Wake County, N. C. is likewise a biotite monzogranite. The granite at the quarry of the Rion Crush Stone Corp., in Fairfield County, S. C., is a biotite-quartz monzonite; and that at the Blair quarry, in the same county, is likewise a biotite-quartz monzonite, veering toward a monzogranite. Thus it appears that most of the monazite-bearing granites, excepting the pegmatites, are either quartz monzonite, or other granitic rocks not far removed from the monzonitic family.

Few of the monazite-bearing granite gneisses have been found in contact with their saprolites, but generally they appear to conform in petrographic character with the less-gneissic granitic rocks. Evidence accrues that monazite is much more widely distributed in granite gneisses than in massive granitic intrusives.

The data so far obtained, together with that gleaned from the several publications of T. L. Watson (1902, 1906, 1910) on the granitic rocks of the southeastern States, indicate that most of these rocks, though of different ages and origins, will have similar petrographic designations. Petrography alone is evidently an inadequate means of geological mapping. Correlation of the granitic rocks by means of their heavy minerals will be of great value in mapping; but determinations of absolute and relative ages by radiometric, chemical, and spectrographic studies of the radiogenic elements in the heavy minerals will be much more effective.

Heavy minerals in bedrock

Most of the samples of heavy minerals that have been recovered from the granitic rocks of the southeastern states were taken from saprolites, but some necessarily were obtained by panning powdered hardrock. About one-third of these samples, lying mainly within the two monazite belts, have been found to contain monazite. The mineralogic character of most of the heavies and semiheavies obtained from the monazite-bearing rocks has been determined in the Trace Elements Laboratory of the Geological Survey by counting, but this work is still too incomplete to present the results in tabular form. Samples of purified monazite have also been separated for future chemical and spectrographic work. Only the content of magnetite has yet been determined in those samples that contain no monazite.

The mineralogical results so far obtained lead to some tentative generalizations. Comparison of concentrates that have not been recomputed free of quartz and other rock-forming minerals, suggest the following conclusions. The average content of concentrates recovered from monazite-bearing rocks has been found to be 0.068 percent; from the non-monazite-bearing rocks, 0.18 percent; the difference is caused by the lower tenor of iron ores in the rocks containing monazite. The average percentage of magnetite in concentrates obtained from monazite-bearing rocks is 13 percent; the average percentage in concentrates from rocks that contain no monazite is 37 percent. This difference is still more marked when the average percentage of magnetite in the rocks is computed, as the corresponding values for the monazite-bearing and non-monazite-bearing rocks are found to be

0.017 and 0.094 percent. The mean tenor in ilmenite has been determined only for the monazite-bearing rocks, and is found to be 26 percent of the concentrates, and 0.025 percent of the rocks. Comparing these two values with the corresponding values for magnetite, namely, 13 and 0.017 percent, it is apparent that ilmenite is much more plentiful than magnetite in the monazite-bearing concentrates and rocks. The relative plenitude of these two minerals in many concentrates is even more marked when it is stated that about one-third of the monazite-bearing rocks contain less than 0.01 percent ilmenite.

The percentages of the minerals comprising about two-thirds of the monazite-bearing concentrates have been determined, and recomputed free of quartz and other minerals having a specific gravity less than 3.0. The writer is well aware of the fallacy of averaging percentages to obtain mean tenors, but so many possible errors are present in the initial determinations of these minerals, that the work involved in the proper method seems hardly warranted.

The principal minerals of the concentrates are monazite, ilmenite, magnetite, zircon, rutile, and garnet, with smaller amounts of epidote, sillimanite, kyanite, sphene, hematite, and opaque black minerals. The content of monazite is calculated to range from a trace to 98 percent, with a mean value of 34 percent. The tenor in the host-rocks ranges from 0.00005 to 0.02 percent, with a mean value of 0.006 percent, though the tenor in pegmatite and pegmatized country rock may attain 0.1 percent. No linear relationship exists between the mean tenors of the concentrates and of the rocks, as concentrates that are very high in monazite are likely to constitute only a very small percentage of the host-rock.

The total and relative amounts of iron ores present in the monazite-bearing granitic rocks permit a three-fold classification of these concentrates, which may or may not correlate with differences in the origin or ages of the host-rocks. The first type, which includes 44 percent of these concentrates, contains less than 20 percent of iron ores, almost entirely ilmenite; about one-fifth of these are entirely free of iron ores; and about three-fifths contain from a fraction of 1 percent to 10 percent of iron ores. The second type, which includes 37 percent of the concentrates, contains from 20 to 99 percent iron ores, in all of which the content of ilmenite exceeds that of magnetite. About three-fifths of the concentrates of the second type contain no magnetite, and another fifth contains from a fraction of 1 percent to 10 percent of magnetite. The remainder of the concentrates, constituting the third type, contain ilmenite and magnetite in varying proportions, but six-sevenths of these contain more magnetite than ilmenite. These three types of concentrates are therefore designated respectively as the low iron-ores type, the high-ilmenite type, and the high-magnetite type. This classification appears to apply both to the granitic intrusives and to the granitic gneisses that are monazite bearing.

Next to monazite and the iron ores, zircon is the most plentiful mineral of the concentrates. It occurs in about 80 percent of the monazite-bearing concentrates, ranging in tenor, where present, from a trace to 96 percent of the heavies. The mean tenor is about 13 percent. The percentage of zircon in the rocks that contain no monazite has not yet been determined, so that no comparison can be made with the monazite-bearing rocks. The monazite-bearing granite gneiss of the Shelby quadrangle, however, was found to contain more zircon than the monazite-bearing granitic intrusives; and this fact was used in the field to differentiate between saprolites of gneiss and granite that were not otherwise distinguishable. This relationship may be only of local application.

Rutile has been identified in almost 40 percent of the monazite-bearing concentrates so far examined, ranging in tenor from a trace to as much as 63 percent of the heavies, with an average tenor, where present, of about 7 percent. The high maximum and the low mean contents show that rutile rarely constitutes any large part of the heavies. Garnet has been recognized in about 27 percent of the monazite-bearing concentrates, ranging in tenor from a trace to 98 percent of the heavies, with an average tenor, where present, of about 13 percent. Three samples of concentrates were obtained in which garnet constitutes more than 70 percent of the heavies, yet it is absent entirely in 62 percent of the monazite-bearing concentrates. Comparison of the mean tenors of garnet and zircon show them to be about the same, but zircon is nearly three times as widely distributed as garnet.

Xenotime, the yttrian counterpart of monazite, has been identified in 10 percent of the monazite-bearing concentrates, but may be present in a still larger proportion. One sample of concentrates, 52 Mt 91, which was collected from a coarse-grained granitic gneiss in Powhatan County, Va., consists mainly of xenotime and ilmenite with no recognizable monazite. The xenotime constitutes about half of the heavies, and about 0.003 percent of the rock. The next highest tenor found in xenotime was in sample 52 Mt 164, of a pegmatitic gneiss, collected a short distance south-southeast of Hartwell, Ga. About half of these concentrates consist of xenotime, the remainder being mainly monazite and zircon. No iron ores are present. A third sample worthy of mention is 50 Mt 120, collected northeast of Honea Path, S. C. The concentrates include 62 percent of monazite and 15 percent of xenotime. Three other of the samples so far examined contain more than 10 percent xenotime, but the mean tenor, where recognized to be present, is 3 percent or less.

Epidote has been found in a very few of the monazite-bearing granitic rocks, but where present, it may constitute a high percentage of the concentrates. Two samples of concentrates in which epidote is plentiful come from the granite near Mt. Airy, Surry County, N. C., and from the granite near Blair, Fairfield County, S. C. It must be emphasized, however, that epidote is not universally present in the granite at Mt. Airy, as samples of concentrates have been obtained wherein this mineral is absent. Sillimanite has been identified in about 9 percent of the concentrates, mainly in those obtained from metamorphosed granitic rocks. Its average tenor, where present, is about 7 percent of the heavies.

The quartz monzonite at Acre Rock, Cleveland County, N. C., exemplifies that type of rock which yields concentrates low in iron ores. Its heavies are largely garnet, with relatively small amounts of zircon, rutile and monazite, and practically no iron ores.

A more typical example, because it contains little or no garnet, is a granite (49 Mt 45) from Greenville County, S. C., whose concentrates contain about 83 percent monazite, 16 percent zircon, 1 percent ilmenite, and 0.2 percent xenotime. Many similar granites are known. Monazite-bearing granitic gneisses also fall in this class. Thus the concentrates of samples 50 Mt 172 and 50 Mt 196 contain respectively 0.7 and 4.5 percent ilmenite, and 87 and 83 percent monazite. Also the granitized gneiss of the Wissahickon formation, 50 Mt 233, from Dinwiddie County, Va., yields concentrates that contain 0.1 percent ilmenite and 61 percent monazite.

The granitic intrusive south of Zetella, Spaulding County, Ga., exemplifies the second type of concentrates, as the heavies comprise about 94 percent ilmenite, no magnetite, and about 6 percent monazite. The volume of concentrates per pound of bedrock is very large, so that the tenor in monazite, though low in the concentrates, is about 0.017 percent of the bedrock. Another representative of this type is a granite in the northern suburbs of Spartanburg, Spartanburg County, S. C. The concentrates of this rock comprise 86 percent ilmenite, no magnetite, 10.7 percent monazite, 0.7 percent rutile, and 2.6 percent of opaque dark minerals. The tenor of monazite in bedrock is about 0.003 percent. This type of intrusive is also well represented in the eastern monazite belt. Thus the granitic rock near Norlina, Warren County, N. C., yields concentrates that contain about 89 percent ilmenite, no magnetite, about 11 percent monazite, and a little rutile. The volume of concentrates is fairly large, so that the percentage of monazite in the host-rock is about 0.005 percent. The granite near Rolesville, Wake County, N. C., however, yields concentrates that comprise about 77 percent ilmenite, 16 percent magnetite, 4 percent monazite, and about 3 percent zircon. The tenor of monazite in bedrock is about 0.003 percent.

Some of the monazite-bearing granitic gneisses also belong to the type high in ilmenite. An example in the western belt is a part of the Carolina gneiss that crops out as saprolite just west of Woodbury, Meriwether County, Ga. The concentrates from this rock contains about 42 percent ilmenite, 2 percent magnetite, about 45 percent monazite, and about 11 percent zircon. The tenor of monazite in bedrock is about 0.007 percent. An example from the eastern belt is a granitic gneiss (50 Mt 251) from Hanover County, Va., whose concentrates contain about 97 percent ilmenite, a trace of magnetite, 3 percent monazite, 1 percent garnet, and 61 percent zircon. The tenor of monazite in bedrock is 0.0015 percent.

Concentrates of the third type constitute only about one-fifth of all the samples. Two examples in the western belt are granite gneisses, samples 50 Mt 122 and 50 Mt 123, from Laurens County, S. C. Two from the eastern belt are granites from the quarry of the Rion Crush Stone Corp., and the Blair quarry, both in Fairfield County, S. C.

Origin of monazite belts

The restriction of monazite largely to two belts warrants some consideration. The western belt extends southwestward from east-central Virginia to Alabama, for a distance of about 600 miles; the eastern belt extends from the vicinity of Fredericksburg, Va., south-southwestward for 200 miles, but seems to reappear 175 miles farther along its trend, near Rion, S.C. These belts are not geological formations, as they include various kinds of crystalline rocks. Indeed most of the rocks within these belts are not monazite-bearing; the belts merely delimit the areas within which monazite-bearing rocks are likely to be found.

Monazite is restricted largely to granitic rocks, or to derivatives thereof. Under this general heading are included a variety of granitic intrusives, granitic gneisses of both sedimentary and intrusive origin, and granitized country rock. Granitic intrusives, including both massive granitic rocks and orthogneiss, are the original source-rocks. Granitic rocks of sedimentary origin, in which monazite was originally a detrital constituent, constitute a second major source. Geologists consider that most of the granitic gneisses of the southeastern Piedmont are paragneiss, but the ratio of paragneiss to orthogneiss has not been determined. A third source-rock comprises various types of country rock, into which monazite has been introduced secondarily. Certain monazite-bearing schists have also been mentioned, wherein the origin of the monazite has not been determined.

Monazite occurs in certain formations within the monazite belts, but not contiguously in the same formations outside the belts. It appears, moreover, that the monazite belts do not everywhere follow the strike of the country rocks, but more commonly cut across the strike. The junction of the western with the eastern monazite belt, as shown in plate 1, is ample evidence of this general condition. It follows from these two conditions that the belts, rather than the rocks or rock structure within the belts, are the really significant features.

Finally it has been shown that monazite occurs in three types of concentrates, called the low iron ore, the high ilmenite, and the high magnetite types. As these types are reasonably distinct, without continuous gradations from one to the others, it is surmised that they may have some significance in the origin of the host rocks.

These environments of monazite, apparently unrelated primarily to the petrology, structure, or geologic age of the various host-rocks, are hard to explain; but possibly a speculative hypothesis is warranted. Let it be assumed that certain monazite-bearing granitic rocks were injected in this country, possibly about the time when the granites of the Laurentian series were elsewhere emplaced. Let it further be supposed that the original country rock that existed at the time of this intrusion was subsequently deeply eroded, baring some or all of the underlying granitic intrusives; and that all of these events occurred in early pre-Cambrian time. Later, certain of the rocks that are now described collectively as the Carolina gneiss originated as sedimentary formations; and these finally were metamorphosed to produce the paragneisses and schists that are now exposed in the Piedmont. Any of the original granitic intrusives that now remain, and are bared to erosion, would naturally have become orthogneisses.

These ancient sedimentary rocks were doubtless of various types, but if rivers existed then as now, it appears reasonable that some part of these sediments may have been of fluviatile origin. Let it be assumed that at least two master valleys existed in the area that we now call the southeastern Piedmont region; and that the monazite released from the original intrusives of Laurentian age was distributed in the fluviatile deposits of these valleys. In order to be preserved, such fluviatile deposits were probably deeply buried, in one or more geosynclines, of the same or different ages; and these, together with many other sediments of diverse origin, were reconstituted to form what is now known as the Carolina gneiss. Later, perhaps much later, parts of the Carolina gneiss, including some of the original fluviatile deposits, were melted by heat and pressure, and were injected into their surrounding host-rock. Also some of the original granite of the Laurentian series may also have been remelted, and injected as another granite intrusive into the Carolina gneiss. And finally, remnants of the original Laurentian, now a granite gneiss, may have been bared to recent erosion, thus constituting the minor proportion of orthogneiss in the Carolina gneiss.

This composite hypothesis, unproven and at present unprovable, would account for the presence of monazite in two well-defined belts that join each other. It would also explain the presence of monazite in diverse types of granitic intrusives, in orthogneisses, and in metamorphosed sedimentary rocks, such as paragneiss and certain schists. An alternative hypothesis, considered by the writer, is that the two monazite belts represent concentrations of heavy minerals along pre-Cambrian beaches. But this hypothesis was rejected because beaches move inland and seaward during successive physiographic cycles, with the result that heavy minerals are likely to be distributed over a foreland of considerable width. The present distribution of monazite in all the formations of the southeastern Coastal Plain exemplifies this condition; the distribution of gold on the foreland north of Nome, Alaska is another example. Other explanations that have no relation to sedimentation, but instead deal entirely with igneous geology, are certainly possible; but none has occurred to the writer that conforms so well with the field evidence.

The iron ores in the early pre-Cambrian granites should have included both magnetite and ilmenite, as magnetite is much more prevalent than ilmenite in many of the granitic rocks outside the monazite belts. But ilmenite is known to have a much greater resistance to weathering than magnetite. The heavy minerals now being recovered in Florida, for example, contain about 38 percent ilmenite and only 4 percent magnetite or less, although no such relationship exists between the iron ores in the rocks of the Piedmont. Therefore the paucity of magnetite in most of the monazite-bearing granitic rocks can be explained by supposing that most of it was oxidized during one or more stages of sedimentation earlier in the pre-Cambrian.

This explanation has two implications. First, it suggests that most of the monazite was at one time deposited in sedimentary rocks that were subsequently changed either by regional metamorphism to paragneiss, or by remelting to later granitic intrusives. Under such conditions the resulting metamorphic and igneous rocks would have much more ilmenite than magnetite. But the quantitative effects of this process remain to be demonstrated. Ilmenite, although much more resistant to weathering than magnetite, eventually succumbs to oxidation. Thus the so-called ilmenite produce now being recovered at the plant east of Jacksonville, Fla., is reported to contain about 4.5 percent FeO, 26.5 percent Fe_2O_3, and 61.5 percent TiO_2, whereas ilmenite theoretically should contain no Fe_2O_3 and a much lower content of TiO_2. This product may be arizonite. Similarly at the plant southeast of Starke, Fla., nearly 20 percent of the ilmenitic iron ores are really leucoxene, and the remainder similar to those above described. It therefore may not be stated how much ilmenite should occur in the paragneiss of the Carolina, or in its palingenetic derivatives; nor may the chemical character of the ilmenite be anticipated. These conditions will depend upon the nature and duration of the physiographic cycles, through which the iron ores have passed. Great variations may be expected in the paragneisses, but in general the tenor in magnetite should be relatively low.

A second implication is that certain other gneisses and granitic intrusives should occur within the monazite belts that are relatively high in magnetite. Such rocks would represent the original intrusive of Laurentian age, now converted to an orthogneiss, and remelted parts of this orthogneiss that would constitute a part of the monazite-bearing intrusive granitic rocks. The presence of rocks have already been mentioned, containing concentrates in which magnetite predominates over ilmenite. As might be expected, rocks yielding concentrates of this type are relatively uncommon. The nature of the iron ores, both in the granitic intrusives and in the granitic gneisses, therefore appear to be consonant with the hypothesis that has been outlined.

The foregoing considerations suggest a statistical approach to a study of the origin of granitic intrusives and gneisses in the southeastern Piedmont region. If such rocks have passed through one or more sedimentary stages in their evolution, this fact might well be reflected in the amounts and character of their iron ores, and particularly in the chemical composition of the contained ilmenite. It is impossible to predict the results that might result from this approach, but the method is worthy of investigation. The iron ores from more than 500 samples of granitic concentrates that have already been collected in the southeastern Piedmont province could constitute a beginning for such a research program.

REFERENCES CITED

Griffitts, W. R., and Overstreet, W. C., 1952, Granitic rocks of the western Carolina Piedmont: Am. Jour. Sci., vol. 250, no. 11, pp. 777-789.

Hewett, D. F., and Crickmay, G. W., 1937, The warm springs of Georgia, their geologic relations and origin, a summary report: U. S. Geol. Survey Water Supply Paper 819, pl. 1.

Houk, L. G., 1943, Monazite sand: U. S. Bur. Mines Inf. Circ. 7233, pp. 11-12.

Keith, Arthur, 1907, The Pisgah quadrangle, North Carolina: U. S. Geol. Survey Atlas (folio 147), p. 4.

Keith, Arthur, and Sterrett, D. B., 1931, The Gaffney and Kings Mountain quadrangles, South Carolina and North Carolina: U. S. Geol. Survey Atlas (folio 222), p. 6.

Laney, F. B., 1917, The geology and ore deposits of the Virgilina district of Virginia and North Carolina: Virginia Geol. Survey Bull. 14, pp. 35-36, map.

Lester, J. G., 1938, The geology of the region around Stone Mountain, Ga. (abstract): Colorado Univ. Studies, vol. 26, no. 1.

__________, 1939, Garnet segregations in granite gneiss of De Kalb County, Ga.: Jour. Geology, vol. 47, no. 8.

Pegau, A. A., 1932, Pegmatite deposits of Virginia: Virginia Geol. Survey Bull. 33, pp. 15, 29, pls. 2, 3.

Watson, T. L., 1902, A preliminary report on a part of the granites and gneisses of Georgia: Geol. Survey of Georgia Bull. 9-A, 367 pp.

__________, 1910, Granites of the southeastern Atlantic States: U. S. Geol. Survey Bull. 426, 282 pp.

Watson, T. L., and Laney, F. B., 1906, The building and ornamental stones of North Carolina: North Carolina Geol. Survey Bull. 2, 283 pp.

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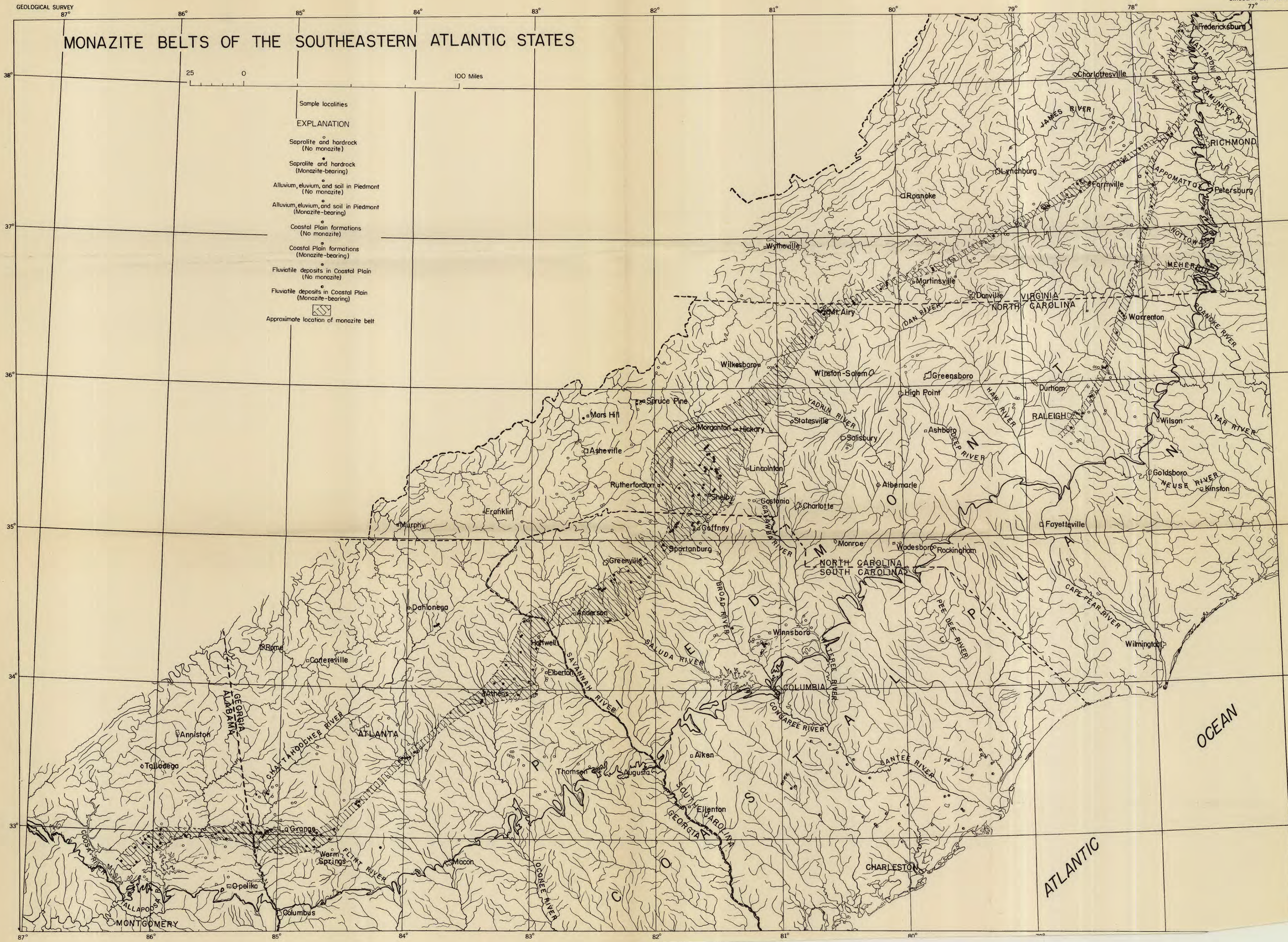
MONAZITE BELTS OF THE SOUTHEASTERN ATLANTIC STATES
25
0
100 Miles
Sample localities
EXPLANATION
Saprolite and hardrock (No monazite)
Saprolite and hardrock (Monazite-bearing)
Alluvium, eluvium, and soil in Piedmont (No monazite)
Alluvium, eluvium, and soil in Piedmont (Monazite-bearing)
Coastal Plain formations (No monazite)
Coastal Plain formations (Monazite-bearing)
Fluviatile deposits in Coastal Plain (No monazite)
Fluviatile deposits in Coastal Plain (Monazite-bearing)
Approximate location of monazite belt
87°
86°
85°
84°
83°
82°
81°
80°
79°
78°
77°
38°
37°
36°
35°
34°
33°
Fredericksburg
Charlottesville
JAMES RIVER
PAMUNKEY R.
MATTAPONI R.
RICHMOND
Lynchburg
Farmville
APPOMATTOX
Petersburg
Roanoke
Wytheville
NOTTOWAY
MEHERRIN R.
Martinsville
Danville
VIRGINIA
NORTH CAROLINA
Mt. Airy
DAN RIVER
Warrenton
ROANOKE RIVER
Wilkesboro
Winston-Salem
Greensboro
High Point
Durham
HAW RIVER
RALEIGH
Spruce Pine
Mars Hill
Morganton
Hickory
Statesville
YADKIN RIVER
Salisbury
Ashboro
DEEP RIVER
Wilson
TAR RIVER
Asheville
Lincolnton
Albemarle
Goldsboro
NEUSE RIVER
Kinston
Rutherfordton
Shelby
Gastonia
Charlotte
Franklin
Murphy
Gaffney
CATAWBA RIVER
Fayetteville
Spartanburg
Monroe
Wadesboro
Rockingham
Greenville
NORTH CAROLINA
SOUTH CAROLINA
CAPE FEAR RIVER
Dahlonega
Anderson
BROAD RIVER
PEE DEE RIVER
Winnsboro
WATEREE RIVER
Wilmington
Rome
Cartersville
Hartwell
SALUDA RIVER
Elberton
SAVANNAH RIVER
COLUMBIA
Athens
CONGAREE RIVER
GEORGIA
ALABAMA
Anniston
ATLANTA
CHATTAHOOCHEE RIVER
SANTEE RIVER
OCEAN
Talladega
Aiken
Thomson
Augusta
Ellenton
SOUTH CAROLINA
GEORGIA
La Grange
COOSA RIVER
Warm Springs
FLINT RIVER
Macon
OCONEE RIVER
CHARLESTON
ATLANTIC
TALLAPOOSA R.
Opelika
MONTGOMERY
Columbus
PIEDMONT
COASTAL PLAIN