Fluvial Monazite Deposits in the Southeastern United States

GEOLOGICAL SURVEY PROFESSIONAL PAPER 568

Prepared on behalf of the U.S. Atomic Energy Commission

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With a section on Mineral Analyses

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Occurrences of detrital monazite in the western Piedmont of Virginia, North Carolina, South Carolina, and Georgia, and methods used to appraise them

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By William C. Overstreet, Amos M. White, Jesse W. Whitlow, Paul K. Theobald, Jr., Dabney W. Caldwell, and Norman P. Cuppels

ABSTRACT

A system of simple field, laboratory, and office procedures adapted to the reconnaissance study of fluviatile monazite placers was evolved and used at five places in the monazite-bearing area of the Inner Piedmont belt from Virginia through Georgia. The methods used permit an evaluation that can serve as a guide to placers best suited for physical exploration, but the results of the reconnaissance are not recommendations for their development. Similar reconnaissance techniques could be used to search for a wide variety of resistate ore minerals in areas of deeply weathered rocks overlain by residual soil.

No similar attention had previously been given the placers, although the monazite-bearing area between the Savannah River in South Carolina and the Catawba River in North Carolina had been the main monazite-producing district in the United States between 1887 and 1917, during which period a total of 5,476 short tons of monazite was produced. Small-scale hand methods had been used in the placers, because only shallow narrow headwater deposits were mined, and most of the placers were worked by the individual landowners. Such methods were economically feasible because of low wages and a high price for monazite at that time. Climatic features permitted year-round mining, but the area was principally an agricultural region, and concurrent demands of the agricultural cycle relegated much of the mining activity to sporadic work in slack seasons at hundreds of small placers. A relatively few moderate-sized properties were operated on a year-round basis. Under these conditions, maximum annual production reached 1,573,000 pounds of monazite in 1895. When mining ceased in 1917, the cause was the low price of imported monazite, which could be delivered in New York cheaper than a rough concentrate could be obtained at the creeks in the Carolinas. When the placers were abandoned, immense resources in monazite were left in the streams.

The monazite occurs as a minor accessory mineral in paragneisses and paraschists of upper amphibolite facies and in granite, quartz monzonite, granodiorite, and pegmatite intrusive into these metasedimentary rocks. The monazite-bearing rocks are dominantly Ordovician in age, but some are late Precambrian and others are Carboniferous. At least as early as Late Cretaceous these plutonic rocks were exposed to weathering and erosion, and the accessory monazite was freed from its host and entered cycles of stream transport. Erosion in the region has not overtaken weathering; thus, the upper surface of the plutonic rocks is nearly everywhere saprolite. Saprolite is composed of clays formed by the chemical weathering of feldspar and other soluble silicates and grains of resistate minerals like quartz which preserve the original textural features and planar and linear structures of the crystalline rock. Mostly, the saprolite is 20–40 feet thick, but locally, it is as much as 180 feet thick. Overlying the saprolite locally is residual soil and colluvium, some of which is at least as old as pre-Wisconsin, and some of which is forming at present. Erosion and transport of saprolite, residual soil, and colluvium provides a constant flow of fine-grained detritus to the valleys, where it has been spread out over the valley floors in flood plains of variable size. Most of the flood-plain sediments are Recent in age. They consist dominantly of fine sand and silt having considerable clay and about 10 percent gravel. In most flood plains, gravel forms a thin veneer on saprolitic bedrock and is overlain by 10–20 feet of the other sediments. At the top of the sequence of flood-plain sediments a layer of reddish-brown sandy silt often 2–7 feet thick has been deposited, owing to accelerated erosion since agriculture was introduced in the region in the late 1700's and early 1800's. The monazite placers are in Recent flood-plain sediments in the stream valleys and in Recent and older colluvium and residual soils on the hillsides. Only the placers in the flood plains a mile or two downstream from headwaters, and from that point to the trunk streams, possess a size and tenor that might, under special conditions of price and sale of coproducts and byproducts, permit mining with machinery. None of the placers could be economically mined at the prices prevailing in the 1950's and early 1960's.

Five areas were studied. They are (1) the area in Stokes and Surry Counties, N.C., and Patrick County, Va., between the Yadkin and Dan Rivers; (2) the area between the Savannah and Catawba Rivers, S.C.–N.C.; (3) the area in Oconee, Clarke, Oglethorpe, Barrow, and Jackson Counties, Ga., in the basin of the Oconee River; (4) the area in Spalding and Pike Counties, Ga., in the basin of the Flint River; and (5) the area in Troup, Meriwether, and Harris Counties, Ga., in the basin of the Chattahoochee River. The deposits in the Savannah River-Catawba River area, South Carolina-North Carolina, are better than those in the other areas.

In the Savannah River-Catawba River area, 84 fluviatile placers were found which were appraised as being better potential sources for monazite than other deposits in the Inner Piedmont belt. None, however, is an economic source for monazite.

Industrial minerals of potential use associated with the placer monazite have the following average abundance (pounds per cubic yard): ilmenite, 6.0; rutile, 0.2; magnetite, 0.3; zircon 0.6; garnet, 1.0; and high-alumina minerals (principally sillimanite), 0.5. Gold averages 0.2 milligram per cubic yard of sediment. Assuming that these minerals could be sold, the value of the product from the monazite placers would be between 25 and 33 cents, plus some small sale of sand and gravel. Scant increase in the value of the product would be achieved by seeking deposits in which ilmenite, zircon, or the high-alumina minerals were extraordinarily abundant, because there is not enough difference from place to place in the abundance of these minerals to effect any notable increase in value of the concentrate. Garnet, however, offers a real possibility. If the placer garnet is acceptable to the abrasives industry, the value of the concentrate could be tripled by selecting garnet-rich placers.

Combined thoria and rare-earth oxides in the placer monazite are adequate to meet commercial specifications. The analyses of monazite show that the greatest quantities of thoria are in deposits on the southeastern side of the core of the Inner Piedmont belt in the drainage basin of the Broad River, N.C. A unique analysis of monazite from the extreme southeastern side of the belt showed six times as much U_3O_8 as the usual 0.35 percent. Additional analyses are needed to determine if similar uranium-rich monazite has been concentrated in the large placers north of Lincolnton, N.C.

INTRODUCTION

MONAZITE AND MONAZITE PLACERS

Monazite is a heavy subtransparent to opaque mineral with resinous luster; it crystallizes in the monoclinic system. It is commonly yellow but ranges in color from shades of reddish brown and brownish yellow to greenish yellow and green. Rarely, it is pink, white, black, or nearly colorless. Its specific gravity is between 4.6–5.4 and is commonly about 5.1. Its hardness is 5–5½. Monazite is biaxial positive with high relief, strong dispersion, and small optic angle. The least, intermediate, and greatest indices of refraction are 1.787, 1.788, and 1.849 (Winchell, 1933, p. 139).

Monazite is an anhydrous thorium-bearing orthophosphate of the cerium earths. It is an ore for thorium and the cerium earths. Because monazite generally forms small grains, rarely larger than a few hundredths of an inch across, which occur as minor accessory minerals in plutonic rocks, natural mechanical concentration of monazite is usually required before it can be mined. Such natural mechanical concentrations are called monazite placers. Fluvial monazite placers in the southeastern United States were the source of 5,483 short tons of monazite between 1887 and 1917. This report discusses those deposits.

Investigations of the southeastern monazite deposits were begun by the U.S. Geological Survey in 1945, and by 1951 they led to the recommendation by J. B. Mertie, Jr. (1953), that exploration should be undertaken along the larger flood plains intermediate between the headwaters and lower reaches of monazite-bearing streams. In 1951 the U.S. Geological Survey proposed a general systematic reconnaissance of monazite-bearing streams in the western Piedmont from Virginia through Georgia (W. C. Overstreet, V. E. McKelvey, and F. N. Houser, unpub. data, 1951). The proposal was accepted by the Division of Raw Materials of the U.S. Atomic Energy Commission, and with their sponsorship, fieldwork was begun in July 1951 by the Geological Survey.

PREVIOUS WORK

There is an extensive literature on the monazite placers of the western Piedmont, but it consists mostly of general discussion and is concerned largely with methods of production and output. No systematic study of the geology of the deposits was undertaken before 1945, but during the life of the monazite industry to 1917 the deposits in the Carolinas were frequently visited by State and Federal geologists. Brief, but excellent, summaries of the geology of the placers were written in the early 1900's, and in 1909 a bibliography listing 44 papers on monazite in North Carolina was published (Laney and Wood, 1909, p. 403). A detailed review of the literature was prepared by Overstreet (1967); therefore, it is only briefly summarized below.

The first mention of monazite in the area is a reference in 1849 by C. U. Shepard (1849, p. 275; 1852, p. 109) to monazite in concentrates from gold placers in Rutherford County, N.C. Similar occurrences were again mentioned as mineralogic curiosities between 1881 and 1885 (Genth and Kerr, 1881, p. 72–73; American Naturalist, 1883, p. 313; Hidden, 1885). Shortly thereafter an industrial need arose for monazite as an ore of thorium for use in the manufacture of Welsbach mantles, and the mining of monazite began in North Carolina with an output of 10 tons in 1887. Descriptions of the Carolina monazite placers and concentrates were promptly forthcoming (Genth, 1891, p. 77–78; Mining Jour., 1894; Mezger, 1896, p. 822–824; Eng. Mining Jour., 1896; Nitze, 1897, p. 129; Boudouard, 1898, p. 10–12; Sci. American, 1899). Between 1895 and 1901 a series of annual reviews of the status of the monazite industry in the Carolinas began to appear in publications of the Geological Surveys of North Carolina and the United States. They were continued until the collapse of the industry in 1917 (Nitze, 1895, p. 667; Pratt, 1901, p. 30–31; 1902, p. 58–62; 1904a, p. 15; 1904b, p. 1163; 1904c, p. 34–40; 1905, p. 45–46; 1906, p. 1314; 1907a, p. 37–42; 1907b, p. 109–120; 1908, p. 61–66; 1914, p. 15–19; Pratt and Berry, 1911, p. 72–82; 1919, p. 104–105; Sterrett, 1911, p. 897). During this time general descriptions of the monazite placers were given by Graton (1906, p. 116–118) and Böhm (1906), and the origin, size, and distribution of the placers were discussed by Pratt and Sterrett (1910), Sterrett (1908), Sloan (1905, p. 137, 140–142; 1908, p. 129–142), and Pratt (1916, p. 26–28) or appeared anonymously (Eng. Mining Jour., 1906). Between 1917 when the monazite industry closed in the Carolinas and 1943 when the Tennessee Valley Authority examined some placers (McDaniel, 1943, p. 2–15; Lefforge and others, 1944), no field studies of the monazite placers in the western Piedmont were made, although several notes mentioned them (Schaller, 1919, p. 156; Drane and Stuckey, 1925, p. 19; Bryson and others, 1937, p. 15–16).

PRESENT INVESTIGATION

PERIODS OF WORK

Field studies of the monazite placers were begun on July 16, 1951, in Cleveland and Rutherford Counties, N.C., by W. C. Overstreet, P. K. Theobald, Jr., and J. W. Whitlow. A. M. White joined the project in October 1951, N. P. Cuppels and D. W. Caldwell, in February 1952. During two field seasons extending from July 16 to November 1, 1951, and from April 2 to December 5, 1952, most of the fieldwork was completed, but intermittent investigations, mainly auger drilling, were made between April and November 1953. Investigations were made of 1,328 streams in 452 drainage basins covering an area of 7,138 square miles. In this area, 4,245 concentrates were panned from samples of alluvium, and 622 auger holes were drilled in flood plains for a total footage of 10,144 feet.

During the winter of 1951–52 and the fall and winter of 1952–53, project personnel cooperated in the churn-drilling programs of the U.S. Bureau of Mines. Physical exploration by the Bureau covered 11 fluvial placers recommended by the U.S. Geological Survey (Overstreet and Theobald, unpub. data, 1951). Project personnel prepared topographic and planimetric maps of the explored areas and coauthored text of joint reports (Griffith and Overstreet, 1953a–c; Hansen and Caldwell, 1955; Hansen and Cuppels, 1954, 1955; Hansen and Theobold, 1955; Hansen and White, 1954). The present report was assembled intermittently after 1954 and completed in 1966.

Laboratory studies in support of the fieldwork, principally grain counts and spectrographic analyses, were made by members of the U.S. Geological Survey between August 1951 and October 1953. This laborious work is described, and the individuals who completed it are acknowledged in appropriate parts of the text.

OBJECTIVES AND SCOPE

The objectives of the geologic reconnaissance of the fluvial monazite placers were to examine systematically the deposits in the western Piedmont from Virginia to Georgia, to appraise the deposits, and make estimates of local and regional reserves of detrital monazite, to make recommendations to guide physical exploration, and to determine the origin of the monazite. Basic data gathered to meet these objectives include areas of flood plains measured for all streams in the region between the Savannah and Catawba Rivers, S.C.–N.C.; thickness, sequence, and classes of flood-plain sediments determined throughout the five areas; volume and tenor of the flood-plain sediments estimated for the region between the Savannah and Catawba Rivers; local and regional distribution of monazite and other heavy minerals determined for the five areas and related to sources in the crystalline rocks, mode of deposition of the flood-plain sediment, and class of sediment; relative ages of the flood-plain sediments determined.

This report summarizes the regional geology of the crystalline rocks, discusses the origin of monazite in the western Piedmont and the geology of the fluvial placers, describes procedures used, reviews the history of monazite mining in the area, describes the methods used in the reconnaissance, and points out the most favorable places for exploration.

BYPRODUCTS

Major byproducts from the investigation are a discussion of the gold pan as a quantitative geologic tool (Theobald, 1957) and reviews of regional heavy-mineral reconnaissance as a geochemical technique (Overstreet, 1962, 1963). Several minor byproducts of the investigation, in addition to the joint reports with the U.S. Bureau of Mines previously mentioned, have been published. The most important of these are a description of a nomogram used to obtain percent composition by weight from grain counts (Berman, 1953); a preliminary description of the southeastern monazite placers (Overstreet, Cuppels, and White, 1956); discussion of methods used in heavy-mineral prospecting (Overstreet, Theobald, Whitlow, and Stone, 1956); an interpretation of the regional geology (Overstreet and Griffitts, 1955); an explanation of the multiple-cone sample splitter (Kellagher and Flanagan, 1956b); estimates of thorium resources in the area between the Savannah and Catawba Rivers (Overstreet, Theobald, and Whitlow, 1959); an examination of the relation between metamorphic grade and the abundance of ThO_2 in monazite (Overstreet, 1960); lead-alpha ages of zircon from the Carolinas (Overstreet, Bell, Rose, and Stern, 1961, p. B103–B107); a geologic map of the southern half of the Casar quadrangle, North Carolina (Overstreet, Whitlow, White, and Griffitts, 1963); and an airborne radioactivity survey of the northern part of the Shelby quadrangle, North Carolina (Overstreet, Meuschke, and Moxham, 1962).

GEOGRAPHIC SETTING

LOCATION AND TOPOGRAPHY

Geologic reconnaissance of fluvial monazite deposits was extended over five areas in the western Piedmont of the southeastern United States. For the purposes of this report they are called (fig. 1) (1) the Savannah

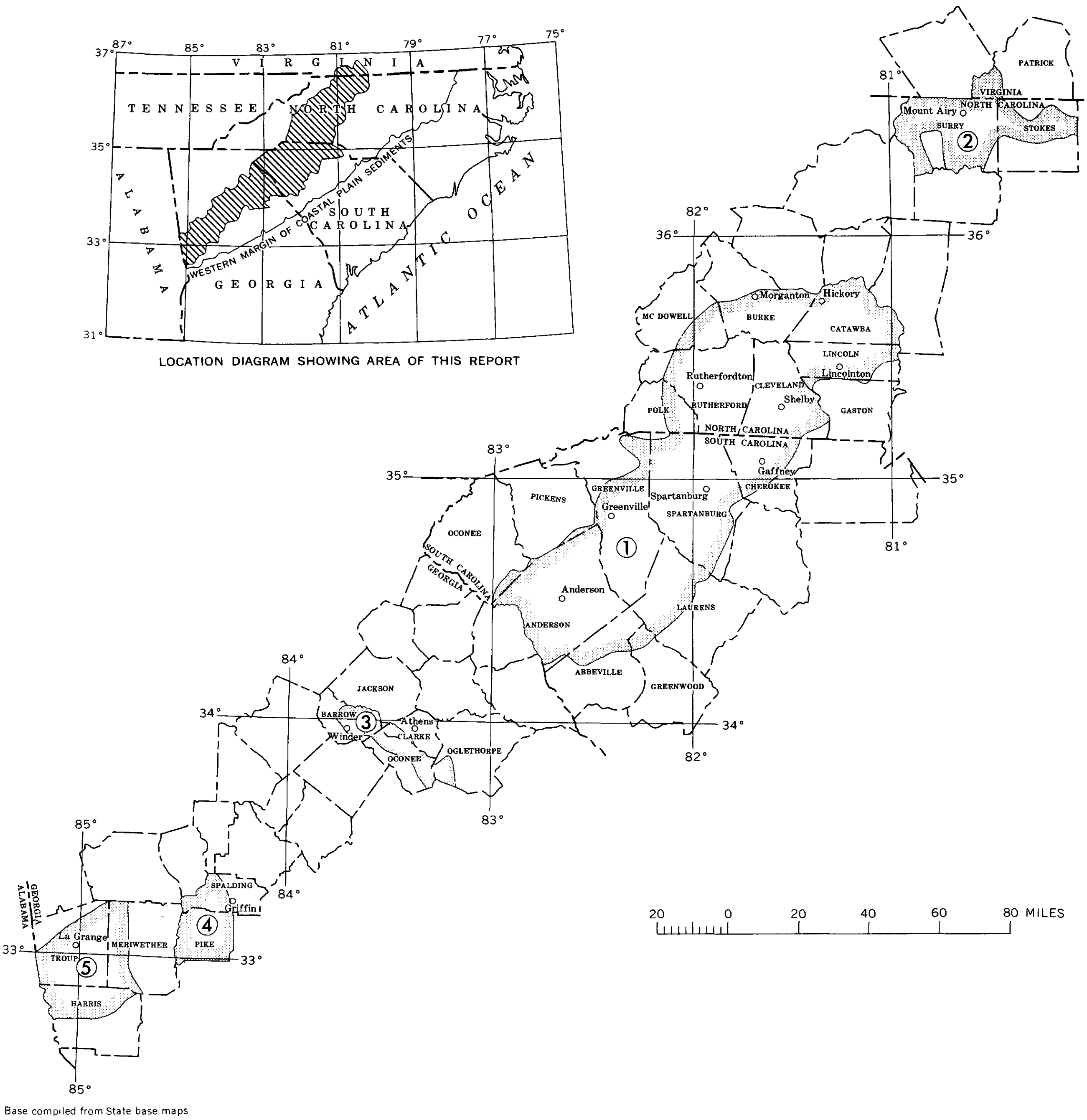

FIGURE 1.—Areas studied for placer monazite in the western Piedmont of Virginia, North Carolina, South Carolina, and Georgia. 1, area between the Savannah and Catawba Rivers, S.C.–N.C.; 2, area between the Yadkin and Dan Rivers, N.C.–Va. Areas in Georgia are, 3, in the drainage basin of the Oconee River; 4, in the drainage basin of the Flint River; and 5, in the drainage basin of the Chattahoochee River.

River-Catawba River area, South Carolina–North Carolina; (2) the Yadkin River-Dan River area, North Carolina–Virginia; (3) the Oconee River area, Georgia; (4) the Flint River area, Georgia; and (5) the Chattahoochee River area, Georgia.

The Savannah River-Catawba River area was selected to cover the region in the Carolinas that was mined for monazite between 1887 and 1917 (Pratt, 1916, pl. 1). The other areas to the northeast and southwest of the historic sites of mining were chosen to give representative examples of fluvial deposits in regions discovered by John B. Mertie, Jr. (1953, pl. 1), to contain monazite-bearing crystalline rocks. The Yadkin River-Dan River area is northeast of the mined region, and the areas in Georgia are to the southwest of the mined region. The largest of these five areas, and also the one with the best display of fluviatile placers, is between the Savannah and Catawba Rivers.

The Savannah River-Catawba River area lies between the Savannah River at the border of Georgia and South Carolina and the Catawba River in west-central North Carolina. It covers 5,266 square miles and includes all or parts of the following counties: Greenwood, Abbeville, Anderson, Oconee, Pickens, Greenville, Laurens, Spartanburg, and Cherokee Counties in South Carolina; Polk, Rutherford, Cleveland, Gaston, Lincoln, Catawba, Burke, and McDowell Counties in North Carolina.

In addition to the defining rivers at the northwest and southwest ends of the area, five major streams head northwest of the area and flow across it. One major stream, the South Fork Catawba River, rises within the area. The drainage basin area of each trunk stream in which placer deposits were examined is as follows:

Trunk stream (river)	*Area of drainage basin studied (square miles)*
Savannah	802
Saluda	740
Enoree	351
Tyger	402
Pacolet	491
Broad	1,380
South Fork Catawba	488
Catawba	612

Most of the region between the Savannah and Catawba Rivers is in the western part of the Piedmont physiographic province. Gently rolling hills and broad relatively flat interfluves range in local relief from 100 to 200 feet and typically have about 140 feet of relief. At the west margin of the area, the local relief increases northeastward to 1,700 feet as the margin approaches the east flank of the Blue Ridge in Greenville County, S.C., and enters the South Mountains in Polk, Rutherford, and McDowell Counties, N.C. Likewise, the gradients of the streams increase toward the northwest from 4–10 feet per mile on trunk streams and 20–40 feet per mile on smaller tributaries in the Piedmont to 60 feet per mile on the major streams and hundreds of feet per mile on the smaller tributaries in the mountains. In the same direction there is a steepening of valley walls, an increase in the frequency of constricted valleys, and a decrease in the size and continuity of flood plains.

The northernmost area is between the Yadkin and Dan Rivers at the border of North Carolina and Virginia. It includes parts of Surry and Stokes Counties, N.C., and Patrick County, Va. It extends northward to the crest of the Blue Ridge, westward to the Little Fisher and Fisher Rivers, southward to the Yadkin River, and eastward to the Dan River, a total area of 690 square miles. Local relief and the gradients of the streams increase toward the north and west as the Blue Ridge is approached; in the eastern part of the area, relief steepens where isolated quartzite ridges stand above the low hills of the Piedmont.

Three of the areas are in Georgia. The northernmost includes 310 square miles drained by tributaries to the Middle Oconee and Oconee Rivers in Oconee, Barrow, Clarke, Jackson, and Oglethorpe Counties. Farther to the southwest, on streams that lead to the Gulf of Mexico, the area in the drainage basin of the Flint River includes 210 square miles in Spalding and Pike Counties, and the area on the Georgia side of the Chattahoochee River comprises 660 square miles in Troup, Meriwether, and Harris Counties. In the three areas the interfluves are broad and flat, and except for parts of Harris and Meriwether Counties where Pine Mountain rises 600 feet above the general Piedmont surface, the local relief rarely exceeds 100 feet.

LAND UTILIZATION AND DEVELOPMENT

The western Piedmont from Virginia to Alabama was settled and opened to agriculture in the 18th and 19th centuries. It is still a largely agricultural region, but manufacturing related to textiles and forest products has grown vigorously since 1900 and occupies an increasing number of urban dwellers. Mining is not a large industry. Small mica deposits are common and have been mined for at least 80 years. A few granite quarries have been opened. A little gold, tin, barite, iron, graphite, and beryl have been mined, and recently large deposits of spodumene and kyanite have been developed to the east of the monazite-bearing part of the western Piedmont. Placer monazite was widely mined between the Savannah and Catawba Rivers during the period 1887–1917.

An excellent network of paved State and Federal highways and paved or graded secondary roads is within the area. Individual flood plains are seldom farther than 1–2 miles from a public road.

The large towns are served by railroads, and sidings are maintained at many of the smaller communities. Electricity is generally available; electric distribution lines reach more than three-fourths of the farms in the 30 counties.

The annual average temperature along the five areas ranges from 56°F at Mount Airy, N.C., to 63°F at La Grange, Ga., but the annual average precipitation, which ranges from 42 to 53 inches, does not closely parallel differences in latitude. Weather records for major communities in the western Piedmont show that the climate is suitable for year-round mining (U.S.

Weather Bureau, 1952). The summers are normally hot and humid, and the winters are damp.

From 38–89 percent of the land area in the 30 counties (U.S. Weather Bureau, 1952) is in farms, but not all the farmland is cleared and tilled. North of the Catawba River, tobacco is the principal crop, but south of the river the most widely raised crop is cotton, and in Spartanburg and Greenville Counties, S.C., large acreages are in peach orchards. Grain is widely grown, but in recent years many acres of hillside land have been taken out of cultivation and converted to permanent pasture. Bottomland may be planted with corn—in the South Mountains the principal farmed areas are the valley bottoms—but over most of the monazite area the flood plains are usually pasture or wasteland. Where left as wasteland, the bottoms are commonly overgrown with mixed stands of deciduous trees and shortleaf pine, most of which is scrubby and has low value for lumber or pulpwood. A tangle of low brush, honeysuckle, greenbrier, blackberry bushes, and kudzu renders much of the wasteland nearly impassable.

MAP COVERAGE

In the early 1950's, when the fieldwork was done, the five areas were incompletely covered by topographic quadrangles, but uniform planimetric coverage was provided by county road maps issued by the State Highway Departments at an approximate scale, 1 inch=1 mile or an approximate scale, 1 inch=2.4 miles. These maps show streams and culture, and they have been compiled into base maps for the five areas discussed in this report.

Aerial photographs at a scale of 1:20,000 and 1:24,000 made for the U.S. Department of Agriculture cover the five areas. Most of these photographs are available from the Production and Marketing Administration, but a part of the drainage tributary to the Catawba River in North Carolina is covered by aerial photographs obtainable from the Soil Conservation Service.

The planimetric maps used for the appraisal of monazite placers in the area between the Savannah and Catawba Rivers, S.C.–N.C., were made in the field from uncontrolled mosaics of the aerial photographs.

ACKNOWLEDGMENTS

The investigation represents the direct and indirect contribution of many persons besides project personnel. John B. Mertie, Jr., through his investigations, influenced the choice of areas to examine and contributed ideas related to methods. Special acknowledgment is due the mineralogists of the U.S. Geological Survey who, under the direction of Jerome Stone, made the thousands of grain counts on the samples of heavy minerals. Individual credit for the grain counts and other analyses are given in the section on laboratory procedure and in the tables of analyses. In the field the geologists were assisted by J. W. Keeler in 1951 and by B. F. Spradlin, P. E. Myers, J. W. Wissert, Jr., R. R. Thompson, J. B. Pollard, Jr., F. G. Barstow, G. A. Miller, W. J. Hoppes, and B. R. Long in 1952. R. F. Griffith and L. A. Hansen were the project engineers with the U.S. Bureau of Mines on the joint exploration of selected placers. Field representatives of the Soil Conservation Service and Production and Marketing Administration of the U.S. Department of Agriculture provided information on conservation and stream characteristics. The cooperation of thousands of landowners, who kindly granted access to their property, assured the freedom of movement needed to complete the reconnaissance.

MONAZITE MINING IN THE WESTERN PIEDMONT

HISTORY AND PRODUCTION

Monazite, zircon, and other rare minerals attracted the attention of Thomas A. Edison in the late 1870's as a source for materials possibly useful in the manufacture of illuminating apparatus. In 1879 he sent W. E. Hidden to North Carolina to search for minable deposits of these minerals, and in November 1880, Hidden dispatched to Edison about 50 pounds of concentrate containing 60 percent monazite from the Brindletown gold-placer district (Genth and Kerr, 1881, p. 84). This concentrate was the first commercial monazite shipped from the Carolinas, and it was the first monazite mined in the United States. However, further mining was not undertaken until some time in 1886, when placers in the Brindletown district, Burke County, N.C., began to be worked in a small way for monazite. During 1887 the district produced 12 tons of monazite. Between 1888 and 1892 a few tons of monazite was mined annually by hand methods at Brindletown and adjacent gold-placer areas, but records of the output were not kept (Nitze 1895, p. 689; Pratt, 1902, p. 61; 1903, p. 183; Schaller, 1919, p. 156). A sustained production was achieved in North Carolina from 1893 through 1910, and an intermittent output continued into 1917 (table 1). Between 1903 and 1910 South Carolina added a small annual contribution to the output.

When the industry closed in 1917 the total amount of monazite produced in the western Piedmont of the Carolinas was 5,483 short tons. The abrupt decline in output in 1896–97 was caused by the introduction of Brazilian monazite in world commerce. The Carolina industry collapsed after a sharp drop in the price of thorium nitrate in 1906 (table 2) and the commencement of monazite mining in India (Houk, 1946, p. 11–12; Roots, 1946, p. 50). By 1915, clean monazite from Brazil and India was cheaper in New York than crude monazite concentrate in the Carolinas (Pratt, 1916, p. 67).

TABLE 1.—*Monazite produced, in short tons, in the western Piedmont of North Carolina and South Carolina, 1887–1917*

[Sources of data: 1887–92 from Pratt, 1902, p. 61; 1893–1917 from Santmyers, 1930, p. 15; Houk, 1946, p. 11–12]

Year	North Carolina	South Carolina	Total	Year	North Carolina	South Carolina	Total
1887	12		12	1904	343	29	372
1888–92	(1)			1905	447	225	672
1893	65		65	1906	349	74	423
1894	273		273	1907	228	46	274
1895	787		787	1908	155	56	211
1896	15		15	1909	196	75	271
1897	22		22	1910	42	8	50
1898	125		125	1911–12	(2)		
1899	175		175	1913–14			
1900	454		454	1915	18		18
1901	374		374	1916	19		19
1902	401		401	1917	39		39
1903	387	44	431	Total	4,926	557	5,483

[1] A few tons annually, but records not maintained.
[2] Small production, not marketed.

TABLE 2.—*Approximate price of thorium nitrate, 1888–1911*

[Modified from Sterrett, 1907, p. 1209; Pratt, 1916, p. 35, 68]

Year	Price (dollars per pound)	Year	Price (dollars per pound)
1888	500.00	1904	4.26
1894	215.91	1905	5.14
1895 Jan	97.07	1906	3.49
1895 July	53.98	1907	2.97
1895 Nov	32.39	1908	2.65
1896 May	16.19	1909	1.89
1896 Oct	9.72	1910	1.76
1899 Oct	3.24	1911	1.97
1900–03	5.72		

Much of the monazite mined in the western Piedmont of the Carolinas was exported to Germany and England, except in the last years of production. Until 1909, little monazite concentrate was imported, but beginning in 1908 imports of thorium as thorium nitrate were higher than the amount of thorium produced domestically from monazite (table 3). After 1910, imported ore supplanted domestic sources for monazite used in the United States.

Mining ceased in the western Piedmont because the cost was more than it was at operations on beach placers in Brazil and India, not because reserves were depleted. In 1915 the reserves were conservatively estimated at 15,000–20,000 tons of monazite (Kithil, 1915, p. 19), and 2 years after mining ceased, the streams were said to contain an abundance of monazite (Schaller, 1919, p. 156). Estimates made from the work described in this report show resources of at least 784,000 short tons of monazite in fluvial deposits between the Savannah and Catawba Rivers, S.C.–N.C. (Overstreet, Theobald, and Whitlow, 1959, p. 712).

TABLE 3.—*Imports of thorium nitrate, 1904–11*

[Modified from Pratt, 1916, p. 68]

Year	Thorium nitrate (pounds)	Thorium in imported thorium nitrate (pounds)	Monazite equivalent to imported thorium nitrate [1] (short tons)
1904	58,655	28,154	280
1905	52,378	25,141	250
1906	40,090	19,243	190
1907	51,441	24,691	250
1908	65,289	31,338	310
1909	124,833	59,920	600
1910	124,808	59,908	600
1911	121,111	58,133	580

[1] Assuming monazite having about 5.5 to 6 percent thorium oxide, typical of the Carolinas. This monazite contains about 100 pounds of thorium per short ton.

Efforts to revive mining in Burke and Cleveland Counties were made between 1929 and 1936, but even in the depression years monazite could not be mined cheaply enough to compete with foreign sources (Bryson and others, 1937, p. 132). Between 1951 and 1953 some private exploration for monazite was undertaken in Cleveland, Rutherford, and Burke Counties, N.C., and a placer was opened on the First Broad River in Rutherford County. It is said to have been the source of some monazite in 1953 (Councill, 1955, p. 6). Except for this venture, monazite was not produced in the western Piedmont of the Carolinas after 1917.

By the time mining ceased, monazite had been found in all or parts of 18 counties in North and South Carolina. Monazite was not mined in Georgia or Virginia.

METHODS OF MINING

Most of the monazite produced in the Carolinas until 1902 was mined by local landowners who sold rough concentrate to domestic companies. These companies also bought or leased land for mining. In 1903, foreign companies began to buy land, erect concentrating plants, and purchase rough concentrate. No data are available on the relative production of the independent operators and the companies, but the size of the workings suggest that most of the monazite was mined on a small scale by independent operators (figs. 2, 3).

Monazite was mined chiefly from the gravel and sand in the channels of streams and from the coarse-grained basal sediments in flood plains adjacent to the channels. Some monazite was recovered from the topsoil on hillsides sloping to the flood plains, and, rarely, it was concentrated from saprolite in banks bordering the streams. At localities on Hickory Creek and near Carpenter Knob in Cleveland County, unsuccessful efforts were made to mine monazite from the crystalline rock.

Five geologic factors controlled the location of the mines: (1) relation of the stream to monazite-bearing

A

B

FIGURE 2.—The Downs monazite mine, 1 mile northwest of Carpenter Knob, Cleveland County, N.C. *A*, Characteristic topography of the mined area. *B*, Gasoline-powered concentrating table of the Carolinas Monazite Co. Photographs made about 1906 by D. B. Sterrett, of the U.S. Geological Survey.

A

B

FIGURE 3.—The J. M. Lemmons monazite mine, 4 miles northwest of Gaffney, Cherokee County, S.C. *A*, Colluvial soil underlain by thin gravel layer; both were sluiced into the stream. *B*, second sluicing of the stream. Photographs made about 1910 by D. B. Sterrett, of the U.S. Geological Survey.

crystalline rock, (2) thickness of gravel, (3) thickness of fine-grained overburden, (4) flow of water in the stream, and (5) height of the water table in the flood plains. Each tended to restrict mines to headwater areas where stream channels are small and flood plains are narrow.

Streams were mined only in areas underlain by monazite-bearing crystalline rocks, and some of these streams were worked all the way to the gullies or springs at their sources. Knob Creek (fig. 4) Cleveland County, N.C., is an excellent example of the geologic controls affecting small-scale mining. Big Knob, Little Knob, Bald Knob, and Poundingmill Creeks are underlain by monazite-rich bedrock (Overstreet, Whitlow, White, and Griffitts, 1963). All these streams were mined, and some of the smaller tributaries were worked to their sources. Only Adams Branch and the upstream part of Bob Branch were not mined. They are in areas where some gabbro and hornblende gneiss is present. These rocks are barren of monazite and contain abundant accessory magnetite which enters these streams and masks the monazite from other source rocks. Although the actual tenor in monazite is high on Adams Branch, the percentage of monazite in the concentrates is low compared with magnetite-free concentrates obtained elsewhere along Knob Creek; these two streams, therefore, were avoided by the miners.

The effect of overburden is also shown by the position of the workings along Knob Creek. It was the general practice to strip 1–3 feet of overburden at all the mines to get at the monazite-rich gravel, and a maximum of 5 feet of overburden was removed at a few places. The mined areas shown in figure 4 met this stripping ratio, and the gravel thus exposed ranged in thickness from a few inches to 13 feet. Probably it averaged about 2 feet thick. The downstream ends of the mined areas lead into large unmined flood plains where the overburden is 10–20 feet deep and the gravel is only 2 or 3 feet thick. This great thickness of overburden could not be handled by the methods then used to mine monazite, despite the fact that it is monazite bearing and the average tenor of the sediment in this part of Knob Creek valley is 1.67 pounds of monazite per cubic yard (Griffith and Overstreet, 1953a, p. 8).

Sufficient water for sluicing was available on most of the small streams; however, continuous mining downstream was prevented by too great a flow of water. Flooding caused by torrential rains was said in a contemporary report to result frequently in loss of equipment and works at the small placers (Kithil, 1915, p. 21).

The height of the water table in the flood plains restricted the depth of stripping. Deeply buried gravel was not sought because water would enter the pits too rapidly to be bailed. Because the gradient of the streams is low, it was impractical to drain the deep flood plains.

Small-scale hand mining was practiced throughout the area, and on a few streams hydraulicking was introduced where gold was associated with the monazite. Pitting and trenching reached away from the stream channels toward the valley walls. Trenches covered areas where the gravel was continuous, and pits were sunk where the gravel was discontinuous. The first mining operations ruined the land for farming, but by 1906, efforts were begun to reclaim the land as mining progressed. Gravel in one block of stripped ground was washed, then returned evenly to the bedrock surface, and as an adjoining block was stripped, the overburden was thrown on the replaced gravel to produce an even surface for further cultivation or use as pasture (Sterrett, 1907, p. 1201). Where these efforts were not made, as, for example, on Beatty Creek, Rutherford County, N.C., old tailing piles project as low heaps of gravel through fluvial silts deposited after mining ceased. Some projecting tops of old tailing piles have been flattened by cultivation of the flood plain, but most of them remain as low brush-covered mounds.

Surface runoff from cultivated land in monazite-rich areas replenished some streams with enough monazite to permit their channels to be rewashed profitably every few years. Streams with narrow valleys bordered by tilled hillsides could be mined every year, and sundry small creeks and gullies were reworked after every hard rain. Some miners preferred to follow the mining and to rewash tailing piles, some of which contained enough monazite to make the effort pay. Eight tailing piles in the drainage basin of Knob Creek were sampled in 1952 and were found to contain 0.3–8.0 pounds of monazite per cubic yard (table 4).

TABLE 4.—*Tenor of tailings left from placer mining on Knob Creek, Cleveland County, N.C.*

[Tenors computed from mineral analyses by M. N. Girhard, Jerome Stone, and E. J. Young, U.S. Geol. Survey]

Sample	*Monazite (pounds per cubic yard)*
52-JW-29	0. 9
30	. 5
118	. 3
132	1. 2
134	1. 7
161	2. 4
163	. 4
174	8. 0
Average	1. 9

Generally, rough concentrates which contained 5–70 percent and averaged 30 percent monazite (Sterrett,

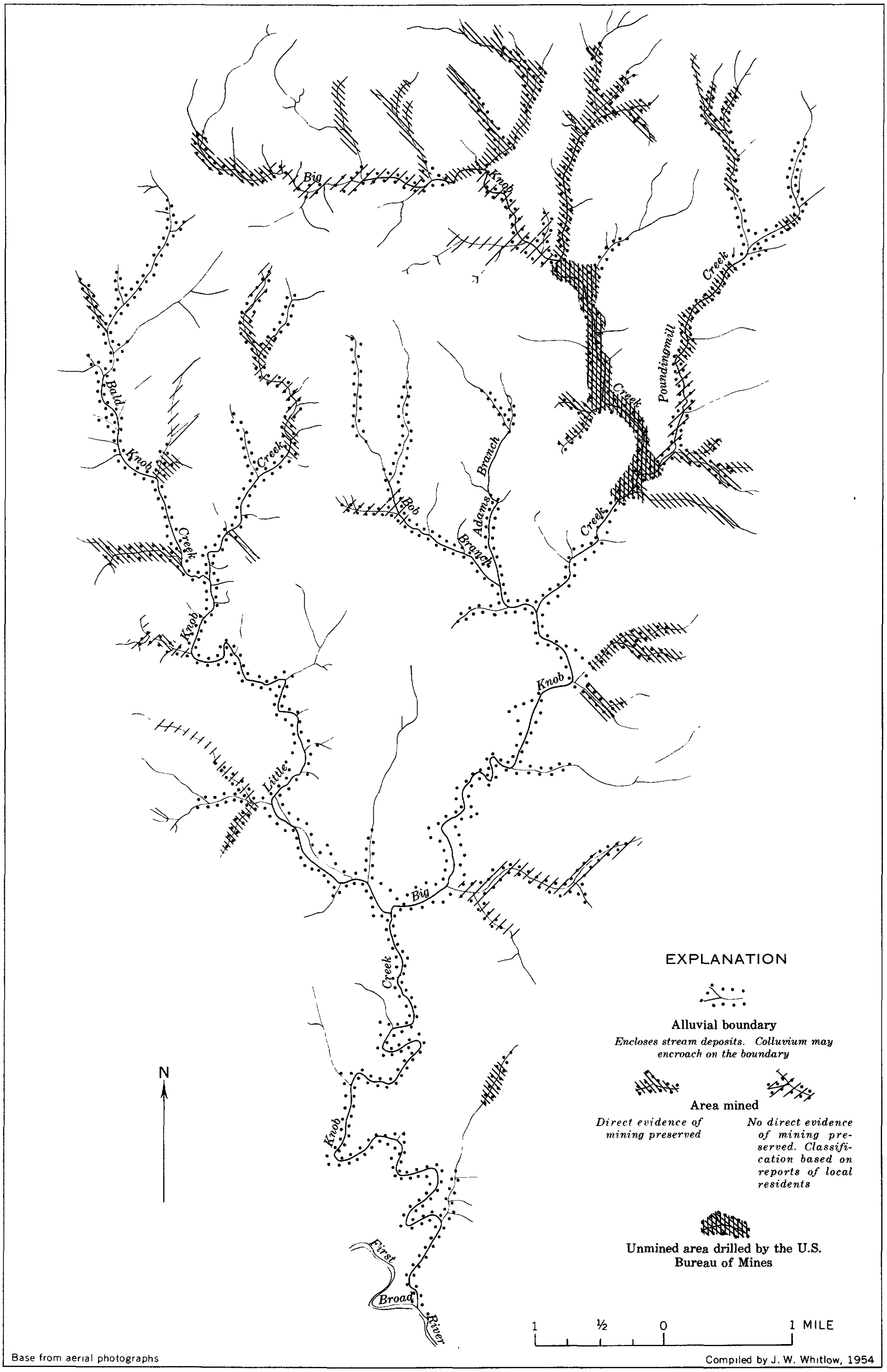

FIGURE 4.—Map of Knob Creek, Cleveland County, N.C., showing areas mined and explored.

1907, p. 1201) were prepared by washing the monazite-bearing sand in sluice boxes, and occasionally the concentrate from the sluices was upgraded by panning. In 1906 some companies introduced gasoline-powered concentrating tables (fig. 2*B*) to clean the rough concentrates at the mine and make a product that contained 50–90 percent monazite. Byproduct recovery of gold was insignificant; in the better areas it is said to have averaged 1 dollar per day for each sluice box.

The rough concentrate was dried in the sun or over wood fires before it was sold to cleaning plants or to neighborhood dealers. Monazite ranged in price from \$100 per ton in 1896 to \$360 per ton in 1906. Miners received 1.5–6 cents for a pound of concentrate in 1903 (Pratt, 1904b, p. 1169–1170). In 1906 the average price for concentrate was 8 cents per pound, but miners received from 1.5 cents per pound for low-grade material having low-thoria monazite to 15 cents per pound for the best grade of concentrate having high-thoria monazite (Sterrett, 1907, p. 1201). When the price of clean monazite concentrate dropped to a few cents per pound delivered in New York, the prices at the creeks in the Carolinas were too low to permit mining.

GEOLOGY

The monazite deposits examined in this investigation are in the western part of the Piedmont physiographic province in the Southeastern States. The geology of the Piedmont is not well known in detail, but at the time this fieldwork was carried on, the general character of the area was disclosed by State geologic maps at a scale of 1:500,000 for Virginia (Stose, 1928), Georgia (Stose and Smith, 1939; Crickmay, 1952), and Alabama (Adams and others, 1926), and the geologic map of the United States at a scale of 1:2,500,000 (Stose and Ljungstedt, 1932). Other publications concerning the province include a small number of geologic quadrangle maps by State and Federal surveys, groundwater investigations, State and county maps 50–100 years old, papers on special problems, and reports on mining districts and studies of regional mineral resources representing research that extended back to the early decades of the 19th century. Despite the fact that the area of monazite-bearing crystalline rocks is depicted on State and the United States geologic maps, little more than a hint at the complexity of this metamorphic terrain can be gathered from these sources because broadly inclusive units were used for mapping, correlations were largely based on lithology, and rank of metamorphism was used to establish relative ages of the units mapped.

During the 1950's and early 1960's new insight into possible age relations and stratigraphic correlations in the Piedmont were developed through tectonic considerations (King, 1955; Stuckey, 1958; Stuckey and Conrad, 1958; U.S. Geol. Survey and Am. Assoc. Petroleum Geologists, 1962), review of the pattern of regional metamorphism (Overstreet and Griffitts, 1955), and interpretations of the ages of minerals (Rodgers, 1952; Long and others, 1959; Overstreet and Bell, 1965a, b), but very little new detailed geologic mapping of the crystalline rocks was added to the inadequate coverage available at the start of this study.

The monazite placer investigation included virtually no geologic mapping of the crystalline rocks; only part of one quadrangle was mapped (Overstreet, Whitlow, White, and Griffitts, 1963). The investigation contributed hitherto unknown facts about the areal distribution of metamorphic index minerals, which aided us in interpreting patterns of regional metamorphism in the crystalline rocks in the western part of the Piedmont and in forming a hypothesis for the origin of monazite. Comprehensive coverage of the monazite area by detailed geologic maps does not exist. Until the region is so covered, the most fundamental facts of stratigraphic succession, age, metamorphism, periods of igneous activity, tectonics, and geochemical relations in the crystalline rocks will remain in dispute.

The unconsolidated sediments in the monazite-bearing area in the western Piedmont are the sites of the fluviatile placers. They are alluvial detritus derived from the products of the weathering of the crystalline rocks. These sediments appear to be very young; for the most part they are post-Wisconsin. They have formed in response to climatic factors related to the geographic and topographic situation of the monazite-bearing area.

CRYSTALLINE ROCKS

REGIONAL RELATIONS

One of the most characteristic regional geologic features of the Piedmont is the zonal arrangement of crystalline rocks into northeasterly elongated belts which persist across the Southeastern States. In its gross aspect the zonal arrangement was recognized as early as 1802 in South Carolina (Drayton, 1802, p. 10–11). The concept was later developed and elaborated (Sloan, 1908, pl. 1; Jonas, 1932, p. 230–231) until in 1955 P. B. King (p. 337–38) proposed names for the belts. King assigned the name Inner Piedmont belt to the zone of most profoundly metamorphosed rocks. He found that these rocks occupy the western part of the Piedmont physiographic province, and locally, some of the eastern part of the Blue Ridge physiographic province. Rocks of the Inner Piedmont belt are separated on the northwest from the Blue Ridge belt by a narrow band of blastomylonite and phyllonite, called by King the Brevard belt, which persists from Alabama to southern Virginia (U.S. Geol. Survey and Am. Assoc. Petroleum Geologists, 1962). The Inner Piedmont belt is separated on the southeast from plutonic rocks of the Charlotte belt in northern Georgia, South Carolina, and central North Carolina by a narrow band of low-grade metamorphic rocks called the Kings Mountain belt. Northeast of central North Carolina and southwest of central Georgia the rocks of the Inner Piedmont belt are apparently in contact with those of the Charlotte belt.

Certain ore deposits have long been known to be associated with particular belts, an observation that was used by Sloan (1908, pl. 1) in his description of the economic geology of South Carolina. Ores and industrial minerals associated with the Inner Piedmont belt are sheet muscovite, sillimanite, and monazite. Monazite-bearing crystalline rocks occupy the core of the Inner Piedmont belt, and themselves form a belt extending from Virginia to Alabama. This belt was defined in 1951 by J. B. Mertie, Jr. (1953, pl. 1). He found that within the Inner Piedmont belt some granitic rocks, gneisses, and schists contained monazite and others did not. Mertie's concept of a source for monazite restricted to a belt of monazite-bearing crystalline rocks was used as a guide in selecting areas to be examined for detrital monazite in the present work (W. C. Overstreet, V. E. McKelvey, and F. N. Houser, unpub. data, 1951).

The areas examined for detrital monazite are spaced along the Inner Piedmont belt to give representative examples of placers from the border between Virginia and North Carolina to the border between Georgia and Alabama (fig. 1). Only two regional geologic relations are known to connect the areas: occurrence in the Inner Piedmont belt and presence of monazite. Few detailed geologic data on the areas are available, and continuous detailed geologic mapping does not exist between them. It is not known whether they are parts of the same stratigraphic sequences. Tectonic relations among them, necessarily complex, are virtually unknown. For these reasons descriptions of the crystalline rocks in the five areas are given separately. Correlation must await further mapping.

DESCRIPTIONS OF THE FIVE AREAS

SAVANNAH RIVER-CATAWBA RIVER AREA, SOUTH CAROLINA-NORTH CAROLINA

The geology of the crystalline rocks in the Savannah River-Catawba River area, S.C.–N.C., is partly shown by six geologic quadrangle maps (Keith, 1905; Keith and Sterrett, 1907, 1931; Sterrett, 1912; Overstreet, Yates, and Griffitts, 1963a); several maps accompanying commodity investigations (Griffitts and Olson, 1953a, fig. 77; 1953b, fig. 104; Griffitts, 1958, pl. 1; Espenshade and Potter, 1960, pls. 7–11) and groundwater surveys (LeGrand and Mundorff, 1952, figs. 11, 13, 15, 19, 21; LeGrand, 1954, fig. 11); geologic maps of great antiquity for counties in South Carolina (Lieber, 1858a, b, 1859, 1860); and old maps of that State (Hammond, 1883, map; Sloan, 1908, pls. 1, 2).

Some of these miscellaneous investigations in the Inner Piedmont belt, along with material covering the other geologic belts in North and South Carolina, were compiled and interpreted by P. B. King (King, 1955). Parts in North Carolina were presented at a scale of 1:500,000 on the State geologic map (Stuckey, 1958; Stuckey and Conrad, 1958). An interpretation of the geology of the Inner Piedmont belt in the Savannah River-Catawba River area, based on the distribution of metamorphic index minerals in monazite placers, was presented by Overstreet and Griffitts (1955). The parts of these miscellaneous investigations in South Carolina, together with an interpretation of the source rocks of residual soils shown on published county soil surveys (Taylor and Rice, 1903; Drake and Belden, 1906; McLendon and Latimer, 1908; McLendon, 1910; Latimer and others, 1924; Watkins and others, 1924; Lesh and others, 1934, 1937; Shearin and others, 1943), was compiled in a geologic map of the crystalline rocks of South Carolina at a scale of 1:250,000 (Overstreet and Bell, 1962, 1965a, b).

The geologic interpretations of Griffitts and Overstreet (1952), Overstreet and Griffitts (1955), and Overstreet and Bell (1965a, b) as they apply to the Savannah River-Catawba River area, S.C.–N.C., are summarized below to give the geologic setting of the monazite placers. The reader is referred to the full report on the geology of the South Carolina segment of this area for particulars and a geologic map. As far as possible, discussion in the present report of the geologic setting of the Savannah River-Catawba River area is related to data obtained from heavy-mineral concentrates and interpreted by the use of previously unpublished mineral isogram maps [1] (pls. 1–4).

The isogram map for epidote and staurolite (pl. 1) discloses a concentration of these minerals in fluvial sediments occurring along the southeastern and northwestern flanks of the Inner Piedmont belt. Staurolite is virtually restricted to a narrow band which extends northeastward along the southeastern part of the belt from the vicinity of Gaffney, Cherokee County, S.C., to the limits of data at the Catawba River east of Newton,

[1] Methods used to make the mineral isogram maps were described by Overstreet, Theobald, Whitlow, and Stone (1956).

Catawba County, N.C. Epidote occupies broad discontinuous areas on each flank of the belt. The mineral evidently increases in abundance beyond the southeastern and northwestern limits of the areas where data have been obtained, because epidote contours rise in those directions. In the central core of the Inner Piedmont belt, epidote is generally absent, especially from the vicinity of Spartanburg, S.C., northeastward to the Catawba River.

The isogram map for magnetite (pl. 1) displays a greater percentage of magnetite in fluvial concentrates from areas along the southeastern and northwestern parts of the Inner Piedmont belt than from the central core of the belt. For the most part, magnetite-rich concentrates occur where concentrates also contain abundant epidote. A general rise in the percentage of magnetite accompanies the appearance of staurolite between Gaffney and the Catawba River. Contours beyond those areas from which data have been obtained show that on the southeastern flank of the Inner Piedmont belt the amount of magnetite increases toward the southeast, and on the northwestern flank the percentage increases toward the northwest. Magnetite is least common in the core of the belt between Spartanburg and the Catawba River. A large area in which magnetite-rich concentrates occur centers around Anderson in Anderson County, S.C. It is not clearly matched by epidote-rich concentrates, but epidote has a tendency to increase along the north-trending axis of this magnetite high.

The isogram map for amphibole (pl. 1) shows well-defined linear zones along the southeastern edge of the Inner Piedmont belt in which the fluvial concentrates contain a few percent amphibole, principally hornblende. Hornblende from the flanks of the belt is pleochroic green, brown green, and blue green, but hornblende from the core of the belt is pleochroic brown (Overstreet and Griffitts, 1955, p. 557). In the South Carolina segment of the northwestern flank of the belt, amphibole is uncommon and sporadically distributed. In North Carolina the northwestern flank of the belt is occupied by a broad area where concentrates commonly contain as much as 10 percent amphibole and, locally, as much as 50 percent. This area is also the source of epidote- and magnetite-rich fluvial concentrates.

The strong similarity in the distribution of epidote, staurolite, magnetite, and amphibole along the flanks of the Inner Piedmont belt evidently indicates control by the lithologic character of the source rocks from which the detrital minerals were derived.

The isogram map for sillimanite and kyanite (pl. 2) discloses that the few occurrences of kyanite in concentrates from this part of the Inner Piedmont belt tend to be along the southeastern and northwestern flanks of the belt where epidote, staurolite, magnetite, and amphibole are present. Sillimanite-bearing concentrates occupy two large and homogeneous areas in the core of the belt where concentrates are devoid of, or have only small percentages of, epidote, staurolite, magnetite, and amphibole. Several smaller areas from which sillimanite-bearing concentrates were obtained extend the well-defined trends of the large areas in the core of the belt. Many minor occurrences, generally single samples, are peripheral to the main areas, or they are sharply isolated out on the flanks of the belt. The percentage of sillimanite in fluvial concentrates increases toward the core of the belt. The areas where sillimanite rises above 5 percent of the concentrate are somewhat asymmetrically placed with respect to the 1-percent isogram for sillimanite. They tend to be southeast of the center of the core in North Carolina, almost central at the State line, and northwest of the center line of the core in South Carolina.

The isograms for rutile (pl. 2) in fluvial concentrates show that the mineral tends to occupy broad but irregular and interrupted areas in the core of the Inner Piedmont belt. These areas form two main groups. The larger group extends northeastward from Spartanburg to the Catawba River. It is the principal sillimanite-bearing region, but its main axis is displaced slightly southeast of the axis of the sillimanite area, and high-value isograms for rutile present an asymmetry remarkably like that of the sillimanite isograms between Spartanburg and the Catawba River. The smaller group of areas in which rutile occurs in concentrates extends southward from Paris Mountain to the Saluda River in the same general region, but partly east of the smaller of the two main sillimanite-bearing regions. High-value isograms for rutile are only coincident with high-value isograms for sillimanite in the vicinity of Paris Mountain, Greenville County, S.C. The southwest-trending zone indicated by the 1-percent isogram for rutile in Abbeville County is associated with several small areas where concentrates contain 1 percent or more of sillimanite, as is the area of rutile-bearing concentrates at the Seneca River in Anderson County; but sillimanite generally constitutes less than 1 percent of concentrates from these areas. For the Savannah River–Catawba River area as a whole, the association of rutile with sillimanite is strong.

Isograms for ilmenite (pl. 2) show that no concentrate from fluvial deposits in the area between the Savannah and Catawba Rivers lacks ilmenite. Ilmenite is generally less common in concentrates from the flanks of the belt than in concentrates from the core. In areas where rutile is unaccompanied in concentrates by sillimanite, such as the vicinity of the Seneca River in

Anderson County, the southwest-trending zone in Abbeville County, and the region in eastern Greenville County and western Laurens County, the concentrates contain copious ilmenite. It is possible that in these areas the relations among rutile, ilmenite, and sillimanite are caused by different geologic factors than those giving the apparently direct relation between rutile and ilmenite.

The distribution of garnet shown by the isograms (pl. 2) conforms closely to the regional occurrence of sillimanite. Garnet is commonest in concentrates from the core of the belt and decreases in concentrates from the flanks, except in the extreme northwestern part of the area in the vicinity of Marion, N.C. Many concentrates from the southeastern and northwestern flanks of the belt are barren of garnet in areas where epidote, magnetite, and amphibole are common. Garnet in the core of the belt around Shelby, N.C., is pale-pink, rose, and lavender almandine which ranges in index of refraction from $n=1.796$ to $n=1.816$, with an average of $n=1.81$, and ranges in specific gravity from 4.00 to 4.28, with an average of 4.16 (Overstreet, Yates, and Griffitts, 1963b). The color of garnets varies in the Savannah River-Catawba River area, having an apparent trend toward brown and dark-red garnets on the flanks of the belt and pale-pink, rose, and lavender garnets in the core. Details as to regional variation in composition of the garnets are being investigated by M. E. Mrose, of the U.S. Geological Survey (oral commun., 1963).

Similarity in the distribution of sillimanite, rutile, ilmenite, and garnet in concentrates from fluvial sediments in the core of the Inner Piedmont belt evidently means that these detrital minerals are derived from similar crystalline rocks. The striking antipathetic arrangement of the detrital minerals from fluvial sediments—sillimanite, rutile, ilmenite, and garnet being dominant in concentrates from the core of the belt, and epidote, staurolite, kyanite, magnetite, and amphibole being dominant in concentrates from the flanks of the belt—is interpreted to reflect major regional differences of the rocks in the drainage basins of the streams. The differences probably resulted from the progressive regional metamorphism of sedimentary and volcanic rocks (Overstreet and Griffitts, 1955, p. 555–561; Overstreet and Bell, 1965a). The climax of regional metamorphism is believed to have been reached along the core of the Inner Piedmont belt, where sillimanite-bearing and isogradic sillimanite-free rocks at the sillimanite-almandine subfacies (Turner, 1948, p. 85–87) are exposed. To the southeast and northwest of the core, a lower rank of regional metamorphism was attained, and the exposed rocks are at the staurolite-kyanite subfacies (Turner, 1948, p. 81). Thus, the Inner Piedmont belt in the Savannah River–Catawba River area possesses regional metamorphic symmetry with a high-rank core and lower rank flanks. The structural framework which gives this symmetry has been tentatively interpreted as a northeasterly elongated anticlinorium. The anticlinorium consists of dominantly pelitic rocks in the core and pelites with interbedded volcanic rocks and local quartzite and marble on the flanks. These rocks are tightly folded, and the folds are generally overturned toward the northwest (Overstreet and Griffitts, 1955, p. 566; Overstreet, Yates, and Griffitts, 1963a; Overstreet and Bell, 1965a, fig. 1). Metamorphic isograds are commonly athwart the regional trend of the stratified rocks, and differences in grade of regional metamorphism tend to produce the zonal arrangement of rocks described as belts.

The metamorphosed sedimentary and volcanic rocks in the Savannah River-Catawba River segment of the Inner Piedmont belt are thought to belong to three stratigraphic sequences separated by erosional unconformities (Overstreet and Bell, 1965a). These sequences are inferred to be younger than rocks in the Blue Ridge belt to the northwest of the Inner Piedmont belt. By decrease in metamorphic grade the rocks in the Inner Piedmont belt pass into rocks exposed to the southeast in the Kings Mountain belt. The metamorphic rocks in the three sequences in the Inner Piedmont belt broadly resemble one another and are thus difficult to distinguish. Each was originally a eugeosynclinal sequence in which sedimentary and volcanic rocks were interlayered. The original sequences were composed of shale, siltstone, graywacke, felsic and mafic tuffaceous shale, tuffs and flows, very minor limestone and conglomerate, and local manganiferous shale possibly restricted to the upper sequence. Fossils have not been found in the metamorphosed sedimentary and pyroclastic rocks of the Inner Piedmont in the more than 150 years that have elapsed since geologic investigations were begun in the Carolinas, and firm correlations of the sequences have not been accomplished. Until the early 1950's the metamorphosed sedimentary rocks were generally regarded as being Precambrian, but in the 1950's and early 1960's the dominant opinion has been that the rocks are late Precambrian and Paleozoic, most of them being Paleozoic (U.S. Geol. Survey and Am. Assoc. Petroleum Geologists, 1962).

The rocks of successively younger eugeosynclinal sequences are interpreted to be separated from older rocks by erosional unconformities (Overstreet and Bell, 1965a). Each of the eugeosynclinal cycles is thought to have culminated in a period of metamorphism, igneous intrusion, and tectonic activity. In the Inner Piedmont belt the youngest cycle closed with the intrusion of granite at about 260 million years ago. Rocks of the middle sequence are interpreted to have been involved in a profoundly plutonic event with the formation of the sillimanite zone in the core of the belt and widespread emplacement of granitic rocks at about 450 million years ago. This is the strongest orogenic event in the Piedmont, and probably occurred in Ordovican time. Because of the strong metamorphism associated with this event, rocks below the middle sequence and the unconformity at the base of the middle sequence are difficult to identify, but they may be present in parts of the core of the belt around Shelby, N.C. (Overstreet, Yates, Griffitts, 1963a), and in the eastern part of Anderson County, S.C. (Overstreet and Bell, 1965a). These rocks may be Cambrian and late Precambrian in age. Superposition of episodes of metamorphism makes polymetamorphic rocks out of the sedimentary rocks deposited in the early and middle sequences and out of the instrusive rocks emplaced during the early episode.

ROCK TYPES

Paraschists and paragneisses are the common crystalline rocks in the Savannah River-Catawba River segment of the Inner Piedmont belt. They underlie about 86 percent of the area. Orthogneiss, nongneissic granitic rocks, and nongneissic gabbroic and syenitic rocks underlie about 14 percent of the area:

Rock type	*Estimated percentage of area*
Biotitic and muscovitic paraschist and paragneiss	65
Sillimanitic paraschist and paragneiss	20
Amphibolite	1
Granitic orthogneiss	10
Nongneissic granitic rocks	4
Gabbro and syenite	Trace
	100

By far the greatest part of the belt is underlain by biotitic and muscovitic paraschist and paragneiss having considerable mineralogical and textural variation. Compositional layering occurs at all scales, and rocks of strikingly different composition are locally interlayered. Muscovite schist accompanies biotite-muscovite schist along the southeastern flank of the belt and, locally, east of Anderson and between Greenville and Spartanburg, S.C. Muscovite schist is uncommon in the core of the belt, but where it is present, as around Jacob Fork and Henry Fork, N.C., it is associated with occurrences of staurolite and kyanite. Biotite-muscovite schist is present on both flanks of the belt but is uncommon in the core. Locally, as between Gaffney and the Catawba River, it is staurolite bearing. Layers of biotite schist and biotite gneiss occur in all parts of the belt. The commonest varieties of these rocks are biotite schist, garnetiferous biotite schist, biotite gneiss, and garnetiferous biotite gneiss; but the layers may also include quartzite, biotite quartzite, garnetiferous biotite quartzite, hornblende quartzite, diopside quartzite, quartz-feldspar schist, quartz-feldspar gneiss, biotite-muscovite schist, hornblende-biotite schist, garnetiferous hornblende-biotite schist, hornblende-quartz schist, garnetiferous hornblende-quartz schist, and calc-silicate rock (Overstreet, Yates, and Griffitts, 1963a).

Sillimanitic paraschist and paragneiss of regional metamorphic origin is restricted to the core of the belt. At a few minor localities along the flanks of the belt, sillimanitic rocks of probable contact-metamorphic origin are present (Overstreet and Bell, 1965a). The layers of sillimanite schist are invariably more contorted and plicated than adjacent layers of biotite schist, and they are thicker on the crests and in the troughs of small folds than they are on the limbs, which shows that the schist flowed during deformation. Sillimanite-biotite schist, sillimanite-biotite gneiss, and garnetiferous sillimanite-biotite schist are the most common varieties of sillimanitic rocks in the belt. Less common kinds are sillimanite quartzite, garnetiferous sillimanite quartzite, sillimanite-quartz schist, sillimanite-muscovite schist, garnetiferous sillimanite-muscovite schist, tourmaline-sillimanite schist, and graphite-sillimanite-schist (Overstreet, Yates, and Griffitts, 1963a).

Thin sections of these schists show that sillimanite formed from muscovite and biotite. Swarms of fibers of sillimanite appear along cleavage planes in the micas and replace the minerals. At the onset of the reaction, sillimanite darkens biotite, but as the fibers grow, the biotite becomes splintered and the sillimanite fibers coalesce and lengthen. In the last stages of replacement the relicts of biotite can be seen only as a "coloring agent" which imparts a dull-brownish pleochroism to bundles of fibers and large crystal aggregates of sillimanite. Where biotite is completely replaced, the sillimanite forms large crystals around which swarms of hairlike crystals of sillimanite are enclosed in quartz and, rarely, garnet. The reaction involving muscovite was virtually complete, because scant muscovite is left; but the reaction involving biotite was incomplete, because biotite has been only partly replaced, and most of the sillimanitic rocks are biotite bearing. The reaction involving biotite seems to have resulted in the release of titanium oxide (TiO_2), which in the form of rutile and ilmenite is more common in the sillimanitic rocks than in sillimanite-free rocks.

A diverse but minor group of amphibolites underlies parts of the southeastern and northwestern flanks of the belt where the amphibolites are associated with far more common biotite-hornblende gneisses and schists, which appear to be the source of most of the amphibole shown on plate 1. The amphibolites proper comprise hornblende gneiss and schist, which at many places are associated with schistose diorite and schistose gabbro. Some of the amphibolite was derived from mafic volcanic rocks deposited contemporaneously with the sedimentary rocks; some was formed from impure calcareous sedimentary rocks (Kesler, 1944, p. 770–771); and some was metamorphosed mafic intrusive rock younger than the host. The amphibolites, and calc-silicate rocks mentioned under biotitic paraschists and paragneisses, commonly contain sphene in both the core and the flanks of the belt. Presence of sphene in these rocks probably indicates that none reached the granulite grade of regional metamorphism (Ramberg, 1952, p. 73).

The dominant intrusive rock in the Savannah River-Catawba River segment of the Inner Piedmont belt is usually called granite or granite gneiss in recognition of its texture and gross mineral composition, but the rock is more commonly quartz monzonitic or granodioritic than granitic in composition (Mertie, 1953, p. 3). Most of the granitic rocks are gneissic and contain fewer wallrock inclusions than the nongneissic granitic rocks. In the core of the belt from the Catawba River southwestward to the vicinity of Spartanburg and Greenville, S.C., the dominant granitic rock is syntectonic quartz monzonite; thence, southwestward to the Savannah River syntectonic gneissic granodiorite dominates. Genetic relations, if any, between these rocks are unknown. The gneissic quartz monzonite and granodiorite form long sills and sheetlike masses parallel to the foliation of the enclosing schists. Locally, they form dikes and irregular discordant masses. Away from the sillimanitic core of the belt, these rocks, or ones like them, take on increasingly discordant habit. On the flanks of the belt, particularly the southeastern flank, nongneissic posttectonic granitic rocks form thick dikes and crosscutting plutons. West of Spartanburg and in the central part of Anderson County, S.C., discordant nongneissic granitic rocks occur in the core of the belt.

Gabbro and related mafic rocks form small generally circular intrusive masses at a few places in the belt. These mafic rocks are of at least two ages. The youngest ones are younger than the youngest granites but are older than diabase dikes of Triassic age. The older mafic rocks are older than the sedimentary and igneous rocks in the youngest eugeosynclinal sequence and are probably related to the middle sequence. They tend to be deformed and altered. Sparse syenite and syenite pegmatite, especially pegmatite rich in phlogopite and zircon, are genetically related to the mafic rocks of the youngest sequence. They are found locally in northeastern Catawba County, N.C., and in parts of Greenville, Spartanburg, and Abbeville Counties, S.C.

The core of the Inner Piedmont belt in the segment between the Savannah and Catawba Rivers is pervaded by myriads of stringers of granitic and pegmatitic material which thread through the paraschists and paragneisses, but such extensive migmatization is not present on the flanks. However, large dikes of late muscovite-bearing pegmatite are present along the flanks, particularly in the northeastern and southwestern parts of the segment. At none of the other areas investigated for monazite, except possibly the Flint River area, is there an equally well-developed migmatitic complex at the core of the belt.

MONAZITE

The distribution of monazite in concentrates from fluvial sediments in small streams in the segment of the Inner Piedmont belt between the Savannah and Catawba Rivers is shown by isograms on plate 3. The percentage of monazite in concentrates rises from the flanks of the belt, where concentrates generally contain from less than 1 percent to 10 percent monazite, to the core of the belt, where concentrates generally have 10–30 percent monazite and, locally, have as much as 60 percent. The regional coincidence between the 10-percent isogram for monazite and the 1-percent isogram for sillimanite is exceedingly close throughout the Savannah River–Catawba River area, except in Laurens County, S.C. The main patterns of monazite isograms show the same tendency to group into two major areas that was shown by isograms for sillimanite, rutile, and garnet (pl. 2). One area extends from the vicinity of Spartanburg northeastward to the Catawba River, and the other extends southward from the Paris Mountain region to Abbeville County. The regionally concordant trend between the distribution of monazite and that of sillimanite, rutile, and garnet probably resulted from the formation of monazite through processes of regional metamorphism in pelitic sediments (Overstreet, Cuppels, and White, 1956; Overstreet, 1960; Overstreet, 1962, p. 161–162).

The distribution of monazite is remarkably persistent and systematic in the Savannah River–Catawba River area, but zircon, which is contributed to the concentrates very largely, but by no means wholly, by the granitic rocks and pegmatites (Overstreet, Yates, and Griffitts, 1963b, table 1), has a spotty and discontinuous distribution (pl. 4). If the monazite was derived principally from the granitic rocks, its distribution might be expected to resemble that of zircon more than that of sillimanite.

Placer monazite from occurrences inside the area bounded by the 1-percent isogram for sillimanite is richer in thorium oxide (ThO_2) than monazite from the area outside the isogram (pl. 5). The 53 analyses of placer monazite from streams draining the area inside the 1-percent isogram for sillimanite contain an average of 5.83 percent ThO_2, and the 15 samples from streams draining the area outside the 1-percent sillimanite isogram contain an average of 5.27 percent ThO_2. This relation agrees with the world-wide condition that monazite from migmatites at the sillimanite-almandine subfacies is somewhat richer in thorium (5.7 percent for 61 analyses) than monazite from migmatites at the kyanite-staurolite subfacies (5.3 percent for 29 analyses; Overstreet, 1960, 1965a).

Many analyses accompanying the old literature about Carolina monazite show thorium oxide between 0.12 and 6.54 percent (Nitze, 1895, p. 677). These analyses often were made on concentrates containing as much as 67 percent monazite; thus, they do not show the amount of thorium in monazite. Rather similar results were obtained from semiquantitative spectrographic analyses made in 1952 and 1953 by C. S. Annell, Joseph Haffty, E. E. Valentine, and H. W. Worthing, of the U.S. Geological Survey, on 140 concentrates from placers in the Inner Piedmont belt. Several of the concentrates were from parts of the belt to the northeast or southwest of the Savannah River–Catawba River area, but they are included here for convenience of presentation. Of the 140 concentrates, 127 contain monazite (table 5). Thorium was detected in 91 of the monazite-bearing concentrates of which 84 were from the Savannah River–Catawba River area (pl. 5). Thorium is in the range X0.0 to X.0 percent in 40 concentrates; X.0 to 0.X percent in 37 concentrates; and 0.X to 0.0X percent in 14 concentrates. The most thorium-rich concentrates are from the part of the core of the Inner Piedmont belt between Spartanburg, S.C., and the Catawba River, N.C., where concentrates commonly contain 20 percent or more monazite (pl. 3).

Monazite from crystalline rocks in the core of the Inner Piedmont belt near Shelby, N.C., has a wider range in percentage of thorium oxide than monazite from the placers, but the mean content is about the same. Analyses by K. J. Murata and H. J. Rose, Jr., of the U.S. Geological Survey, of 126 samples of pure monazite from the crystalline rocks showed 2.1–11.2 percent ThO_2 and an average of 5.5 percent (Overstreet, Yates, and Griffitts, 1963b, table 4).

The amount of uranium in the monazite was ignored in the older literature on the placers, and reports as late as 1944 (Lefforge and others, 1944) on the placers in North Carolina do not include analyses for uranium. By 1953, however, analyses for uranium had been made, and J. B. Mertie, Jr. (1953, p. 12), showed that uranium oxide (U_3O_8) in monazite from 53 placers in North Carolina, South Carolina, and Georgia ranged in abundance from 0.18 to 0.98 percent. Analyses made by the U.S. Bureau of Mines on monazite from 19 fluviatile deposits in North and South Carolina showed 0.30–0.80 percent U_3O_8 (Griffitts and Overstreet, 1953a, p. 16; 1953b, p. 10; 1953c, p. 25; Hansen and White, 1954, p. 21; Hansen and Cuppels, 1954, p. 21; 1955, p. 18; Hansen and Caldwell, 1955, p. 16; Hansen and Theobald, 1955, p. 24). The average abundance of U_3O_8 in placer monazite as reported by Mertie is 0.38 percent, and as given by the U.S. Bureau of Mines is 0.52 percent. The distribution and values of analyses for U_3O_8 made on monazite from placers between the Savannah and Catawba Rivers, S.C.-N.C., are shown on plate 5.

Eleven samples of monazite from crystalline rocks in Cleveland and Rutherford Counties, N.C., contained 0.057–2.34 percent U_3O_8 (Overstreet, Yates, and Griffitts, 1963b, table 5). Of these 11 samples, 10 had 0.057–1.48 percent U_3O_8, with an average of 0.54, which is nearly identical with the average value obtained by the U.S. Bureau of Mines for U_3O_8 in placer monazite from North and South Carolina. Monazite having 2.34 percent U_3O_8 comes from quartz monazite in the northeastern part of the Savannah River–Catawba River area. It is the most uranium-rich monazite reported from the United States (Overstreet, 1967).

Commercial requirements call for 65 percent total rare earths plus thoria in monazite and exact a penalty on the price of lower grade material. Of the scores of analyses of monazite from the southeastern United States, particularly on material from the Savannah River–Catawba River area, only 29 analyses show the combined rare earths and thoria in mechanically pure monazite. These 29 analyses show that the placer monazite meets the commercial minimum of combined rare earths plus thoria. The regional average abundance of the total rare earths plus thoria in the placer monazite is about 68.4 percent, of which we estimate 62.8 percent is rare earths and 5.6 percent is thoria.

Two early analyses of monazite from North Carolina listed by Pratt (1916, p. 27) give 68.75 and 70.34 percent total rare earths plus thoria. Mertie (1953) reported that 20 samples of monazite from North and South Carolina contained 65–71 percent rare earths plus thoria, with an average tenor of 68.23 percent. Seven analyses made by H. J. Rose, Jr., of the U.S. Geological Survey, on monazite from saprolite in Cleveland and Rutherford Counties, N.C., show 64.04–69.00 percent total rare earths plus thoria (Murata and others, 1957, p. 148). The average of the seven analyses is 67.48 percent. Thus, of 29 samples of monazite from the center of the former monazite-mining region in the Caro-

TABLE 5.—*Mineral composition, in percent, of spectrographically analyzed concentrates from fluvial monazite placers in the southeastern United States*

[Mineral analyses by R. M. Berman, Jerome Stone, M. N. Girhard, H. B. Groom, Jr., R. P. Marquiss, J. P. Owens, L. A. Weiser, M. E. Morisawa, C. J. Spengler, and E. J. Young, U.S.Geol. Survey. Tr., trace; leaders indicate not present]

Field No.	Laboratory No.	State and county	Stream	Monazite	Ilmenite	Rutile	Garnet	Zircon	Sillimanite	Magnetite	Tourmaline	Staurolite	Amphibole	Quartz	Epidote	Others
		North Carolina														
51-JW-37	62611	Cleveland	Maple Creek	1	14	2	6	----	74	1	----	----	1	1	----	----
39	62614	do	Grassy Branch	5	33	Tr.	6	Tr.	5	Tr.	3	8	Tr.	40	----	Tr. hematite.
61	64046	do	Big Harris Creek	7	63	3	4	3	11	----	1	----	----	8	----	----
97	64082	do	Beaverdam Creek	9	57	1	14	Tr.	3	1	Tr.	----	----	15	----	----
99	64084	do	Hickory Creek	4	34	----	22	----	6	2	3	----	----	29	----	----
51-KR-23	62677	do	Buffalo Creek	10	42	1	20	2	5	2	Tr.	----	----	17	----	1 kyanite.
48	64171	do	do	22	38	2	14	2	4	----	2	----	----	16	----	----
63	64187	do	do	12	43	1	19	----	9	1	Tr.	Tr.	----	15	----	----
80	67754	do	Crooked Run	37	39	Tr.	5	3	4	----	----	----	----	12	----	----
84	67761	do	do	17	60	Tr.	11	1	1	----	----	----	----	10	----	----
86	67763	do	Buffalo Creek	5	71	1	8	Tr.	4	Tr.	Tr.	Tr.	1	10	----	----
109	67786	do	Wylie Branch	3	27	1	31	Tr.	10	4	Tr.	4	4	16	----	----
111	67788	do	Buffalo Creek	3	41	Tr.	2	Tr.	----	24	----	12	----	18	----	----
116	67793	do	Jakes Branch	Tr.	67	Tr.	5	Tr.	----	Tr.	Tr.	14	----	14	----	----
118	67795	do	Beason Creek	Tr.	72	----	6	1	----	Tr.	----	2	----	19	----	----
51-OT-71	62651	do	Brushy Creek	27	36	3	10	1	12	1	----	----	----	10	----	----
89	64102	do	Adams Branch	9	39	----	1	2	2	42	Tr.	Tr.	----	5	----	----
93	64106	do	Knob Creek	11	46	Tr.	14	----	1	12	----	----	----	16	----	----
107	64120	do	Little Knob Creek	16	50	Tr.	9	----	6	3	Tr.	Tr.	----	16	----	----
166	67717	Gaston	Lick Fork Creek	6	70	3	1	----	7	1	----	----	7	5	----	----
		South Carolina														
213	71226	Cherokee	Boween River	8	26	----	21	Tr.	Tr.	5	----	14	----	14	----	12 kyanite.
		North Carolina														
51-PK-12	63985	Cleveland	Sandy Run	9	65	2	8	1	5	1	----	----	----	9	----	----
45	64020	do	do	13	65	2	7	1	3	Tr.	----	----	----	9	----	----
53	64028	do	do	21	55	2	8	1	2	2	Tr.	----	----	9	----	----
59	67640	do	Ashworth Creek	25	47	Tr.	6	4	5	Tr.	----	----	----	13	----	Tr. biotite.
66	67647	Rutherford	Suck Creek	10	51	2	4	1	17	1	2	----	----	12	----	----
74	71013	do	Cane Creek	13	31	----	1	14	----	21	----	----	2	4	14	----
91	71030	McDowell	do	4	35	----	1	4	----	9	----	----	5	31	11	----
123	71062	Rutherford	Puzzle Creek	22	55	----	11	2	1	Tr.	----	----	----	9	----	----
131	71070	do	Webbs Creek	13	60	----	2	1	2	1	----	----	----	21	----	----
137	71076	do	Mill Creek	21	42	Tr.	5	2	10	1	----	----	----	19	----	----
142	71081	do	Little Camp Creek	----	29	----	Tr.	3	----	26	----	----	9	19	14	----
145	71084	do	Camp Creek	2	30	----	2	8	----	38	----	----	3	8	9	----
158	71097	do	Second Broad River	3	27	----	4	1	----	49	0.5	0.5	3	10	2	----
166	71105	do	do	2	21	----	8	1	----	49	----	Tr.	3	12	4	----
177	71120	do	Hollands Creek	2	15	----	----	14	----	51	----	----	1	15	2	----
180	71123	do	Catheys Creek	1	24	----	2	2	2	9	----	----	21	22	17	----
187	71130	do	do	4	27	----	1	11	----	35	----	----	2	16	4	----
226	7117[illegible]	do	Prices Branch	21	50	Tr.	7	----	3	1	2	----	----	16	----	----
233	71186	do	Hopper Mill Creek	33	26	1	12	2	1	6	----	----	----	19	----	----
245	71198	do	Floyds Creek	15	45	Tr.	8	2	5	1	3	----	----	21	----	----
		South Carolina														
52-PK-22	90575	Cherokee	Stratt Creek	9	48	----	4	----	1	1	----	----	----	37	----	Tr. kyanite.
42	90[illegible]5	do	Morgan Creek	3	31	3	15	----	8	2	2	3	----	32	----	1 kyanite.
128	109546	do	Thicketty Creek	7	53	4	9	----	1	1	----	----	----	25	----	----
142	None	do	Little Thicketty Creek.	1	45	2	12	Tr.	1	1	Tr.	----	----	37	----	1 kyanite.
151	109559	do	Goucher Creek	1	44	Tr.	----	Tr.	Tr.	9	Tr.	5	2	25	12	1 hematite, 1 spinel.
		Georgia														
174	110754	Oconee	Barber Creek	8	63	7	2	4	Tr.	2	----	----	----	14	Tr.	----
198	110776	do	McNutt Creek	13	48	1	2	3	Tr.	4	----	----	Tr.	26	----	3 hematite.
269	110846	do	Rose Creek	2	48	Tr.	2	1	1	20	----	----	----	22	Tr.	4 hematite.

NOTE.—Sample 52-PK-65 (98833), Cherokee County, S.C., Cherokee Creek, lost in laboratory after spectroscopy.

		North Carolina														
52-WE-23	81232	Rutherford	Richland Creek	10	32	1	6	1	3	5	8		Tr.	34		
39	81248	do	Cleghorn Creek	7	28	Tr.	Tr.	Tr.	Tr.	35			2	28		
55	81264	do	Mountain Creek		13		Tr.	1	Tr.	70			Tr.	10	4	2 hemaitite.
65	81274	do	do	13	44	Tr.	6	Tr.		17			Tr.	20		
70	82790	do	do	12	45		1	3		26			1	12		
79	82799	do	do	1	9		1			67		Tr.	1	21	Tr.	Tr. xenotime.
104	82824	do	Cove Creek	1	50		11			28		Tr.	2	7	1	Tr. kyanite, Tr. xenotime.
132	82852	Polk	Greens Creek	8	44		6	6		16			1	18	1	
156	82876	do	Walnut Creek	1	57		11			5			1	25	Tr.	
161	88412	Rutherford	White Oak Creek	2	34		Tr.	8		7			3	36	10	
170	88421	McDowell	Second Broad River	1	17		3	Tr.		39			2	34	4	
200	88444	do	South Muddy Creek	16	39		Tr.	20		7					18	
217	88461	do	do	7	28		6	2		12			8	29	8	
218	88462	do	do	6	45		4	5	1	22			3	13	1	
235	90667	do	North Muddy Creek	4	44		9	2		20			1	17	2	1 kyanite.
308	90750	Burke	Silver Creek	2	37		9	4		16			3	16	13	
311	90753	do	Hunting Creek	Tr.	34		2	4		6			8	22	24	
373	98687	do	Double Creek	20	62	Tr.		Tr.	5	Tr.	Tr.			13		
446	98750	Surry	Fisher River		76		6	1		3		Tr.		14	Tr.	
509	98810	do	Stewarts Creek		80		6	4		1				9		
524	98825	do	Ararat River		78		5			1				16	Tr.	
536	110212	do	Toms Creek	Tr.	54	Tr.	3	2	Tr.	24		4	Tr.	9	3	1 hematite, Tr. kyanite.
550	110226	Stokes	Big Creek		34	Tr.	5	Tr.	Tr.	41	1	6	2	9	1	1 kyanite.
595	110274	Burke	Henry Fork River	6	53	1	21	1	2	2	1	Tr.	3	9	1	
701	110387	Catawba	Jacob Fork River	6	61	Tr.	19	2	1	3	1	2		4	1	Tr. hematite.
741	110427	do	do	2	47	1	2	5	5	8	1	1	3	22	3	
833	110695	do	Lyle Creek	3	69	1	3	3	Tr.	16				1	Tr.	Tr. hematite, 4 kyanite, Tr. xenotime.
845	110706	do	Mountain Creek	1	41	Tr.	Tr.	Tr.		21	Tr.	27	Tr.	4	3	3 sphene.
		South Carolina														
52-DC-26	82888	Anderson	Weems Creek	3	48	Tr.		Tr.		27			2	20		
61	82925	do	Mountain Creek		10			2		68				20	Tr.	
84	82948	do	Little Beaverdam Creek.	Tr.	65		3	Tr.		9			1	19	3	
93	82953	do	Six and Twenty Mile Creeks.	Tr.	69	Tr.	Tr.	Tr.		21				8	2	
149	88251	do	Cuffie Creek	1	80		Tr.	1		15				3		
165	88267	do	Twenty-three Mile Creek.	1	86		Tr.	Tr.		7				6		
175	88276	Oconee	do	3	85	Tr.	4	1		4				3		
181	88282	do	Big Beaverdam Creek.	4	71		5	Tr.	1	2				17		
199	88298	do	Coneross Creek	1	10		Tr.			79				10	Tr.	
202	98968	Anderson	Eighteen Mile Creek	Tr.	37		1	1		50			2	8	1	
233	88309	do	Wilsons Creek	2	42	Tr.		2		40				14	Tr.	
253	99007	do	Big Beaverdam Creek.	Tr.	40		3	Tr.		38			1	17	1	
298	99047	do	Broadway Creek	1	80		1	3		5				10	Tr.	
323	99071	do	Hen Coop Creek		85		3	2		2	1			5	2	
354	99100	Abbeville	Little River	4	76	6	1	1	3	1				8		
377	99122	Anderson	Broadmouth Creek	21	73		1	1	Tr.	2				1	1	
402	99147	do	Big Creek	8	77		3	1	2	Tr.			2	7		
500	99245	Greenville	Grove Creek	1	74		4	3		16				2	Tr.	
544	99289	do	Huff Creek	11	71	1	4	1	1	2				9		
573	109738	do	Horse Creek		41					3				54	2	Tr. hematite.
586	109751	do	Laurel Creek	18	44	1	19	2	6	2	Tr.			7	1	
635	109800	Laurens	South Rabon Creek	10	63	2	5	1		6			4	7	1	1 xenotime.
649	109814	do	North Rabon Creek	6	55		1	Tr.		32			Tr.	6	Tr.	Tr. hematite, Tr. xenotime.
697	109862	Abbeville	Hogskin Creek	24	50	Tr.	3	6	1	12				4	Tr.	Tr. hematite, Tr. xenotime.
		Georgia														
710	110860	Troup	Yellow Jacket Creek	4	32		1	1		55		Tr.	1	4	1	1 hematite.
730	110880	do	Long Cane Creek	Tr.	27		2	Tr.	1	53	Tr.	Tr.	2	11	Tr.	4 hematite, Tr. spinel.
777	110927	Harris	Flat Shoal Creek	4	77	2	Tr.	3		2	Tr.			12		Tr. xenotime.
783	110933	do	Mountain Creek	2	70	1	2	3	3	Tr.	2	1	Tr.	4		11 kyanite, 1 spinel.
790	110940	Spalding	Flat Creek	11	64	3		Tr.		11				11		
795	110945	do	Shoal Creek	Tr.	31	Tr.			Tr.	57				12	Tr.	
804	110954	do	Heads Creek	Tr.	37		Tr.			54		Tr.	Tr.	6	1	2 hematite.

TABLE 5.—*Mineral composition, in percent, of spectrographically analyzed concentrates from fluvial monazite placers in the southeastern United States*—Continued

Field No.	Laboratory No.	State and county	Stream	Monazite	Ilmenite	Rutile	Garnet	Zircon	Sillimanite	Magnetite	Tourmaline	Staurolite	Amphibole	Quartz	Epidote	Others
		North Carolina														
52-DC-844	110998	Lincoln	Pott Creek	4	39	1	16	4	10	7	Tr.	Tr.	1	13	1	4 hematite, Tr. kyanite.
853	111007	do	Clark Creek		41		Tr.	1	2	8		37	3	7	1	
864	111018	do	Indian Creek	3	43	5	22	4	8	9		Tr.	Tr.	6	Tr.	Tr. kyanite.
		South Carolina														
52-CS-51	82645	Spartanburg	South Pacolet River	5	40		2	1		43	Tr.		Tr.	8	1	
54	82648	do	Alexander Creek	5	7		Tr.	Tr.		74	Tr.		Tr.	14		Tr. sphene.
92	82688	do	North Pacolet River	Tr.	21		Tr.	4		1	4		8	37	25	
113	82709	do	Buck Creek	12	70	2	3	5	1	2				5	Tr.	
123	82719	do	do	45	39		6	1	1					8		
138	82736	do	Hines Creek	10	56		14		Tr.	1				19		
160	82760	do	Cherokee Creek	8	30	1	25		4	10				22		
167	82768	do	Peters Creek	10	52	Tr.	11	1	14				1	11		
186	88318	do	Island Creek	14	49	Tr.	17	1	3	2			Tr.	12		2 hematite.
224	88356	do	Richland Creek	2	58		2			19			3	16		
258	88390	do	Beaverdam Creek	4	59		2	1	1	19			Tr.	14		
281	90409	do	Lawson Fork Creek	5	27		1	Tr.		50				16	1	
331	90466	do	do	14	36		23	1	3	8				15		
355	90490	do	North Tyger River	5	36		3	2	1	27			Tr.	24	2	
406	90541	do	Dutchman Creek	Tr.	70			2		25				3	Tr.	
437	109901	do	North Tyger River		17	Tr.	Tr.	1	Tr.	66				14	1	1 hematite, Tr. spinel.
446	109910	Greenville	Middle Tyger River	Tr.	31	Tr.	Tr.	8		49				6	5	1 hematite.
479	109941	do	South Tyger River	Tr.	32		10	Tr.	Tr.	33	1			13	8	3 hematite.
534	109997	Spartanburg	Ferguson Creek		33			Tr.		57				6	2	2 hematite, Tr. sphene.
578	110041	Greenville	Mountain Creek		31	Tr.	53		4	2	3			7	Tr.	
597	110060	do	Brushy Creek	6	84	Tr.	5	1	1	1	Tr.	Tr.	Tr.	2	Tr.	
642	110113	do	Gilder Creek	4	46	4	17	1	11	1	2	3	2	8	1	
726	110204	Laurens	Warrior Creek	1	62	Tr.	Tr.	1	Tr.	29	Tr.		Tr.	4	Tr.	3 hematite.
734	110510	do	South Durbin Creek	2	64	Tr.	Tr.	Tr.	1	19			Tr.	11	3	Tr. hematite.
		North Carolina														
757	110533	Cleveland	Wards Creek	12	59	1	14	Tr.	1	3	1	2	Tr.	6	Tr.	Tr. hematite, 1 xenotime.
760	110536	do	Duncans Creek	25	41	Tr.	22	2	1	2	Tr.			7		
802	110579	do	First Broad River	7	47	Tr.	22	1	Tr.	2			3	16	2	
52-0T-37	81138	do	Hinton Creek	18	44	5	14	Tr.	4	2	Tr.			13		Tr. kyanite.

linas, only 1 sample is slightly below the commercial minimum for combined rare earths plus thoria.

The monazite from crystalline rocks analyzed by Rose (Murata and others, 1957, p. 148) averages 59.0 percent cerium earths (La_2O_3, CeO_2, Pr_6O_{11}, Nd_2O_3, Sm_2O_3) and 1.9 percent yttrium earths (Gd_2O_3, Y_2O_3). In placer monazite the regional averages are estimated to be about 61.0 percent for the cerium earths and 1.8 percent for the yttrium earths. Some addition of the yttrium earths to commercially prepared monazite concentrates would come from xenotime, the tetragonal phosphate of the yttrium metals, which commonly accompanies the monazite in the Savannah River–Catawba River area. Xenotime from Rutherford County, N.C., is reported in an old analysis quoted by Palache, Berman, and Frondel (1951, p. 690) to contain 56.81 percent yttrium earths, 0.93 percent La_2O_3, a trace of ThO_2, and 4.26 percent U_3O_8. In the same table, Palache shows 64.97 percent yttrium earths in xenotime from the South Mountains, N.C., a group of hills at the junction of the boundaries of Rutherford, Cleveland, Burke, and McDowell Counties. A recent partial analysis of xenotime from Rutherford County gives 0.20 percent ThO_2 and 1.40 per cent U_3O_8 (Griffith and Overstreet, 1953c, p. 20). In commercial practice xenotime probably would be separated with the monazite despite its somewhat greater magnetic susceptibility, and the theoretical result would be to increase slightly the amount of the yttrium earths and uranium and to diminish slightly the percentages of the cerium earths and thorium in the monazite concentrate. The practical effect on the composition of the monazite concentrate by admixture of xenotime in the small proportions ordinarily observed in the placers would be negligible.

The semiquantitative spectrographic analyses of 140 concentrates (samples listed in table 5) show that the cerium earths are predominant over the yttrium earths in the Inner Piedmont belt (table 6). The concentrates consist of mixtures of monazite, ilmenite, garnet, zircon, sillimanite, magnetite, and quartz, and small amounts of rutile, tourmaline, amphibole, biotite, epidote, sphene, kyanite, staurolite, and hematite. Of the 140 concentrates, 111 have 1–45 percent monazite, 15 have less than 1 percent monazite, and 13 have no monazite (table 5). Among the cerium metals detected spectrographically, lanthanum, cerium, neodymium, and samarium were found in, respectively, 131, 127, 132, and 102 concentrates. Gadolinium, ytterbium, and yttrium were detected in 70, 138, and 135 concentrates. The cerium metals occur predominantly in the range X.0 to 0.0X percent, whereas the common range in abundance for the yttrium metals is 0.X to 0.00X percent. The presence of cerium and yttrium metals in some monazite-free concentrates is shown by the appearance of lanthanum, cerium, neodymium, ytterbium, and yttrium in more than the 127 monazite-bearing samples. The monazite-free concentrates are also barren of xenotime. Thus, the rare earths in some of the monazite-free concentrates may be attributed in part to the local appearance of rare-earth-bearing minerals like fergusonite, gadolinite, and euxenite, which have been observed in Carolina placer concentrates by Sloan (1908, p. 129–142) and Pratt (1916, p. 39), or to thorite and unidentified radioactive opaque minerals reported by Hansen and White (1954, p. 15), Hansen and Cuppels (1954, p. 17), and Hansen and Theobald (1955, p. 18). In part, possibly mainly, the rare earths in the monazite-free concentrates are in silicates like zircon,

TABLE 6.—*Relative amounts of the cerium and yttrium earths in concentrates from the Inner Piedmont belt*

[Compiled from semiquantitative spectrographic analyses made by C. S. Annell, Joseph Haffty, K. E. Valentine, and H. W. Worthing, U.S. Geol. Survey]

Element	Number of occurrences of each metal in each range (percent indicated)						Total number of occurrences of each metal
	Plus x0.0	x.0–x0.0	0.x–x.0	0.0x–0.x	0.00x–0.0x	0.000x–0.00x	
Cerium earths							
Lanthanum		6	73	47	5		131
Cerium	1	22	84	20			127
Praseodymium			32	15			47
Neodymium		4	88	40			132
Samarium		1	51	49	1		102
Europium				3			3
Yttrium earths							
Gadolinium		1	22	47			70
Terbium				6			6
Dysprosuim				28	13		41
Holmium			1	4	1		6
Erbium				10			10
Ytterbium				9	110	19	138
Yttrium		1	75	50	8	1	135

garnet, epidote, and emphibole (Rankama and Sahama, 1950, p. 524; Murata and others, 1957, p. 149). The same sources are responsible for part of the rare earths observed in the analyses of the monazite-bearing concentrates. The analyses show that no significant concentration of the rare earths plus thorium is found outside the monazite-rich concentrates. Therefore, they support the observation that monazite is the only ore for thorium and rare earths in the Savannah River–Catawba River area.

YADKIN RIVER-DAN RIVER AREA, NORTH CAROLINA-VIRGINIA

The Yadkin River–Dan River area, North Carolina–Virginia, is in the Inner Piedmont belt about 40 miles northeast of the Catawba River. Rocks of lower metamorphic rank than those in the Savannah River–Catawba River underlie the Yadkin River–Dan River area, and monazite is sparse and patchily distributed (Stose, 1928; Davis and Goldston, 1937, 1940; Hunter and White, 1946; Mundorff, 1948, pl. 1; Griffitts, Jahns, and Lemke, 1953, fig. 60; Overstreet and Griffitts, 1955, p. 561–564; Stuckey, 1958; Bryant and Reed, 1961).

Sheared gneiss and schist of the Brevard belt passes northeastward along the northwestern edge of the belt near Mount Airy, Surry County, N.C. (fig. 1), and separates crystalline rocks of the Inner Piedmont belt from schist, gneiss, and granite of the Blue Ridge belt (Bryant and Reed, 1961, fig. 316.1). The Brevard belt conforms closely to the northwestern edge of a zone of staurolite-bearing muscovite schist in the Yadkin River–Dan River area. This schist and isogradic staurolite-free biotitic rocks of the staurolite-kyanite subfacies make up the core of the Inner Piedmont belt; sillimanite is virtually absent. Rocks of the sillimanite-almandine subfacies do not reach the Yadkin River–Dan River segment of the Inner Piedmont belt. They extend northeastward from the Savannah River–Catawba River area to a point in northwestern Yadkin County about 2 miles south of the Yadkin River (Hunter and White, 1946, map). There the grade of regional metamorphism at the core of the Inner Piedmont belt declines to the staurolite-kyanite subfacies. The western flank of the belt is cut off in the Yadkin River–Dan River area by the Brevard fault zone, but on the eastern flank of the Inner Piedmont belt the metamorphic grade declines to the greenschist facies. The tectonic framework of the Inner Piedmont belt in the Yadkin River–Dan River segment may be extremely complex, with the possibility that much of the area is an overthrust plate of Inner Piedmont rocks (Bryant and Reed, 1961, p. D62).

The dominant rocks in the Yadkin River–Dan River segment of the Inner Piedmont belt are fine-grained layered, biotite gneiss and biotite schist probably derived from pelitic sediments. Amphibole schists and gneisses are present locally and at places are richly garnetiferous. Pyroxenite is associated with hornblende gneiss in the southeastern part of the district. Quartzite in which bedding is preserved forms conspicuous ridges and knobs in the eastern part of the district. The quartzite is interpreted by Bryant and Reed (1961, p. D62) to be Cambrian(?) in age and to underlie an overthrust plate of Inner Piedmont schist and gneiss. Sericitic phyllite, garnetiferous muscovite schist, and biotite schist are common in the northern part of the area. Massive granite and gneissic granite crop out at many places, but pegmatite is scarce, and migmatitic rocks resembling those in the Savannah River–Catawba River area are not present in the Yadkin River-Dan River area.

The monazite appears to be associated principally with crosscutting bodies of mesozonal leucogranodiorite (Dietrich, 1961, p. 10) that occur in the staurolite-kyanite subfacies rocks east and south of Mount Airy. A very little monazite is derived from schist and gneiss underlying quartzite exposed in the main thrust-plate window (Bryant and Reed, 1961, fig. 316.2) east-southeast of Mount Airy. Dietrich (1961, p. 10) reports that the monazite in the leucogranodiorite is generally surrounded by epidote, which seems to be replacing the monazite. Apatite and sphene also seem to replace monazite in this rock. These relations were interpreted by Overstreet (1967), as possibly resulting from lack of stability of magmatic monazite under conditions of mesozonal emplacement. Incomplete reaction between monazite and the magma were inferred to have led to partial replacement of monazite by epidote, apatite, and sphene. Where the reaction was complete, monazite was eliminated as a mineral phase in the rock. Present patchy distribution of the monazite may relate to variations in the completeness of the reaction. Relations of monazite in the schist and gneiss underlying the quartzite are unknown.

The composition of monazite from the Yadkin River-Dan River area is not known. Possibly the amount of thorium in it is less on the average than it is in monazite from the Savannah River–Catawba River area.

Five concentrates (table 5) from the area were analyzed spectrographically, and thorium was below the limit of detection (0.1 percent). Inasmuch as four of the concentrates were monazite free, and one contained less than 1 percent monazite, the spectrographic results confirm the mineralogic study in showing that thorium minerals are rare in the crystalline rocks and streams in the Yadkin River–Dan River area.

OCONEE RIVER AREA, GEORGIA

The Oconee River area, Georgia (fig. 1), is in the Inner Piedmont belt about 45 miles southwest of the Savannah River. It is flanked on the northwest by the Brevard belt. Underlying the Oconee River segment of the Inner Piedmont belt are highly metamorphosed sedimentary rocks into which granites and pegmatite have been introduced to produce a complex of injection gneiss and migmatite (Stose and Smith, 1939; Parizek, 1953, p. 24–30; 1955; Overstreet and Griffitts, 1955, p. 564). The geologic map of Georgia (Stose and Smith, 1939) shows that rocks in the Oconee River area are mainly biotite gneiss and biotote schist. A small body of massive granite is shown in the gneiss and schist in Clarke County west of Athens. A large mass of the same kind of granite is shown along the northwestern part of the area in Barrow and Jackson Counties, and a different type of granite is shown at the southeastern edge of the area in Oglethorpe County. The granite near Athens was found by Parizek (1952, oral commun.; 1953, fig. 3; 1955) to be larger than the State map indicates. It underlies most of Clarke County and widens toward the south. It is massive with gneissic or flow-banded margins. Inclusions of garnetiferous cordierite-bearing biotite-muscovite schist are common, and, where flow banding is present, the inclusions are oriented parallel to the banding. The wallrocks consist of biotite schist, biotite-muscovite schist, biotite gneiss, sillimanite schist, and minor hornblende gneiss.

The granite in Clarke County contains monazite, zircon, rutile, tourmaline, and magnetite (Mertie, 1953, p. 21; Parizek, 1953, p. 25), but the granite in Barrow and Jackson Counties on the northwestern flank of the area and the granite in Oglethorpe County on the southeastern flank of the area was found in the present investigation to be monazite free. Heavy-mineral suites from the granites along the margins of the area differ markedly from each other and from the suites typical of the granite in Clarke County. Gneissic phases of the granite in Barrow and Jackson Counties give concentrates with abundant magnetite, some zircon, and no monazite; massive phases of the rock are the source of virtually monomineralic zircon concentrates. The granite in Oglethorpe County gives concentrates consisting almost entirely of magnetite with scant zircon and no monazite. Each of these concentrates is very large in volume in contrast to the small suites from the monazite-bearing granite in Clarke County.

The sillimanite core of the Inner Piedmont belt persists southwestward from the Savannah River through the Oconee River area. Sillimanitic schists and gneisses are common in Clarke and Oconee Counties in the core of the belt. They are flanked to the northwest in Barrow and Jackson Counties and to the southeast in Oglethorpe County by epidote- and magnetite-rich rocks locally containing staurolite and kyanite.

Monazite is associated with sillimanitic biotite schists and gneisses and with granite containing inclusions of sillimanitic and cordierite-bearing schists in the core of the belt. The composition of monazite from streams in the Oconee River segment of the Inner Piedmont belt is not known. Two concentrates containing 8 and 13 percent monazite (table 5) were analyzed spectrographically and found to have 0.X percent thorium. A third concentrate having only 2 percent monazite had thorium below the limit of detection. This percentage of thorium resembles that found for many monazite-bearing concentrates from the Savannah River–Catawba River area. Possibly monazite from the Oconee River area has about 5 percent ThO_2.

FLINT RIVER AREA AND CHATTAHOOCHEE RIVER AREA, GEORGIA

The monazite-bearing segments of the Inner Piedmont belt in the drainage basins of the Flint River and Chattahoochee River, Ga., are, respectively, 120 miles and 160 miles southwest of the Savannah River (fig. 1). Sillimanite-bearing rocks are uncommon. Where present, they form narrow cores bounded to the north and south by epidote-bearing and kyanitic biotite schists and gneisses. Staurolite schists are virtually absent. The most common detrital minerals derived from the crystalline rocks are magnetite, ilmenite, and garnet, which are of scant aid to an interpretation of the regional metamorphism.

The northern edge of the Flint River monazite area is about 30 miles southeast of the Brevard belt, and the southern edge is defined by the Towaliga fault (Stose and Smith, 1939; Crickmay, 1952, p. 49; Clarke, 1952, pl. 3). The area is underlain by a large mass of biotite-muscovite granite intrusive into biotite gneiss and schist. Monazite has been reported from the granite (Mertie, 1953, p. 20–21), and it occurs in fluvial sediments in streams on schist and gneiss to the south and east of the granite in the area between Griffin, Spalding County, and Zebulon, Pike County. Monazite has not been found in Pike County south of the Towaliga fault, nor has it been found in streams in Spalding County north or west of Griffin.

Monazite from granite in Spalding County was reported to contain 4.42 percent ThO_2 and 0.26 percent U_3O_8 (Mertie, 1953, p. 12). One spectrographic analysis of a fluviatile concentrate which contained 11 percent monazite (table 5) disclosed 0.X percent thorium, and two other analyses of concentrates having only a trace of monazite failed to show thorium but thereby indicated that monazite is the thorium-bearing detrital mineral in the area.

The northern edge of the monazite-bearing area in the Chattahoochee River segment of the Inner Piedmont belt is 15 miles southeast of the Brevard belt, and the southern edge is for the most part the Towaliga fault (Hewett and Crickmay, 1937, pls. 1, 2; Stose and Smith, 1939). Very little monazite was found in streams south of the fault. Hewett and Crickmay (1937, p. 31) describe the Towaliga fault as separating kyanitic rocks on the south from more highly metamorphosed rocks on the north. The monazite-bearing rocks north of the fault are fine- to coarse-grained granite gneiss, biotite gneiss, biotite schist, and hornblende-biotite gneiss. They are intruded by weakly foliated biotite granite which is coarser grained than the gneisses. Locally, the granite, gneisses, and schist are intruded by pegmatite.

Monazite has been reported from granite and granite gneiss in Meriwether and Troup Counties in the Chattahoochee River area (Mertie, 1953, p. 21–22). It is more commonly present in streams on biotite gneiss and schist than in streams on the granite. A little monazite in several streams south of the Towaliga fault is of uncertain origin. It may have come from kyanitic mica schist south of the fault, or it may be recycled detrital monazite that originated in the crystalline rocks north of the fault.

The composition of monazite from the Chattahoochee River area is not known. A fluviatile concentrate from Troup County having 4 percent monazite (table 5) was analyzed spectrographically and found to contain 0.0X percent thorium. Another concentrate having only a trace of monazite had too little thorium to be detected.

MONAZITE IN CRYSTALLINE ROCKS

The distribution of monazite in crystalline rocks in the Inner Piedmont belt was not studied in this investigation, but it was examined in reconnaissance by J. B. Mertie, Jr. (Mertie, 1953). Its distribution in one quadrangle in the belt has also been investigated in detail (Overstreet, Yates, and Griffitts, 1963b). Data for the following discussion are drawn largely from the detailed work.

ABUNDANCE RELATED TO ROCK TYPE

The amount of monazite in a given type of crystalline rock was found by Mertie and by Overstreet and others to vary widely along and across the strike, and variations in the amount of monazite within one rock mass were found to be as great as variations between separate masses of the same kind of rock. A wide overlap was observed between the range in amount of monazite in one type of rock and the range in other types, but the average amount of monazite was discovered to be clearly greater in quartz monzonite and sillimanite schist than in biotite schist (Overstreet, Yates, Griffitts, 1963b, table 1):

Rock (Gives percentage of area underlain by rock and number of samples)	*Monazite (weight percent [1])*
Sillimanite schist (underlies 30 percent of area):	
Maximum (out of 150 [2])	0.06
Average (out of 110 [3])	.002
Biotite schist (underlies 62 percent of area):	
Maximum (out of 198)	.008
Average (out of 107)	.001
Biotite gneiss (underlies 1 percent of area):	
Maximum (out of 59)	.06
Average (out of 47)	.006
Toluca Quartz Monzonite (underlies 7 percent of area):	
Maximum (out of 96)	.04
Average (out of 93)	.004
Microcline-oligoclase-quartz pegmatite (underlies less than 1 percent of area):	
Maximum (out of 329)	.08
Average (out of 289)	.006

[1] Recalculated from volume percentage in reference.
[2] Number of samples examined for monazite; maximum for each rock type is similarly obtained.
[3] Number of samples found to contain monazite; average for each rock type is similarly obtained.

The actual importance of the different rocks as sources for monazite depends on their areal distribution as well as the frequency with which monazite occurs in them and its abundance where present. In the segments of the Inner Piedmont belt between the Savannah and Catawba Rivers, S.C.–N.C., and Oconee River, Ga., the source rocks for monazite, in order of decreasing contribution to placers, are: sillimanite schist, granitic rocks (quartz monzonite, pegmatite, granite, granodiorite), biotite schist, and biotite gneiss. In the Yadkin River–Dan River area, North Carolina–Virginia, and in the Flint and Chattahoochee River areas, Georgia, the granitic rocks and biotite gneiss are the chief sources for monazite, and the schists are minor sources. An average of 0.006 percent monazite was found by Mertie (1953, p. 15, 28) for 175 samples of monazite-bearing granitic rocks in the Southeastern States. The value is identical with the average found for pegmatite in the Shelby quadrangle, but it is about three times greater than the possible regional average for all monazite-bearing rocks, which may be about 0.002 percent monazite.

Hornblende gneiss, hornblende schist, and diorite are rare in the Shelby quadrangle, but where they are present, they are barren of monazite. Whatever monazite is present in streams draining areas underlain by hornblendic rocks in the Inner Piedmont belt is inferred by us to have come from intercalated layers of biotite schist and sillimanite schist or from intrusive granitic rocks.

The amount of monazite in the crystalline rocks is too low to permit direct mining of the rock for monazite, although this was attempted at two localities in Cleveland County, N.C.: the Campbell mine of the British-American Monazite Co. on Hickory Creek about 3 miles northest of Shelby and the F. K. McClurd mine near Carpenter Knob (Pratt, 1901, p. 31; Sterrett, 1907, p. 1204–1205; Keith and Sterrett, 1931, p. 10).

At the Campbell mine, monazite was recovered for several years from migmatitic biotite schist which had an average of about 0.4 percent monazite and a range of about 0.03 to 1.1 percent. After several years of mining the operation closed in 1907 because the grade of the ore declined. When work stopped, the mine consisted of a shallow and irregular quarry 5–20 feet deep, 24–75 feet wide, and 450 feet long. Records of output have not been published, but it would seem from the size of the opening and the reported grade of ore that the production may have been nearly 100 tons of monazite. At the McClurd property weathered pegmatite-impregnated biotite schist that contained 0.3 pound of monazite per cubic yard was sluiced with placer gravel (Sterrett, 1908, p. 281). The amount of monazite thus produced probably was not large, but records are not available. No area is known in the investigated parts of the Inner Piedmont belt where monazite might be mined successfully from the crystalline rocks.

THORIUM RELATED TO ROCK TYPE

The amount of thorium in monazite related to type of source rock in the Inner Piedmont belt has been examined only for the area of the Shelby quadrangle, North Carolina (Murata and others, 1957; Overstreet, Yates, and Griffitts, 1963b, table 4), but the results seem to be valid for the belt as a whole (Overstreet, 1967). The range in amount and average abundance of thorium oxide (ThO_2) was found from analyses by Murata and associates, of the U.S. Geological Survey, to vary with the type of rock. Monazite from metamorphosed sedimentary rocks (biotite schist and sillimanite schist) has less ThO_2 than monazite from quartz monzonite and pegmatite (Overstreet, Yates, and Griffitts, 1963b, table 4):

Source rock for monazite	Number of analyses	ThO_2 in monazite [1] (percent)	
		Range	Average
Biotite schist	31	2.1– 6.9	4.8
Sillimanite schist	16	3.4– 9.0	4.8
Biotite gneiss	9	3.7– 8.8	5.4
Toluca Quartz Monzonite	23	4.3– 8.8	6.1
Pegmatite	43	3.8–11.2	6.1
Quartz vein	1	----------	6.1

[1] ThO_2 determined with quantitative spectrochemical methods by K. J. Murata and H. J. Rose, Jr.

These results fit the general pattern for distribution of thorium oxide in monazite from igneous rocks, metamorphic rocks, and veins (table 7). This pattern shows that monazite from synkinematic granitic rocks and pegmatite contains more thorium oxide than monazite from associated metamorphosed sedimentary rocks, and that monazite from high-grade metamorphic rocks has more ThO_2 than monazite from low-grade metamorphic rocks (Overstreet, 1960, table 27.1; 1967). In areas in the Inner Piedmont belt outside the Shelby quadrangle the amount of thorium oxide in detrital monazite declines as the grade of regional metamorphism becomes less (pl. 5).

RELATION TO ASSOCIATED MINERALS IN PLACERS

The relation between monazite and associated heavy minerals in placers in the Inner Piedmont belt is shown by the isogram maps for the Savannah River–Catawba River area (pls. 1–4). The relation is directly attributable to the variety of crystalline rocks in the distributive province of a placer and to the depositional environment. A summary of the influence of sources on the suites of placer minerals is given in table 8.

Fluvial concentrates from headwater placers in areas underlain by sillimanite schist contain sillimanite and commonly more ilmenite than concentrates derived from other sources. Garnet is abundant in streams draining areas of synkinematic quartz monzonite and some gneisses. Monazite-bearing concentrates from streams in hornblende gneiss have large amounts of magnetite, ilmenite, amphibole, and epidote. Many gold-bearing concentrates have come from areas in or bordering hornblende gneiss. Muscovite schist and sericitic phyllite locally are the source of staurolite. Farther from the headwaters where the area of the distributive province is large, the source rocks are heterogeneous, and sorting action of the stream has had greater play; therefore, simple relations between source rocks and placers no longer obtain. Once introduced into the stream, the more readily transported accessory minerals, such as epidote, staurolite, kyanite, and sillimanite, persist downstream. Coarser grained monazite tends to lag near the source areas, and fine-grained monazite is dispersed downstream with the more readily transported heavy minerals. The relations among the heavy minerals are then best explained by reference to the unconsolidated sediments in which they are deposited instead of the source rocks from which they came.

ORIGIN OF MONAZITE BELT

Monazite in the granitic rocks and pegmatite of the Inner Piedmont belt in North and South Carolina was originally thought to have formed as a primary acces-

TABLE 7.—*Amount of thorium oxide in monazite according to source rock of monazite*

[Adapted from Overstreet, 1967]

Source of monazite	Number of analyses	ThO_2 (in percent)		
		Least	Greatest	Average
Metamorphosed pelitic and arenaceous sedimentary rocks:				
Greenschist facies	3	0.00	1.09	0.4
Albite-epidote-amphibolite facies	1	----	----	3.07
Amphibolite facies:				
Middle and upper subfacies	6	3.3	6.1	5.0
Upper subfacies	60	2.1	9.0	4.9
Granulite facies	13	5.28	12.37	8.9
Metamorphosed calcareous sedimentary rocks:				
Greenschist facies	1	----	----	.2
Amphibolite facies:				
Middle and upper subfacies	2	[1]	[1]	1.05
Migmatites:				
Amphibolite facies:				
Middle subfacies	1	----	----	6
Upper subfacies	8	4.8	12.6	8.2
Metamorphosed pelitic and arenaceous sedimentary rocks and migmatites intruded by granitic rocks:				
Amphibolite facies:				
Lower to middle subfacies	1	----	----	4
Middle subfacies	20	3.20	7.28	5.3
Middle and upper subfacies	8	5.0	7.1	6.1
Upper subfacies	53	2.3	8.0	5.7
Upper subfacies and granulite facies	52	5.0	11.0	8.1
Granulite facies	1	----	----	14.3
Igneous rocks:				
Diorite	1	----	----	6.6
Granodiorite	2	2.74	±4	3.4
Unclassified granitic rocks	14	1.99	10.05	5.2
Granitic rocks ranked by grade of metamorphism of wall rocks:				
Greenschist facies	1	----	----	.47
Epidote-albite-amphibolite facies	1	----	----	6.8
Amphibolite facies:				
Lower and middle subfacies	40	2.2	6.9	4.2
Middle and upper subfacies	43	4.1	9.4	6.0
Upper subfacies	92	2.48	13.66	6.0
Upper subfacies of amphibolite facies and granulite facies	1	----	----	7.8
Cassiterite- and wolframite-bearing granitic rocks:				
Granodiorite and granite	3	2	7.29	3
Granite	58	.00	10.80	3.9
Aplite	2	.94	6.2	3.5
Pegmatite ranked by grade of metamorphism of wallrocks:				
Greenschist facies	2	2.25	3.91	3.1
Greenschist facies or albite-epidote-amphibolite facies	5	10.7	19.4	15.7
Albite-epidote-amphibolite facies or lower subfacies of amphibolite facies	2	5.53	6	5.8
Middle subfacies of amphibolite facies	28	3.38	22.29	8.5
Middle and upper subfacies of amphibolite facies	6	5.1	7.1	5.8
Upper subfacies of amphibolite facies	109	.41	31.50	7.8
Cassiterite-, wolframite-, and columbite-bearing pegmatite	42	1.63	17.0	7.7
Alkalic rocks:				
Nepheline syenite	1	----	----	[2]
Carbonate and related volcanic rocks	14	.00	4.4	1.8
Veins, alteration zones, and vugs:				
Epithermal veins	1	----	----	.2
Mesothermal veins and alteration zones	3	.18	2.5	1.4
Hypothermal veins and alteration zones	16	.16	8.0	3.4
Vugs in hypothermal veins	2	.00	1.48	.7
Druse in marble	1	----	----	.05

[1] Unreported in source. [2] Very low.

sory mineral, whereas the monazite in the schists and gneisses was attributed to impregnation from granitic intrusives (Mezger, 1896, p. 823; Nitze, 1897, p. 128; Pratt, 1903, p. 180–181; Graton, 1906, p. 117; Sterrett, 1908, p. 284–285). The restricted occurrence of monazite in a belt in the western Piedmont was well known to the early writers, but they did not explain why monazite was in these rocks and generally absent from far larger masses of granite in the central part of the two States. The localized occurrence of monazite in belts, of which the one in the Inner Piedmont is most conspicuous, was seen by J. B. Mertie, Jr., to be a fundamental factor in the origin of monazite in the Southeastern States. Preliminary statements by Mertie (1953, p. 29–30; 1955;

1956; 1957; 1958, p. 4) suggest that the monazite belt in the Inner Piedmont and the belts discovered by him in the eastern part of the Piedmont and in the Blue Ridge were sites of Precambrian sedimentation, not necessarily active at the same time, in which concentrations of detrital monazite formed when ancient Precambrian monazite-bearing source rocks were eroded. These monazite placers were thought by Mertie to have been later reconstituted by heat and pressure into metamorphic rocks. Some sedimentary material and possibly some of the original source rocks were thought to have been locally melted to form monazite-bearing intrusive rocks. Mertie emphasized that the three belts contain many varieties of monazite-free rocks. He also showed that the belts are not geologic formations and that they cut across the strike of known stratigraphic units. The monazite belts are inferred by Mertie to be the traces of monazite-enriched sedimentary basins, and the grains of monazite are inferred to be principally relict detrital particles that have withstood regional metamorphism (Mertie, 1953, p. 29–30). The reader is referred to the original papers for a discussion of Mertie's dominant concepts that original detrital heavy minerals persist from the sedimentary cycle through the metamorphic cycle, and that their original basins of sedimentary deposition exert control over the present geographic distribution of monazite-bearing rocks.

The results of the present investigation on placers, coupled with results from study of the monazite-bearing crystalline rocks in the Shelby quadrangle (Overstreet, Yates, and Griffitts, 1963a, b), led to an interpretation of the origin of monazite fundamentally different from the one proposed by Mertie. This new interpretation regards the belts of monazite-bearing crystalline rocks as defining zones of regional metamorphic climax in which much of the monazite formed as a metamorphic mineral derived from components available in average shale and sandstone. The composition of the monazite relates to the grade of regional metamorphism. Detrital concentration of monazite is not regarded as a precondition for the localization of the monazite belts. The three belts identified by Mertie are here thought to have formed in three orogenic episodes, and each belt is believed to be associated with a different culmination, progressively younger toward the east. The belt in the Blue Ridge is interpreted to have formed during Precambrian time, the belt in the Inner Piedmont, in the Ordovician, and the belt in the eastern Piedmont, in late Paleozoic time. This interpretation provides a way to predict the occurrence and composition of monazite in crystalline rocks elsewhere in the world. General aspects of the interpretation were given earlier (Overstreet, Cuppels, and White, 1956; Overstreet, 1960). The interpretation is fully developed in a report on the geology of monazite (Overstreet, 1967). The reader is referred to that report for a discussion of the origin of monazite in the crystalline rocks in the Inner Piedmont belt.

TABLE 8.—*Relation of heavy minerals in headwater placers to source rocks*

[H, greater than 20 percent of concentrate; M, 5 to 20 percent of concentrate; L, trace to 5 percent of concentrate; R, absent or rare grains]

Rock underlying distributive province	Area where observed	Monazite	Zircon	Ilmenite	Magnetite	Rutile	Garnet	Amphibole	Kyanite-sillimanite	Staurolite	Epidote	Gold
Sillimanite schist rich in granite.	Savannah River–Catawba River, S.C.–N.C.	H	L	H	L	L	H	R	H	R	L	R
Biotite schist rich in granite.	do	H	L	M	L	L	H	L	L	R	L	R
Granitic rocks and pegmatite.	do	H	L	L	L	L	H	R	L	R	L	R
Sillimanite schist	do	M	R	H	L	L	H	R	H	R	R	R
Biotite schist	do	M	L	M	L	L	H	L	L	R	R	R
Do	Yadkin River–Dan River, N.C.–Va.	L	L	H	M	L	M	L	L	L	L	R
Biotite gneiss	Savannah River–Catawba River, S.C.–N.C.	H	M	L	M	L	H	L	L	R	R	R
Do	Chattahoochee River, Ga.	M	L	M	L	L	H	L	L	R	L	R
Biotite gneiss and granite.	Oconee River, Ga.	M	L	H	M	L	L	R	L	R	R	R
Biotite quartz monzonite	Flint River, Ga.	M	L	H	L	R	L	R	L	R	R	R
Hornblende schist and gneiss.	Savannah River–Catawba River, S.C.–N.C.	L	R	H	H	L	M	H	L	R	H	L
Muscovite schist and sericite phyllite.	Yadkin River–Dan River, N.C.–Va.	R	R	M	M	R	M	R	L	H	L	R
Quartzite	Chattahoochee River, Ga.	R	R	H	L	R	R	R	R	R	R	R

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UNCONSOLIDATED RESIDUAL AND SEDIMENTARY DEPOSITS

The unconsolidated residual and sedimentary deposits in the monazite-bearing areas of the Inner Piedmont belt are saprolite, colluvium, and fluvial terrace, fan, and flood-plain sediments. Saprolite is untransported residual material preserving the structures of the source rock, and colluvium is eroded material showing scant evidence of abrasion or sorting which has been deposited along hillsides and the foot of slopes before reaching streams (Kesler, 1950, p. 24). Unconsolidated sedimentary deposits formed by the stream transport and accumulation of eroded material consist principally of flood-plain sediments which mantle the valley floors. Terrace deposits and alluvial fans are not very common in the monazite areas. Saprolite and colluvium contain eluvial monazite placers, and the flood-plain deposits, alluvial fans, and terraces contain the fluviatile monazite placers. Fluviatile placers in the flood plains constitute the main resource of monazite in the area.

SAPROLITE

Crystalline rocks of all ages and types in the Inner Piedmont belt have undergone profound chemical weathering which has converted them to saprolite. Weathering is deepest on rocks rich in plagioclase feldspar and on strongly jointed or foliated rocks. Apparently, the volume of the original rock was little changed by the weathering, but the specific gravity has been much reduced and the porosity greatly increased. The presence of etched grains of quartz shows that during weathering even silica was dissolved. Many accessory minerals, such as ilmenite, rutile, zircon, monazite, sillimanite, staurolite, epidote, and kyanite, are notably resistant to solution and are preserved among the products of weathering. Other accessory minerals, such as garnet, apatite, and allanite, are more or less soluble and tend to be removed. Weathering tends to cause a convergence in the appearance of different kinds of rocks, so that the most thoroughly weathered rocks seem to be very similar despite differences in origin and original composition (Overstreet, Yates, Griffitts, 1963b).

Erosional processes in the southeast have not kept pace with the rate of chemical weathering of the crystalline rocks; consequently, extensive areas of saprolite are preserved. The term "saprolite" was proposed by Becker (1895, p. 289–290) as a general name for thoroughly decomposed earthy untransported rock in which the texture and structure of the original rock is preserved well enough to permit identification of the rock and to allow measurement of planar and linear features. No disparity is perceptible in structures mapped across alternate areas of saprolite and hard rock. The saprolite erodes so easily that surface outcrops, even on steep hillsides, show virtually no slump, but they may be covered by erosional debris that has moved downhill by mass wasting (Parizek and Woodruff, 1957, p. 63).

The typical color of undisturbed saprolite of all rocks near the surface of the ground is dark red. At depth, the original colors of leucocratic rocks are commonly well preserved in saprolite (White, W. A., 1944, p. 361), but melanocratic rocks change in color when converted to saprolite. Thus, biotite-rich schists and gneisses change from dark-gray fresh rock to bronzy or greenish-yellow saprolite, and dark-green or black hornblende-rich rocks change to yellow-brown or mustard-colored saprolite.

The average depth of saprolite over the Inner Piedmont belt is not known. The maximum reported depth is 185 feet logged in a water well near Cherryville, Gaston County, N.C. In many highway cuts, railroad cuts, and erosion gullies, saprolite 25–50 feet thick is exposed without baring unweathered rock. Pardee and Park (1948, p. 24) report that in most gold mines in the southeast, saprolite is less than 75 feet deep, but at a very few properties it extends 150 feet or more below the surface of the ground. A gradual lessening of the effects of weathering through a zone of several feet is reported (Pardee and Park, 1948, p. 24–27), but the break between weathered and unweathered rock can be remarkably sharp. Layers of unweathered rock may be completely surrounded by saprolite.

It is estimated that 95 percent of the surface area of the Inner Piedmont belt is underlain by saprolite, but the exact area of saprolite exposed, compared with the area of exposed unweathered rock, is unknown. For a small part of the belt, about 265 square miles in the Shelby quadrangle, North Carolina (Overstreet, Yates, Griffitts, 1963b), it is estimated that 90 percent of exposed rock is saprolite. In the mountainous parts of the belt the proportion of exposed hard rock is greater; thus, in the Yadkin River–Dan River area, North Carolina–Virginia, about 65 percent of the exposed rocks is saprolite. In the bottoms of valleys where erosion is vigorous, saprolite predominates over fresh rock. Of 417 auger holes drilled in flood plains in the Savannah River-Catawba River area, 83 percent bottomed in saprolite and 17 percent stopped on hard rock.

The upper surface of this saprolite is generally sharply defined from overlying colluvium and alluvium. It does not conform to the present topography. It is a surface of erosion, as shown by the unconformable superposition of sediments on saprolite at altitudes several tens of feet above present streambeds. Most of the original weathering profile has been removed by erosion; possibly the original weathering profile included at the top an amorphous mass of quartz-bearing red clay residuum, now largely lost. The base of the saprolite is very irregular and like the top does not conform to present land surfaces. Outcrops of unweathered rocks are thus not obviously related to the present topography.

The age of the saprolite is obscure. The presence of thick saprolite indicates that the area had a relatively stable base level for a long time, during which weathering may have been continuous. On the other hand, intermittent episodes of intensified regional weathering are indicated by disordered and leached parts of Coastal Plain formations to the east of the Piedmont. Inasmuch as saprolite has formed in the Piedmont on diabase dikes of Late Triassic(?) age, and beds of kaolinite in the Tuscaloosa Formation of Late Cretaceous age rest unconformably on saprolite of gneiss and schist (Lang and others, 1940, p. 31), the process must have begun before Late Cretaceous time and possibly after Late Triassic(?) time. Fom this time onward the Piedmont has been eroded to supply Cretaceous, Tertiary, and Quaternary detritus to the Coastal Plain. During this erosion, chemical attack of the crystalline rocks probably also proceeded, but it may have been more vigorous at some times than others. For instance, argillaceous and ferruginous residuum locally tens of feet thick on upper Eocene and Oligocene limestone in the Coastal Plain of Georgia (MacNeil, 1947) testifies to long periods of deep weathering in Tertiary time, but no correlation between this residuum and the Piedmont saprolite has been made. At least part, and probably most, of the saprolite in the Piedmont is older than carbonaceous colluvium of possible pre-Wisconsin age (Cain, 1944, p. 19–20). Local presence of cobbles of soft and crumbly granitic saprolite in quartz-cobble conglomerates in Recent fluvial deposits attests that the weathering process itself still continues. The cobbles of granitic saprolite are too friable to have survived transport and deposition with the associated quartz cobbles; therefore, the granite cobbles must have been converted to saprolite after the conglomerate was deposited. Recent weathering certainly can account for only a trifling part of the saprolite.

Particle size in typical saprolites of the Inner Piedmont belt from the drainage basin of Knob Creek, Cleveland County, N.C., was analyzed (fig. 5), and the mechanical composition of quartz monzonite and gneiss was found to be similar but to differ from that of schists. The median size of mineral particles in saprolite of quartz monzonite is 0.268 mm (8 samples), and the median size of particles in saprolite of biotite gneiss is 0.237 mm (7 samples). Particles in saprolites of sillimanite schist and biotite schist have, respectively, median sizes of 0.155 mm (10 samples) and 0.115 mm (4 samples). Distribution of particles in the schists is more strongly skewed toward fine sizes than it is in gneiss and quartz monzonite. Inasmuch as schists are the dominant rocks in the monazite-bearing part of the Inner Piedmont belt, this factor leads to great volumes of fine-grained sediments in the stream deposits.

The dominant grains in saprolite are quartz, relict feldspar, altered biotite, and clay minerals. Mechanical analyses show that about 10–20 percent of the weight of saprolite is clay, 60–75 is made up of particles 200-mesh in size or larger, and 15–20 percent consists of silt-sized grains. The silt is mostly fragments of altered biotite and subordinate quartz and other minerals. Grains above 200 mesh in size are mostly quartz and feldspar, but they also include the resistate heavy minerals in the saprolite.

Krumbein and Tisdel (1940, p. 301–304) discovered that data on the size of quartz grains from weathered crystalline rocks fit Rosin's law of crushing, and they speculated that the fit might indicate evidence of random breakage resulting from crushing during weathering. The fit for mechanically weathered rocks (gruss) was better than for chemically weathered rocks (saprolite). We have not applied Rosin's law to the size data from saprolite, but even if a close fit were found, it seems to us that the size of grains is a relict phenomenon preserved from the unweathered rock to the saprolite, as foliation and schistosity are preserved. In thin section, quartz grains in the crystalline rocks show common strain shadows, healed fractures, and cracks. Perhaps weathering frees the grains from support of the rest of the rock and the grains separate along the old fractures. The weathering would then reveal that the grains had been crushed, but it did not cause the crushing.

Size distribution of grains of resistate heavy minerals in concentrates from saprolite exposed in the drainage basin of Knob Creek, Cleveland County, N.C., is given in tabular form in a discussion of heavy minerals in saprolite of the Shelby quadrangle, North Carolina (Overstreet, Yates, Griffitts, 1963b, table 2). The distributions are biased by partial loss of extremely fine grained and coarse-grained particles during panning (Theobald, 1957, p. 9–23). Despite the bias introduced by the use of panning to make a concentrate, the diagrams clearly show that the coarsest grained concentrates are derived from saprolite of pegmatite, that the finest grained concentrates are from saprolite of the schists, and that concentrates with the greatest range in grain size are from saprolite of quartz monzonite. Monazite from pegmatite saprolite has the greatest range in grain size, and that from the schists and quartz

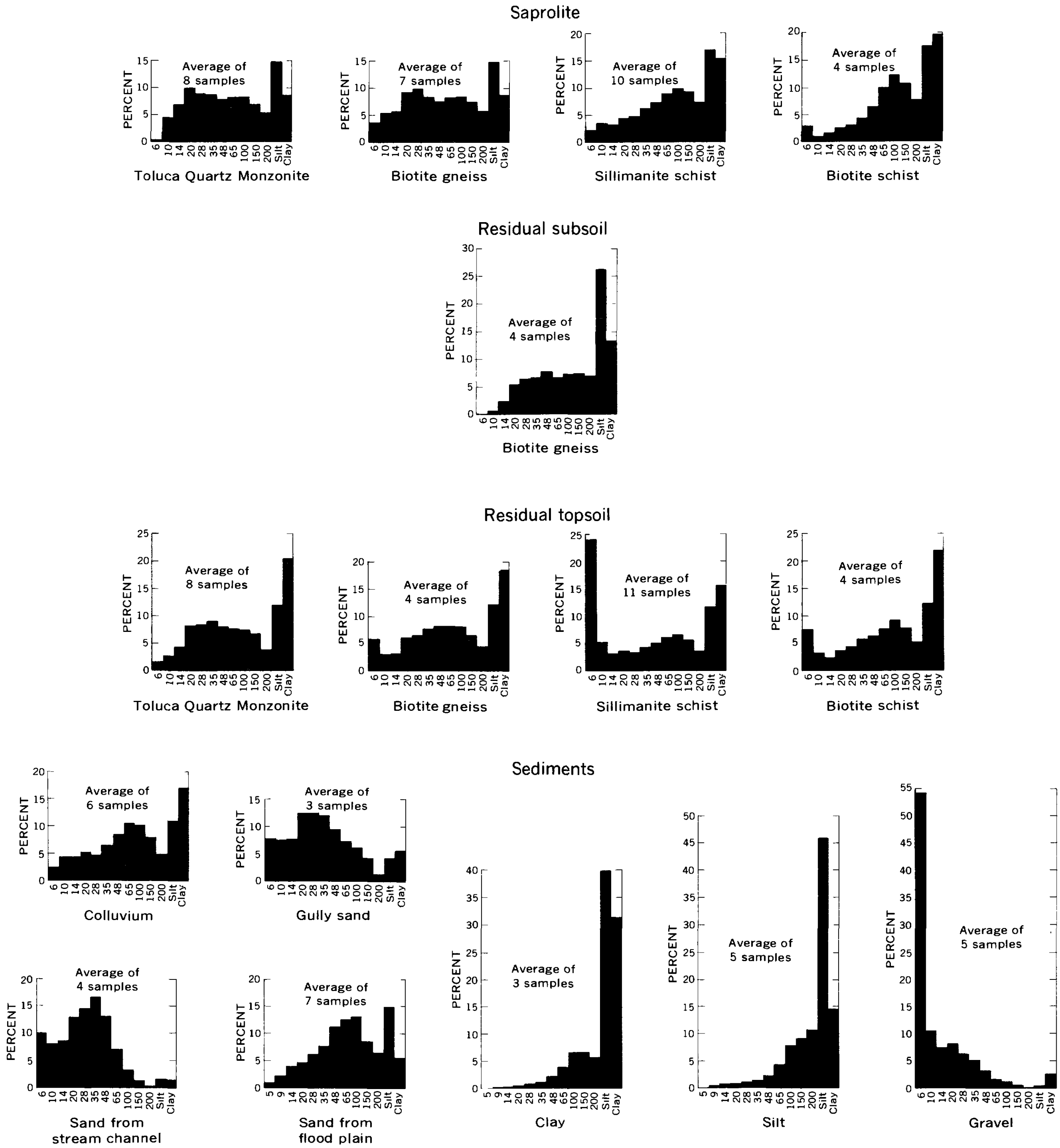

Figure 5.—Mechanical composition of weathered crystalline rocks, residual materials, and stream sediments in the area between the Savannah and Catawba Rivers, S.C.–N.C.

monzonite is fine grained. Ilmenite from pegmatite saprolite also displays the greatest range in grain size, and that from the schists tends to be smallest.

RESIDUAL SURFICIAL MATERIAL

Residual surficial material consisting of massive nonbedded mixtures of clay and sand or of silt-sized particles of quartz forms mantles 1–7 feet thick in some interstream areas in the Inner Piedmont belt. The material grades into saprolite without a clear break. It does not contain round grains, pebbles, or cobbles of quartz, but angular fragments of quartz rarely larger than pebbles are locally present. It appears to have developed by the disintegration in place of saprolite. The age of these residual deposits is not known.

The middle and lower parts of the residual material are finer grained than the upper parts (fig. 5, residual subsoil and residual topsoil) owing to the washing out of fine-sized particles other than clay from the subsoil and topsoil. This effect is especially noteworthy over saprolite of sillimanite schist where resistate nodular intergrowths of quartz and sillimanite are concentrated and add to the coarse fraction in the topsoil. A trend toward the concentration of the coarser sizes of heavy minerals, including monazite and ilmenite, in the topsoil is also attributable to the selective removal of the finest particles by surface runoff. Grain-size distribution among the heavy minerals in the residual subsoil more closely resembles the distribution in saprolite than does that of the heavy minerals in the residual topsoil.

TRANSPORTED SURFICIAL MATERIAL

Transported surficial material consisting of colluvium and alluvium unconformably overlies saprolite in the Inner Piedmont belt. The unconformity is profound. Saprolite at the top of the crystalline rocks is probably chiefly Late Cretaceous and Tertiary in age of formation. The crystalline rocks are mostly pre-Ordovician, but some are as young as Permian and Triassic(?); the transported surficial material is mainly Quaternary (Overstreet and Bell, 1962, 1965a). Within the surficial deposits, breaks in deposition occurred, but they are of small magnitude compared with the break between saprolite and transported surficial material.

COLLUVIUM

Unconsolidated surficial sedimentary materials of several ages unconformably overlying saprolite and unweathered crystalline rocks in the Inner Piedmont belt in North Carolina were described by Kerr as early as 1881 (Kerr, 1881, p. 347; Kerr and Hanna, 1888, p. 331). Kerr showed that some of the surficial deposits were not formed by streams, and he ascribed them to the action of frost during the Pleistocene. In an earlier report, Kerr described a bed of peat, 15 feet thick, at a locality 9 miles west of Morganton, Burke County, N.C. (Kerr, 1875, p. 157). Several small deposits of peat overlain by thick beds of clay were observed in Laurens County, S.C., by Sloan (1908, p. 362–364), who reported that the peat and clay rested on gneiss at an altitude of 120 feet above the bed of the nearest river. These deposits were thought by Sloan to be related to alluvium in the Lafayette Formation of former usage of Pleistocene age (Sloan, 1908, p. 476–480). The unconformity between the crystalline rocks and overlying nonalluvial deposits was diagrammed by Ireland, Sharpe, and Eargle (1939, p. 23), but the age of the deposits was not discussed. Eargle (1940) referred to these deposits as truncating saprolite and as having been formed by soil creep, earthflow, and slumping. Analyses of pollen in material from four exposures in Spartanburg County, S.C., were interpreted by Cain (1944, p. 12) to show a cooler climate than the one that presently prevails, to indicate that the material possibly formed during pre-Wisconsin time, and to reveal oscillations in the climate.

These transported nonfluviatile deposits are colluvium. The colluvium consists of poorly sorted and discontinuously bedded unconsolidated erosional debris derived principally from saprolite and less commonly from old stream sediments or unweathered rocks. Colluvium has been transported by sheet wash, soil creep, and frost action to the lower slopes of hills and to depressions, where it accumulates and reduces the grades of the slopes. It thins uphill. Excellent examples of colluvium are exposed in old gullies, ravines, and swales that have been reopened by erosion during the last 50 or 100 years. Colluvium is also exposed by many roadcuts, especially cuts through valley walls of watercourses. Several illustrations of colluvium in North Carolina are given by Kerr (Kerr and Hanna, 1888, figs. 1–16), and many in South Carolina are shown in photographs and maps by Ireland, Sharpe, and Eargle (1939).

A typical section of older colluvium consists of a basal layer of clayey gravel resting on saprolite or hard rock. This unit is overlain by muck which, in turn, is overlain by mixtures of bedded to unsorted sand and clay. The colluvium ranges in thickness from 10 to 30 feet. Gravel and muck rarely account for more than 15 percent of the total thickness. Such deposits may have formed in intermittently ponded depressions, possibly ancient gullies. At many places muck and gravel are absent, and bedrock is directly overlain by poorly sorted clay and sand. These sequences probably were formed in unponded depressions. The gully deposits lens out or grade into sheet-wash deposits up the flanks of adjoining hills but continue headward into, or near, present interstream divides, where they merge with sheet-wash debris and residual deposits. Older gully sediments are overlain unconformably or truncated by fluviatile deposits in the stream valleys.

Deposits formed by sheet wash and soil creep on the slopes of hills are the most widespread colluvial sediments. They have been observed in all five districts. Along the flanks of hills they unconformably overlie saprolite or hard rock. Locally, the base of deposits formed by sheet wash and soil creep is marked by a thin discontinuous layer of angular fragments of quartz having a few water-worn quartz pebbles and rare blocks of unweathered bedrock. This is the stone line (Sharpe, 1938). The few stream-worn pebbles are derived from small isolated older fluvial deposits at higher altitudes. Angular fragments of quartz and bedrock come from local sources. The overlying clayey sand commonly is unsorted, but it may be poorly and discontinuously bedded.

Deposits formed by sheet wash and soil creep lens out uphill or merge imperceptibly with residual deposits on the divides. Downhill they grade into and overlie colluvium in gullies, and they are truncated by, or lap upon, fluviatile deposits in the valleys. They probably range widely in age. Some appear to be as old as the oldest gully sediments; other deposits are clearly being formed by present accelerated erosion.

WISCONSIN(?) DEPOSITS

Colluvium and underlying vegetal debris are exposed in two erosion gullies on the Lattimore farm 2 miles north of Lawndale, Cleveland County, N.C. (fig. 6). The two gullies, called in figure 6 the North Gully and the South Gully, are situated on opposite flanks of a west-trending spur of the ridge that forms part of the divide between Knob and Maple Creeks. The gullies are extreme headwater tributaries of a small unnamed stream that flows south into Knob Creek. At their heads the floors of the gullies are about 80 feet above the bed of the small stream. According to local residents, the present gullies are more than 30 but less than 60 years old. They dissect colluvium that was deposited during several intervals in ancient gullies or other depressions that were as much as six times wider than the present gullies (see cross sections, fig. 6). The original North Gully has a steplike floor which rises headward in three benches, the lowermost of which is overlain by woody muck (see longitudinal section, fig. 6). The middle bench is overlain by silt which passes downhill over the muck and truncates its lower end, and the upper bench is covered with red-brown sandy silt which extends downhill over the other sediments. A description of the material exposed in the North Gully at cross section *W–W′* was prepared by C. S. Denny and H. E. Malde, of the U.S. Geological Survey (written commun., 1953). It is given in table 9.

The topographic position of the old North Gully high on a divide precludes its having been filled by fluviatile deposits; it was probably filled by slope wash and creep. Abundant clay, particularly clay mixed with angular pebbles, and the poor and disordered bedding in the gully-filling material indicate that the fill is colluvial. Probably the units that are now gray and white were originally colored like adjacent reddish-brown saprolite, but have been chemically reduced following deposition.

The sequence shown in table 9 was tentatively interpreted by Denny and Malde to have begun with exposure of the schist and formation of saprolite, after which the lower part of the original North Gully was formed by erosion. Units 2–4 were deposited, followed by soil formation in unit 4, as shown by the blocky structure and color mottling of the unit. Another period of erosion took place, during which much of the soil formed on unit 4 was lost. Following this erosion, unit 5 was deposited and soil formed on that unit, as shown by the humic horizon, concretions, and mottling. A new cycle of erosion, possibly initiated by cultivation, resulted in the loss of uphill parts of unit 5 and the deposition of unit 6.

The period of erosion preceding deposition of units 2–4 seems to be marked by the carving of the lowest bench in the North Gully, as shown on the longitudinal section in figure 6. Erosion preceding deposition of unit 5 is apparently shown by the truncation of the lower end of the muck and the formation of the floor of the middle bench shown in the longitudinal section. Per-

TABLE 9.—*Section of colluvium exposed in gully on Lattimore farm, Cleveland County, N.C.*

[Measured by C. S. Denny and H. S. Malde, U.S. Geol. Survey]

Top — Description	Depth (feet)
6. Silty sand, yellowish-brown, locally bedded; disturbed at top by plow, probably postcultivation	0–1.5
Sharp erosional contact.	
5. Clayey and sandy silt, quartz-bearing, mottled yellowish- and reddish-brown, massive; topped by a gray humic horizon passing into strong brown horizon below mottled with weakly cemented ferruginous concretions and darker manganiferous(?) splotches; thin layer of fine-grained gravel at base	1.5–4.5
Sharp erosional contact, wavy; relief as much as 2 ft.	
4. Clayey angular sand, sandy clay and silt; light gray becoming white at base; contains scattered granules and pebbles of sharply angular quartz near base; generally massive contorted bedding in places; upper 1.5 ft has blocky structure mottled gray, yellow, and brown; clay films and black manganese(?) stains along joints	4.5–12.5
Sharp to gradational wavy contact.	
3. Sandy clay; gray from disseminated carbonaceous material; contains pieces of carbonized and noncarbonized wood as large as 10 in. in diameter; peat and muck mixed with blue clay containing logs	12.5–16
Gradational contact.	
2. Quartz pebble and cobble gravel, pebbly clay; partly cemented by iron hardpan; includes sparse pieces of unweathered biotite schist; contact sharp, wavy	16–18
Unconformity.	
1. Saprolite of biotite schist and pegmatite	18

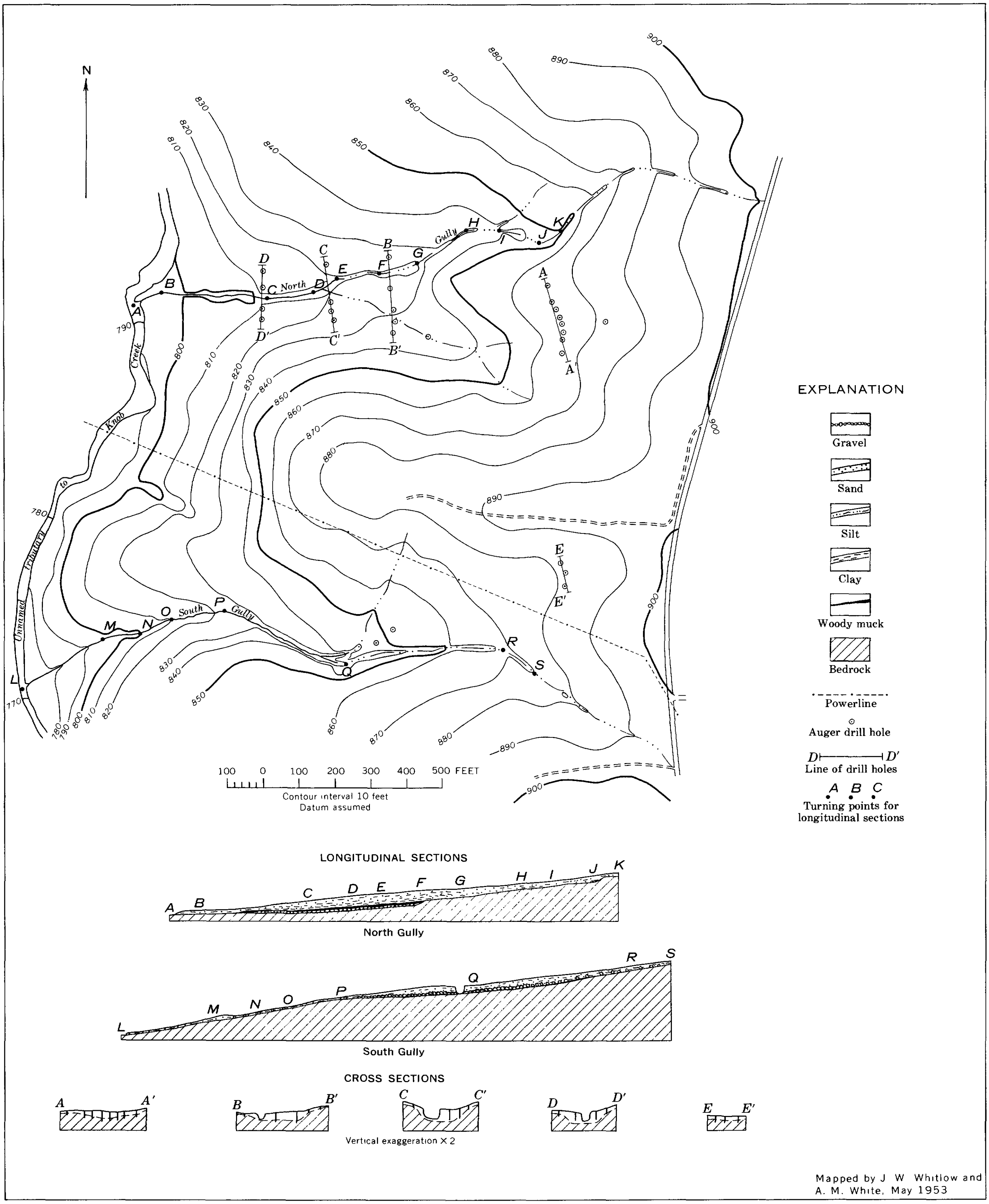

FIGURE 6.—Plane-table map and sections of two erosion gullies in the drainage basin of Knob Creek, Cleveland County, N.C.

haps the most recent cycle of erosion is shown by the uppermost bench on bedrock above the level of the middle bench. Similar headward erosion at three levels is not shown by the data from drilling in the South Gully, but a similar succession of colluvial deposits and soil profiles occurs there. The erosional benches seen in the North Gully seemingly are less persistent, even locally, than the sequential formation of soil profiles.

Wood (field No. 52–JW–326, lab. No. W28) from the base of unit 3 (16 ft below surface) was analyzed for carbon-14, by H. E. Suess, of the U.S. Geological Survey, in 1953 and found to be older than 30,000 years. The wood was examined in 1953 by R. W. Brown, of the U.S. Geological Survey, and was identified as *Tsuga* sp. (hemlock), but it was too poorly preserved to allow further classification.

Eleven samples of sedimentary materials exposed in the North Gully at cross section *B–B′* were examined for pollen by Professor E. S. Barghoorn, of Harvard University. Relation of the samples to the section shown in table 9 is given in table 10. Samples 53–OT–1 through 53–OT–6 were reported by Professor Barghoorn (written commun., 1954) to have sparse organic residue consisting of finely divided angular and amorphous fragments grading down to submicroscopic size, and to lack pollen. The organic content of sample 53–OT–7 was also observed to be low, but it consisted in small part of fair to poorly preserved pollen grains and triturated coalified organic particles. The microfossils were found to be mechanically broken, a feature interpreted by Professor Barghoorn to indicate deposition of the clay by creep and the operation of soil-forming processes. A remarkably high percentage of fern spores was observed in the sample (table 11). In samples 53–OT–7 and 53–OT–8 the herbaceous pollen was reported to be dominated by members of the Compositae, and remains of fungi and fungus spores were more numerous in sample 53–OT–7 than in 53–OT–8. Spruce-fir pollen is highest in sample 53–OT–8 of the entire section.

TABLE 10.—*Position of pollen samples in relation to stratigraphic sequence, North Gully, Lattimore farm, Cleveland County, N.C.*

Sample	Position of sample from surface of ground (feet)	Material sampled (refer to table 9)
53–OT–1	0– 1.5	Silty sand, brown; unit 6.
	2.5– 3.0	Clayey and sandy silt, mottled yellowish and reddish-brown, massive; unit 5.
	4.0– 4.5	Clayey and sandy silt, manganese-stained, nodular; base of unit 5.
	5.0– 6.0	Clay and clayey sand, mottled gray, yellow, and brown quartz-bearing, massive; zone of blocky structure at top of unit 4.
	7.2– 8.0	Clayey sand, gray, pebbly, massive; unit 4.
	9.5–10.5	Similar to 53–OT–5 but more micaceous; unit 4.
	11.7–12.1	Sandy clay, gray, massive; unit 4.
	12.1–12.5	Clayey sand, gray, massive; rests with sharp contact on underlying sample; unit 4.
	12.5–12.8	Clay, dark-gray, carbonaceous, massive; contains much mica; unit 3.
	15.0–16.0	Peaty clay, black, massive; contains rare quartz pebbles, logs common, source of sample 52–JW–326 used for carbon-14; base of unit 3.
	16.0–16.5	Sandy clay, bluish-gray, pebbly, massive; overlies quartz pebble and cobble gravel; top of unit 2.

Pollen was found by Professor Barghoon to be fairly abundant and fairly well preserved in sample 53–OT–9. However, many grains were broken and eroded; this indicates probable transport and possible redeposition from preexisting deposits. Fern spores were less common than in samples 53–OT–7 and 53–OT–8, a higher percentage of pollen from pine was present, the percentage of spruce-fir pollen was high, and the percentage of pollen from hardwood trees was significantly lower than in sample 53–OT–8.

Sample 53–OT–10 was reported by Professor Barghoorn to resemble closely in lithology sample 53–OT–9 but to have a higher organic content, including numerous fragments of twigs and coniferous bark closely resembling that of hemlock. The bark fragments were excellently preserved; they show no evidence of abra-

TABLE 11.—*Plant microfossils from sedimentary materials, North Gully, Lattimore farm, Cleveland County, N.C.*

[Pollen analyses by Professor E. S. Barghoorn, Harvard University, 1954]

Sample	Percentage of total arboreal pollen in—								Microfossils as percentage of arboreal pollen		
	Pinus	*Picea-Abies*	*Tsuga*	*Quercus*	*Carya*	Betulaceae	*Liquidambar*	*Ilex*	NAP [1]	Fern spores	Lycopod spores
53–OT–1 through 53–OT–6 [2]											
53–OT–7	70	3.4	1.4	10.3	14.3			1.4	34.2	119.8	8.0
–8	56.6	13.7	4.9	12.3	8.0	2.4	0.3		18.3	46.0	.3
–9	75.7	14.5	1.6	8.6	4.3		.2		25.8	25.6	2.1
–10 [3]	87.6	2.2		2.8	3.1	2.9	.2		19.1	6.3	1.1
–11 [4]											

[1] NAP, nonarboreal pollen.
[2] No microfossils present.
[3] Location of hemlock log 52–JW–326 dated as greater than 30,000 years by carbon-14 analysis by H. E. Suess, U.S. Geol. Survey.
[4] Microfossils too sparse for count.

sion or long-distance transport and indicate conclusively that coniferous trees were growing in the immediate vicinity of the gully. Organic matter other than pollen grains was said to be not significantly "coalified," which indicates that the accumulation took place below the water table and has not been exposed to aerobic soil conditions since deposition. Conditions of preservation of plant material in this sample resemble 53–OT–9.

Pollen was found by Professor Barghoorn to be extremely scarce in sample 53–OT–11. Three slides prepared of the organic material disclosed only two pine pollen grains. Other microfossils reported were 19 fern spores, 6 lycopod spores, and 14 grass-sedge pollen grains.

In his interpretation of the pollen record at the North Gully, made before either the carbon-14 analysis or figure 6 was available, Professor Barghoorn points out that the microfossil zone is truncated above and below and lies only in the levels 10.5–16.0 feet below the present land surface. Therefore, the record is not continuous to the present, and it is not possible to incorporate the data into a longer established column. The samples containing the microfossils (53–OT–7 through 53–OT–10, particularly 53–OT–9 and 53–OT–10) give the appearance of subaqueous deposition; the possibility exists, therefore, that the fossils may have been in part redeposited from preexisting sediments. Now that the gully has been mapped, this possibility seems more likely for samples 53–OT–1 through 53–OT–8 than for samples 53–OT–9 and 53–OT–10, but the extent to which the sedimentary materials may be reworked cannot be resolved at this one locality. A standard stratigraphic section of late Pleistocene age has not been worked out for this part of the United States. Except for a study by Cain (1944) of buried soil in Spartanburg County, S.C., and pollen analyses by D. G. Frey (1951, 1952) of sediments in the Carolina Coastal Plain, there were no descriptions of comparable deposits for correlation.

The transition in pollen content shown from samples 53–OT–10 through 53–OT–7 was interpreted by Professor Barghoorn to reflect a series of climatic and vegetational changes initiating a forest cover more comparable to modern flora in sample 53–OT–7 than in sample 53–OT–10. However, the pollen content of the uppermost pollen layer, represented by sample 53–OT–7, was interpreted as being unlike that which would be expected in this region at the present or during any time since the postglacial climate optimum (5,000–6,000 yr ago).

The evidence of the pollen, showing that the lower and more strongly developed of the two soil profiles observed in the North Gully is older than the postglacial climatic optimum, and the carbon-14 analysis, showing that the lowest organic debris in the section is older than 30,000 years, indicate that units 2–4 are probably no younger than late Wisconsin. The presence of a younger and less well developed soil profile in unit 5 apparently further indicates that units 2–4 are no younger than late Wisconsin; it may show that the lower units are older than that. Additional work is needed to establish the regional stratigraphic succession of Pleistocene surficial materials, but the exposure of colluvium in the gullies on the Lattimore farm show that in this part of the Piedmont a succession exists.

Colluvial sediments possibly older than those found in the gullies on the Lattimore farm are exposed on U.S. Route 64A in the vicinity of the head of Silver Creek, Burke County, N.C., and near the confluence of Cleghorn Creek and the Broad River, Rutherford County, N.C. These localities are terraces cut into saprolite and unweathered rocks at altitudes of 40–70 feet above the present grades of the streams. Pebble and cobble gravel of fluviatile origin forms a layer about 4 feet thick on the cut terraces. It is overlain by massive silt, sand, and clay about 21 feet thick. Layers of gravel are not present in the silt and clay, and other features indicating fluviatile deposition are also absent. A section of the exposure on U.S. Route 64A was described by C. S. Denny, of the U.S. Geological Survey (written commun., 1953), and is given here as table 12. A section from the exposure near the junction of Cleghorn Creek with the Broad River was described by H. E. Malde and C. S. Denny (written commun., 1963), of the U.S. Geological Survey (table 13). The sections can be interpreted to indicate that the formation of saprolite was followed by the deposition of gravel and colluvium and that the colluvium was deeply weathered. What interval of time is represented by the contact between the gravel (unit 2 in both sections) and the colluvium (table 12, units 3 and 4; table 13, units 3–5) is not known, but it must have been long enough for the streams which deposited the gravel to abandon it permanently. Following deposition of the colluvium, which probably accumulated by creep down the steep slopes which flank the gravel-covered terraces, was an apparently long period of weathering and soil formation. During this time the thick uniform dark-red color and clayey character formed in place in the upper part of the colluvium through the action of soil-forming processes on material like that in the lower units of the colluvial sequence. At the same time, the mottled color and black specks formed in the lower part of the sequence. The uniform dark-red color persists with no perceptible change in appearance to a depth of 15.5 feet in unit 4 at the locality on U.S. Route 64A near the head of Silver Creek. If unit 4 at Silver Creek (table 12) is correlative with the red clay (table 13, unit 5), at Cleghorn Creek, then the possibility exists that unit 5 at Cleghorn Creek was once much thicker than it is at present and that part of it has been removed by erosion. These dark-red soils seem to be the thickest and best formed soils in the Inner Piedmont belt. Correlation between them and the soils exposed in the gullies on the Lattimore farm has not been established, nor have pollen or carbon-14 analyses been made of organic materials associated with these soils; but it is possible that they are older than the Wisconsin(?) soils exposed in the gullies on the Lattimore farm, because they are deeper and their soil more completely formed.

TABLE 12.—*Section of colluvium exposed in cut on U.S. Route 64A near the head of Silver Creek, Burke County, N.C.*

[Measured by C. S. Denny, U.S. Geol. Survey]

Top	Description	Depth (feet)
5.	"Soil," dark colored	0–2
	Sharp contact.	
4.	Colluvium(?), silty, quartz-bearing clay, massive, uniform dark red; contains scattered pebbles	2–15.5
	Transition through 2 ft.	
3.	Colluvium(?), silty sand, massive; scattered pebbles; red at top, grades downward into mottled red and yellow	15.5–21
	Contact gradational.	
2.	Gravel, clay matrix, mottled red and yellow	21–25
	Contact sharp.	
1.	Saprolite.	

TABLE 13.—*Section of colluvium exposed near the junction of Cleghorn Creek and the Broad River, Rutherford County, N.C.*

[Measured by H. E. Malde and C. S. Denny, U.S. Geol. Survey]

Top	Description	Depth (feet)
6.	"Soil," black	0–1
	Contact sharp.	
5.	Colluvium(?), quartz-bearing red clay, massive; uniform color	1–7
	Transition through 2 ft.	
4.	Colluvium(?), quartz-bearing clay and clayey sand, massive; mottled red and yellow, black specks (manganese?)	7–17
	Transition.	
3.	Colluvium(?), clayey sand, yellowish-brown, mottled, bedded	17–20
	Contact sharp.	
2.	Gravel, clayey, pink and gray, bedded	20–23
	Contact sharp.	
1.	Saprolite of biotite gneiss	23

The deep-red soils in colluvium at Silver Creek and Cleghorn Creek have much the same color, texture, and depth of weathering as soils that in the northern States are observed to have formed on drift of pre-Wisconsin age. These soils are very different from younger soils. Whether this relation holds in the different climatic and vegetational zones of the Carolinas is not known (C. S. Denny and H. E. Malde, written commun., 1953). The rate of formation of deep-red soil may be much quicker in the Carolinas, where the material on which the soil formed was already weathered when it was deposited, than it is in the northern States; thus, analogy related to color and texture of the soil is inadequate as a basis for assigning an age to the materials in the Carolinas. The presence of soil profiles in colluvium and the occurrence of pollen-rich organic layers with some soils offer the means for interpreting the stratigraphic succession in the old surficial deposits, but detailed work of this sort was not done as part of the placer appraisal.

RECENT DEPOSITS

Colluvial deposits consisting of amorphous yellowish-brown to reddish-brown silty sand, sandy clay, and sand at least as much as 5 feet thick, constitute the top of the colluvial sequences at many places; they are present on most hillslopes. They rest in erosional contact with underlying colluvium or saprolite, and their upper surface is at the plowline, where they have been much disturbed by agricultural procedures. The deposits were formed by sheet wash and soil creep, and the uppermost parts of the deposits are being formed at an accelerated rate by these processes at present. In table 9 they are represented by unit 6.

In many places the upper parts of the colluvial deposits incorporate artifacts associated with present-day agricultural technology, or buried articles, such as pieces of barbed wire, machine-made nails, and sawed planks, which were introduced into the area since 1800. These sediments are here called agricultural to distinguish them from underlying but also Recent sediments of preagricultural age. They merge and interfinger with fluviatile sediments at the margins of flood plains. Along the valleys of some streams formerly mined for monazite, abandoned tailing piles adjacent to or on the hillslopes are partly buried by colluvium of agricultural age. This colluvium is the source of monazite which locally replenished placers sufficiently to permit them to be mined, or "cropped," several times a year.

Colluvial deposits not incorporating agricultural artifacts associated with machine technology underlie colluvium of agricultural age and, locally, rest in erosional contact on soils formed in older colluvium. These underlying colluvial deposits are also apparently of Recent age and are here classed as preagricultural. Aboriginal stone implements were not observed in colluvium of preagricultural age, but no special search was made for them. Stone implements of several cultures were found in the ploughed and disturbed upper parts of the agricultural colluvial sequence where their source could not be identified. They probably occur in the preagricultural Recent colluvium on hillsides and in residuum on the interfluves.

TERRACE DEPOSITS

Terrace deposits in the Inner Piedmont belt consist of gravel and other alluvium within the confines of the present stream valleys at altitudes of 3 to at least 400 feet above the present flood plains. These deposits appear to have been formed by earlier cycles of erosion and by earlier stages of the present cycle of erosion. In general, the older deposits are at the greatest heights above the present stream beds. Scattered sparse patches of gravel have been noted on major divides in the Inner Piedmont, but very little attention was paid to them in the present investigation. The oldest of these deposits are Cretaceous(?) and Tertiary(?) in age; they have as yet been recognized only in the monazite-bearing area in the basin of the Chattahoochee River, Ga. Elsewhere in the Inner Piedmont belt, the terrace deposits are thought to be of Quaternary(?) age.

CRETACEOUS(?) AND TERTIARY(?) SEDIMENTS

Terrace sediments of possible Cretaceous(?) and Tertiary(?) age were observed in the headwaters of White Sulfur Creek and on Pine Mountain, Meriwether County, Ga., and on the upper slopes of Dowdell Knob, Harris County, Ga. These deposits were mapped by Hewett and Crickmay (1937) as Tertiary(?) and Quaternary(?), and by W. S. White (1943) as Cretaceous(?) and Tertiary(?).

On the northern flank of Pine Mountain in the headwaters of White Sulfur Creek about 5 miles west of Warm Springs, Meriwether County, a roadcut exposes a section of sediments 15 feet thick. The base of the sediments is not exposed. A hole drilled by hand auger to a depth 8 feet below the base of the exposure did not disclose the bottom of the sequence of sediments; thus, they are at least 23 feet thick at this locality.

The deposit consists of four distinct units separated by sharp contacts. At the top is a layer of humus-rich soil 1 foot thick, which overlies massive silty coarse sand that lacks any visible structure. The layer of sand is 3 feet thick. It is yellowish white and consists of nearly pure quartz grains with sparse interstitial clay. Below the massive layer of sand is a bed of pebble and cobble gravel 2 feet thick. Round and subround pebbles of quartz and granite make up about 80 percent of the gravel, and quartzite—the rock which forms the crest of Pine Mountain—constitutes about 10 percent of the gravel. The gravel is tightly bonded in a matrix of clay which was probably in part leached from the overlying sand. Under the gravel is fine-grained horizontally bedded and crossbedded quartz sand having kaolinite masses which persists to the base of the exposure and to the bottom of the auger hole; this unit is therefore at least 17 feet thick. Several lens-shaped masses of kaolinite occur at the base of the exposure and extend below the exposure. One mass about 4 feet thick was penetrated with the soil auger. Nearby, similar exposures reveal masses of kaolinite and bauxite at least as much as 18 feet thick (White, W. S., 1943). Many of the bedding planes are tightly cemented with limonite, which forms layers resistant to erosion and mass movement that stand out conspicuously in the exposure. Steeply dipping to vertical joints cut across the bedding and limonite hardpans and are filled with kaolinite. The joints do not pass upward into the gravel.

This lowest unit was probably formed long before the gravel was deposited, and the gravel rests on an erosional unconformity. The clay- and bauxite-bearing sand was regarded by White (1943) as being Cretaceous(?) in age by analogy with clay and bauxite deposits in the Tuscaloosa Formation of Late Cretaceous age on the Atlantic Coastal Plain. Nearest present deposits of the Tuscaloosa are about 30 miles to the south. Perhaps the deposits near Warm Springs are erosional outliers of the Tuscaloosa. Gravel overlying the sand is interpreted by White (1943) to be Tertiary(?). It may be younger, but data on its age were not assembled during the monazite investigation.

A thin deposit of gravel is exposed about 3 miles south of Warm Springs at the junction of Georgia Routes 190 and 85 on Pine Mountain. The deposit overlies Hollis Quartzite. It consists of a layer of sandy humus-rich soil, about 1 foot thick, which overlies gravel, about 3 feet thick, composed of indistinctly bedded round pebbles of quartzite, which in turn overlies coarse-grained massive quartz sand ½–1 foot thick. The quartz sand at the base of the sequence may be alluvium, but it appears to grade into quartzite and is here interpreted to be saprolite of quartzite. More than 90 percent of the round pebbles in the gravel is made up of quartzite, but a concentrate from the gravel (52–DC–754) contained 1 percent monazite and 3 percent rutile, neither of which is reported among the accessory minerals in the Hollis (Hewett and Crickmay, 1937, p. 28). Thus, at least part of the sediment may have been transported from somewhat more distant source areas.

Similar, but less perfectly, exposed gravel occurs on the upper slopes of Dowdell Knob, Harris County, Ga., and on the long ridge which connects Dowdell Knob with Pine Mountain. The ground surface is littered with more or less angular cobbles of Hollis Quartzite with which are intermingled rounded cobbles of granite weathered to a depth of 3 or 4 inches. Some quartz pebbles and cobbles are subround to round, and they and the granite cobbles seem to be the only detritus that might be described as alluvial. The pebbles of quartzite and granite are in a sandy matrix from which clays have been leached or which originally contained little or no clay, if the matrix is mostly derived by disintegration of the quartzite. A concentrate (52–DC–753) from the matrix of the gravel is mineralogically very simple: 40 percent rutile of distinctive red color, 54 percent ilmenite, 6 percent zircon, and trace of garnet, magnetite, and hematite. Inasmuch as rutile is not known to be present in the Hollis Quartzite, the matrix of the gravel apparently includes some transported material.

The upper surface of the gravel on Dowdell Knob and on Pine Mountain is at an altitude of 400–450 feet above the deposit of clay, bauxite, and gravel on White Sulfur Creek at the foot of Pine Mountain about 2½ miles to the north of these two localities. The gravel on Pine Mountain and Dowdell Knob is provisionally referred to the Tertiary(?) by Hewett and Crickmay (1937, p. 30–31), who think that it was deposited by streams on a formerly more extensive land surface. Remnants of the surface are preserved on ridges supported by the Hollis Quartzite. If these gravels are of Tertiary(?) age, and the ones on the clay at the foot of the mountain are also Tertiary(?), those on the mountain may have been deposited at an earlier stage of the Tertiary than the gravel at the foot of the mountain.

QUATERNARY(?) GRAVEL

Gravel deposits of probable fluvial origin and Quaternary(?) age are inconspicuously present in many, probably most, of the valleys in the Inner Piedmont belt (Sloan, 1908, p. 476–480) at altitudes from 3 to 70 feet, but most commonly to about 40 feet, above the tops of the present flood-plain deposits. At most places the gravel deposits are buried by colluvial debris and do not stand out as conspicuous terraces. Generally, gravel is the only sediment left, and it might be argued that, the deposit was of colluvial origin. However where these deposits are clearly exposed, the gravel rests upon rather flat eroded terraces of saprolite or unweathered rocks; locally, the gravel is covered by remnants of fine-grained sand and silt which have the texture and bedding features characteristic of fluviatile sediments in the present flood plains. The color of the fine-grained sediments in the terrace deposits tends to be gray, whereas that of sediments in the present streams is reddish brown. These color differences are probably related to a greater degree of weathering in the terrace materials than in the present flood-plain sediments. Textural similarities between the fine sediments in the terraces and in the present flood plains probably indicate a similar sedimentary environment and history. Other evidence of the fluviatile origin of the terrace deposits is the rounded shape of many particles in the gravel, a tendency toward a decrease in particle size in a downstream direction, and the presence of detrital grains of heavy minerals not represented among accessory minerals in the immediately underlying saprolite or unweathered rock. Because similar terrace deposits occur over a wide area, the forces responsible for their formation also must have been regional. A regional correlation of the terraces has not been practicable because of the scarcity of field evidence, but a correlation of the causes seems possible.

To illustrate the appearance of the material several representative examples of terrace gravel in South Carolina are described below, but it was observed from Virginia through Georgia.

Gravel is exposed in a cut on South Carolina Route 80 about 300 yards west of the bridge over Big Beaverdam Creek in northwestern Anderson County 3.8 miles east of Fairplay. The upper surface of the deposit was leveled when gravel was excavated to provide fill for the bridge. According to reports of local residents, sand and gravel were removed to a depth of 6 feet below the original top of the deposit, and in 1952 when the site was examined, there remained a flat sandy surface some 40,000 square feet in area.

A small tributary to Big Beaverdam Creek flows parallel to Route 80 and has eroded a channel which exposes a section of the gravel to the underlying saprolite. The gravel is not uniform in coarseness or thickness along the face of the exposure. It ranges in thickness from about 6 inches to 5 feet, and the fragments of quartz composing the gravel range in size from granules to cobbles. Orange gravelly sand overlies coarse gravel which rests on biotite schist saprolite. Where the gravel is thickest, it contains the coarsest particles, which are quartz pebbles about 3 by 2 by 1½ inches in a matrix of orange sandy silt and clay which gives way locally to black-stained sand. A small percentage of the gravel-sized particles is angular fragments of feldspar and, rarely, angular quartz. Bedding is marked by layers of different grain size with a clear tendency for finer sized grains to be in the higher layers, and coarse particles, in the lower layers.

A sharp undulating contact which dips gently toward the south (downstream) separates gravel from saprolite. In places, channels as much as 2 feet deep and 3–4 feet wide are carved in the saprolite. They are filed with cobbles coarser than the average-sized gravel in the deposit.

Near the center of the exposure a nearly vertical fractured vein of quartz extends upward to the top of saprolite. Angular fragments of apparently identical quartz are cemented in gravel overlying the saprolite and within 6 inches of the exposed top of the vein. These angular blocks are surrounded by rounded gravel.

Clay-filled veins extend from the gravel into the saprolite, where they pinch out. Most of the veins are wedge shaped and have the small end down; but some are branching, and a few are of complex and irregular pattern. Most of the veins originated in parts of the gravel now excavated; thus, they lead downward from the present top of the exposure. A few veins start in the gravel below the present top of the exposure and extend into the saprolite. None passes downward below the bottom of the exposed saprolite.

The extent of the gravel in the valley of Big Beaverdam Creek is not known, nor is it known if it is correlative with gravel in a similar deposit exposed about 4 miles upstream.

From the available evidence, notably bedding, vertical sorting, and scour, the gravel exposed near South Carolina Route 80 is interpreted to be fluviatile in origin. Much of the gravel is round to subround, a condition which indicates transport of the quartz, but which may result from the reworking of an older deposit. Angular fragments of quartz close to a local source imply that at least a small part of the material was not transported very far, but we think that the conditions of accumulation do not prejudice the interpretation of fluviatile origin.

About 4 miles upstream from this gravel deposit, additional gravel and associated sediments are exposed for 120 feet along the north side of the road. Along the south side of the road, gravel is exposed for about 100 feet, but the overlying sediments have been removed. The sequence of sediments in this exposure is similar to that in flood plains of present-day streams in the area. Below a thin humus layer is material similar to the reddish-brown sandy silt of the present flood-plain deposits. This sandy silt is 3 feet thick, uniform in composition, and is separated from underlying sediments by a sharp nearly horizontal erosional contact. The silt is deposited on a variable thickness of blue-gray sandy clay, also similar to clays in flood plains of present streams in the area. In its upper part the clay has a few rounded pebbles of quartz scattered through it, but it is otherwise uniform in composition and appearance. About 3 feet below the top of the clay the pebble content increases, and pebbly clay grades into gravel at the base. The size and angularity of the pebbles increase downward. The gravel rests on a gently undulating surface of saprolite cut locally by channel scours 2–3 feet deep. Fillings in these channels contain gravel that reaches boulder size (1 ft by 9 in by 7 in) at the base. Some degree of rounding is shown on all particles in the gravel layer. The most angular fragment is subangular, and many of the cobbles and boulders are well rounded. Only in the channel fillings does the gravel show bedding. The matrix of the gravel is firm orange and white clay. Material exceeding an eighth of an inch in diameter contains about 90 percent quartz and 10 percent feldspar. Lens-shaped layers of finer clastics, coarse sand, and granule gravel are cemented by an unidentified black material found at the previously described locality.

No outcrop of a similar gravel was found on the east side of the valley wall, where a roadcut similar to that on the west side of the stream might expose such gravel if it did exist. The gravel deposit on the west side of the valley does not have the topographic expression of a terrace and could not be mapped as such. The extent of the gravel is not known.

Deep Creek in western Anderson County, S.C., is formed by the confluence of Twentysixmile and Twentythreemile Creeks. About 500 yards downstream from the junction, two small hills project out of the flood plain. Flood-plain sediments surrounding the hills were drilled by power auger and found to consist of a layered sequence, 20 feet thick, with gravel at the base overlain by clay, sand, and discontinous muck. The hills which rise out of the flood plain are supported by saprolite and capped by alluvium thought to be older than that in the present flood plain. The base of the alluvium on the hills is about 30 feet higher than the top of the present flood plain surrounding the hills. In 1952 the sequence of old alluvium on the larger of the two hills was exposed in two silos about 8 feet in diameter and dug to a depth of 15 feet. In the upper part of the silos to a depth of 5 or 6 feet from the top of the hill, bedded gravel, sand, and silt rests in sharp erosional contact on saprolite of biotite schist and granite. At the base of the section of sedimentary material is a bed of well-rounded quartz cobble gravel, 1–2 feet thick, overlain by a layer of crossbedded fine sand and silt with beds of coarse sand and small pebble gravel totaling about 2 feet in thickness. Over the sand is red soil, 2 feet thick, which makes up the top layer of the hill. Interstices in all units of the sedimentary sequence are filled with reddish-brown clay and silt. Clay-filled veins, similar to those observed in the gravel on State Route 80 near Big Beaverdam Creek, extend from the gravel deep into the saprolite.

Terrace deposits consisting of bedded gravel and sandy silt about 6 feet thick are exposed in roadcuts in the headwaters of Broad Mouth Creek, Anderson County, about 2 miles east of Belton, S.C. Rounded quartz-pebble gravel, about 6 inches thick, overlies an undulating surface eroded on saprolite 3 feet above the top of the present flood-plain sediments in the valley of the creek. The gravel is overlain by gray pebbly clay, 3½ feet thick, in which the pebbles are rounded and constitute about 1 percent of the sediment. Above the pebbly clay and forming the top of the deposit is reddish-brown sandy silt. Contacts between the three units are gradational. All the sediments show evidence of soil-formational processes. The silt unit has a small amount of organic matter and has been oxidized to a deep reddish brown. Reticulate mottling produces striking color contrasts of maroon, yellow, and reddish brown in the pebby clay. Evidently, oxidation and some leaching have taken place along intersecting joint surfaces to produce the rectangular patterns in the clay. Clay leached from overlying sediments has been deposited at the base of the pebbly clay and in the underlying quartz-pebble gravel.

A roadcut just south of U.S. Route 76 at a small tributary to South Rabon Creek in the northwestern part of Laurens County, S.C., about 12 miles west of the city of Laurens, exposes, for a distance of 100 feet, terrace sediments deposited on a nearly horizontal surface of eroded saprolite. The base of the sediments is about 20 feet above the top of the present flood plain in the valley of the tributary, and the exposed section of sediments is 7 feet thick. Angular quartz-pebble gravel at the base of the sediments rests on saprolite. It ranges in thickness from 1 to 2 feet. Overlying the gravel is a continuous layer of gray clay, 1 foot thick, which is similar in appearance to clay overlying gravel in the present flood-plain deposits. Above the clay is reddish-brown silt about 4 feet thick on which is an inconspicuous soil profile.

A deposit of terrace gravel is exposed in a roadcut in the headwaters of Grove Creek 8 miles south of the city of Greenville, Greenville County, S.C. Cobble gravel of angular quartz rests on a nearly horizontal surface eroded on saprolite about 10 feet above the present level of the top of the flood plain in the valley of Grove Creek. The gravel is overlain by reddish-brown pebbly clay which gives way upward to reddish-brown sandy silt. This deposit differs from the others here described in that it crops out on both sides of the stream, whereas terrace deposits in this region commonly are found on one valley wall only.

The spatial relations of the terrace deposits was not clearly brought out by the placer appraisal, but at most localities terraces which can be matched on both valley walls at about the same altitude are not present. This may mean that most terraces formed as unmatched terraces, or that possible matching remnants have been eroded or buried by colluvium, or that the reconnaissance failed to discern many matching remnants; but there is little evidence to support an interpretation that holds the terraces to be generally matched.

Matched terraces record a halt in the downcutting processes of a stream and indicate a period of stability and deposition of flood-plain sediments. Unmatched terraces may be formed by the continuous but slow downcutting of a stream (Cotton, 1949, p. 244–246), and no period of stability or halt in downcutting is needed to explain the history of unmatched terraces. The agencies of changing climate, faulting, or stream capture are not needed to account for their presence; however, the degree of weathering shown by terrace deposits indicates some antiquity and possibly reflects some variation in climate since the deposits were laid down.

ALLUVIAL FANS

Alluvial fans have accumulated at the mouths of most little tributary streams with steep gradients, which debouch onto flood plains in broad valleys. Fans are more common in the western part of that part of the monazite-bearing area between the Savannah and Catawba Rivers and in the Yadkin River–Dan River area than they are in Georgia. In the vicinity of the South Mountains, N.C., several large, much modified, and possibly relatively old alluvial fans were observed. These fans form dissected spurs and mounds of alluvium(?) at the mouths of valleys and are situated 10–40 feet above the level of present flood plains. The alluvium(?) is deeply weathered to a homogeneous dark red, and granite cobbles in it are commonly altered or partly altered to saprolite. Fans which lap out on the alluvium of the present flood plains are diminutive. The total amount of alluvium in fans is small compared with the amount in flood plains. Fan deposits were not mapped separately from flood-plain deposits.

FLOOD-PLAIN DEPOSITS

COMPOSITION

Flood-plain deposits in the monazite-bearing parts of the Inner Piedmont belt are very similar in composition and appearance from Virginia to Georgia, although the units may vary somewhat, and one of more of them may be absent at a given exposure. Commonly, the deposits consist of a stratified sequence of fluviatile sediments with gravel at the base and sandy silt at the top. At most places the gravel rests on saprolite; locally, it is on unweathered rock or overlies sand or clay. It is overlain by clay, locally carbonaceous, and above the clay is sand. In most flood plains, silt rests on the sand, and the silt is overlain by sandy silt.

The unit with the most uniform composition and appearance is reddish-brown to brown sandy silt which occurs at the top of the flood-plain deposits. Its distinctive color is interpreted by us to be a characteristic inherited from source materials like saprolite and colluvium exposed on the present hillsides and preserved in an unreduced condition because the unit is young. Silt-sized particles are the dominant component, but where the unit is well stratified, sand-sized particles tend to be more common than silt, and the mixture is a silty sand. Clay-sized particles make up 10–15 percent of the usual mixture of components in the unit. Clay tends to decrease in abundance where sand becomes the commonest component. Flakes of weathered biotite are generally abundant. In most exposures the reddish-brown sandy silt is 1–5 feet thick, but it may be as much as 20 or 25 feet thick in the flood plains of the largest streams and rivers. The unit is rarely absent. Typical examples of this unit in the drainage basin of a moderate-sized monazite-bearing stream in the Inner Piedmont belt are given in the logs of holes drilled in flood plains along Knob Creek and its tributaries in Cleveland County, N.C. (pl. 6.)

At many exposures of flood-plain deposits in the monazite-bearing part of the Inner Piedmont belt, a layer of silt underlies the reddish-brown sandy silt. It is represented on plate 6 at cross sections *M–M′*, *O–O′*, *Y–Y′*, *AA–AA′*, and *BB–BB′*, and by such individual logs of drill holes as D15. The silt ranges in color from buff and brown to gray, and the color changes horizontally in distances of a few feet. Materials of silt and clay size are dominant, and the percentage of clay tends to increase with increasing depth. Sand-sized particles rarely exceed 20 percent of the total. Mica flakes are abundant, but they are not so common as they are in the overlying sandy silt. Where present, the layer of silt is generally at least as thick as the overlying sandy silt. Artifacts have been found in the unit.

The variable color of the unit seems to be the result of incomplete reduction of original brown and probably reddish-brown material to buff and gray. At some places the silt has a gradational contact with the overlying reddish-brown sandy silt; elsewhere, the contact is sharp and is marked by erosion, scour, and channeling. Doubtless the unit is relatively young, and at most places it is probably part of the agricultural sequence, but where artifacts are absent and the unit is scoured on top and sharply separated from the overlying reddish-brown sandy silt, it cannot be assigned with certainty to the agricultural sequence.

Sand is volumetrically the most abundant sediment in the flood plains of monazite-bearing streams in the Inner Piedmont belt. Layers of sand in the flood plains are noticeably finer grained and contain more silt and clay than sand in bars in the present channels of streams. Flood-plain sand has less intermixed clay than colluvial sand, which shows that clay is preferentially moved out of the surficial materials by stream action. The sand grains range in size from granules to very fine sand. The sand is commonly brown to buff, but gray to white sand is also widely present.

Sand commonly overlies clay, but it may be present in any part of the flood-plain sequence (pl. 6). At some places, especially in large downstream flood plains, sand is the only sediment. The most notable examples of thick sequences of sand are large flood plains in the lower part of the valley of the Pacolet River in Spartanburg County, S.C., where a flood in 1916 washed out all earlier sediments and deposited layers of sand 15–20 feet thick directly on bedrock. In Cherokee County, S.C., beds of sand as much as 8 feet thick now cover unweathered rocks that were exposed in Buffalo Creek and served as a fording place as late as 1910. These examples are not cited to show that all sand in flood-plain deposits is part of the agricultural sequence, because it is not, but they do show that considerable thicknesses of sand were laid down in a short time by some streams whose regimen had been changed by culturally accelerated soil erosion (Happ and others, 1940, p. 63).

The flood-plain sediment having the widest range of physical characteristics is clay which generally lies beneath silt or sand and over gravel (pl. 6). In some places the clay is white or yellow and has a uniform texture. Elsewhere, it is blue gray or black, massive, and may or may not contain abundant fragments of fresh or carbonized wood or masses of peaty vegetal debris. Clay at many exposures contains abundant fine white sand and scattered angular pebbles of quartz. Flakes of muscovite, often as much as a ¼–1 inch across, are present in some exposures. Commonly, the top of the clay has been scoured and pitted by the stream. However, clay beds are more resistant to erosion than other flood-plain sediments or the saprolite itself. At many localities, streams had eroded into saprolitic valley walls and carved new and lower channels in the saprolite and had abandoned the parts of their beds protected by clay.

Poorly drained parts of the present surface of flood plains, especially along the edges or in abandoned meanders, are sites for the present accumulation of black carbonaceous sediments. Presumably, similar conditions of poor drainage in the past, and conditions induced by intermittent natural damming of the streams, led to the deposition of carbonaceous clays. Pollen spectra of several samples from carbonaceous clay were reported by Professor E. S. Barghoorn (written commun., 1953) to contain a considerable quantity of pollen from water lilies (included with herbaceous pollen in table 14). The presence of this pollen was interpreted by Professor Barghoorn as indicative of fairly deep, probably stagnant, water in abandoned channels or ponds subsequently drained. Where the carbonaceous clay does not extend across the full width of the flood plain, it probably originated in abandoned channels, but where it persists across the flood plain, it may have been formed by ponding of the streams.

Possibly the preagricultural clays were largely deposited in beaver ponds, but direct fossil evidence of beavers was not found during the placer appraisal. The prevalence of the name Beaverdam Creek indicates that no longer ago than the middle 1700's and early 1800's beavers were plentiful, and their dams were distinctive features of some streams. These same conditions doubtless persisted back into Pleistocene time. The fact that the carbonaceous clays are irregularly distributed, in contrast to the general distribution of noncarbonaceous clay, also indicates that proper conditions for the deposition of carbonaceous sediments were only achieved locally. The distribution of these deposits in the flood plains along Knob Creek, Cleveland County, N.C. (pl. 6), might be attributable to the activities of colonies of beavers at different times.

At the base of the flood-plain sequence is usually an aggregate of quartz-pebble gravel and minor amounts of feldspar and rock fragments bound in a matrix of white, yellow, or buff sandy clay. Rock fragments become increasingly common in the gravel as the headwaters of a stream are approached. All degrees of angularity are found in the component particles of the gravel, but subangular and subrounded fragments are most abundant. The average maximum dimension of pebbles in the gravel is about 2 inches, but cobbles as much as 6 inches in maximum dimension are relatively common.

The distribution of this basal gravel tends to be irregular. In any flood plain close to the headwaters of a stream, the gravel is commonly present and persistent but variable in thickness. Farther downstream the gravel tends to be discontinuous and is thinner in proportion to the other sediments in the sequence than it is in the upstream parts of valleys. This unit contains richer concentrations of monazite than other fluvial sediments in flood plains.

Layers of fluvial gravel other than the one at the base of the flood-plain sequence are present but uncommon in the middle and upper parts of the flood-plain sequence (pl. 6, logs D13, K15, D454, D11, D467). Most gravelly layers above the base of the sequence have less gravel than other classes of components; thus, they are gravelly sand, gravelly silt, or gravelly clay. These layers tend to be long and narrow and were probably formed as channel deposits. At many places they rest on scoured clay.

The size distribution of heavy minerals in the fluvial sediments in the monazite-bearing area between the Savannah and Catawba Rivers in the Inner Piedmont belt has been described in tables by Caldwell (1962), Cuppels (1962), Theobald (1962), and A. M. White (1962), which show that the particle sizes among the heavy minerals decrease by class of sediment from largest particles in basal gravel to smallest particles in silt and clay. These tables also show that the range in particle size is less among heavy minerals from flood-plain gravel and clay and is greatest among heavy minerals from sand and silt.

AVAILABLE DETRITUS FOR COARSE SEDIMENTS

Sheet erosion and gullying supply most of the detritus available for deposition in the flood plains. Of the two, gullying is said to be more important because it usually delivers waste directly to the streams, whereas much debris from sheet erosion lodges directly on the low hillslopes (Happ and others, 1940, p. 76). Sheet erosion affects only surficial material, whereas gully erosion reaches into deeper source materials. In the Inner Piedmont belt where saprolite underlies about 95 percent of the land surface, and is itself overlain by colluvium and residual soil, either process of erosion would make available to the streams large volumes of fine-grained detritus but would produce scarcely any coarse detritus. In saprolitized areas rare fragments of unweathered rock and of quartz from veins and pegmatites, or quartz gravel from earlier fluviatile cycles, are the only debris available to form gravel. Large-sized particles are thus only a small part of the load in streams.

Coarse-grained monazite is very sparse in the source materials, but it is very abundant in fluviatile gravel in flood-plain sediments. The gravel itself contains twice as much monazite per unit volume as the silt and sand and eight times as much per unit volume as the clay (Overstreet, Theobald, Whitlow, 1959, p. 710–711). Therefore, enormous quantities of the source material must have been winnowed to produce the coarse grains of monazite in the gravel.

DOWNSTREAM CHANGE IN SEQUENCE

The thickness and relations of sediments in the flood-plain sequence change in a downstream direction. Flood plains near the headwaters of streams have a greater proportion of coarse clastic to finer grained sediments than do flood plains farther downstream where the gradient is gentler. The amount of sand and silt increases in a downstream direction, and gravel thins in that direction. Because major streams flow about normal to the trend of the Inner Piedmont belt, and rise at the western side of the belt, fine-grained sediments tend to be more common along the southeastern (downstream) edge of the belt than along the northwestern (upstream) edge of the belt.

Carbonaceous clay, muck, and peat generally occur at higher levels in the sequence of flood-plain sediments in the northwestern part of the belt than in sequences in the southeastern part. In the northwest these carbonaceous units are overlain by thinner layers of reddish-brown sandy silt than in flood plains along the southeastern part of the belt. This relation appears partly to result from greater available coarse detritus in the northwestern part of the belt, which forms thicker layers of basal gravel and coarse sand than are found in the southeastern part. It also seems partly to be caused by the later and less extensive development of agriculture in the northwestern part of the belt than in the southeastern part. Culturally accelerated soil erosion was less in the northwest; thus, the tops of former flood plains are less deeply buried there under reddish-brown sandy silt than they are in the southeast.

AGE

The age of the flood-plain sediments is thought to be post-Wisconsin. The sediments can be classed visually in the field into a late Recent (agricultural) sequence of reddish-brown sandy silt which has accumulated since farming was introduced in the area, and an older Recent (preagricultural) sequence which underlies the reddish-brown sandy silt. The typical reddish-brown color of the upper sandy silt, as contrasted with the buff or gray colors of the underlying sediments, is a criterion, but not an infallible one (Happ and others, 1940, p. 65), for establishing the break between agricultural and preagricultural flood-plain deposits. Hard ferruginous concretions are said to be associated with preagricultural deposits only, but such concretions are not common in the lower sediments in the flood-plain sequence.

Twenty samples of preagricultural carbonaceous sediments from flood plains in the Savannah River–Catawba River area were submitted to Professor Elso S. Barghoorn, of Harvard University, in 1952 for pollen analysis. The locations of these samples is given below in the section on sampling. Of the 20 samples, 18 were reported by Dr. Barghoorn (written commun., 1953) to contain pollen species characteristic of the region at the present time (table 14). Differences in pollen spectra among the 18 samples were interpreted by Professor Barghoorn to result mainly from selective loss of plant microfossils through degradational aerobic soil processes. These 18 samples were regarded as being Recent and probably younger than altithermal. Two samples, 52–CS–417 and 52–CS–419, from locations near the heads of streams, differed markedly from the other samples in that they were rich in pollen from spruce and fir. This difference was interpreted by Professor Barghoorn as being caused by a fundamental change in character of vegetation and climate since deposition of the sediment. The paucity of micropaleontologic studies in this part of the United States, and the lack of vertical profiles in the samples, from which climatic changes might be deduced, made correlation with sections in other areas impractical. But the anomalous pollen spectra in sample 52–CS–417, certainly, and in 52–CS–419, possibly, indicate that the deposit was formed in late Pleistocene time.

The inference as to the antiquity of sample 52–CS–417, based on ecologic considerations, was borne out through an age determination by carbon-14 methods. A piece of wood (sample 54–CS–11, lab. No. W–308) from the same sediment as that represented by pollen sample 52–CS–417 from a tributary to Buck Creek at Green Hills Farm, Spartanburg County, S.C., was analyzed at the U.S. Geological Survey by Meyer Rubin (written commun., 1955) and found to be older than 34,000 years. The inferences as to the Recent age of the other pollen samples were supported by carbon-14 age determinations made on a piece of wood (sample 52–WE–406) from the locality represented by pollen sample 52–CS–388 at North Muddy Creek, McDowell County, N.C., at a point 5.2 miles east of Marion and 1.3 miles south of Nebo. The age of one specimen (lab. No. W7) of this wood was determined at the U.S. Geological Survey by H. E. Suess (written commun., 1953) to be 2,370±200 years. The age of a second specimen (lab. No. L167A) of this wood was measured at Columbia University by J. L. Kulp (written commun., 1955) and found to be 2,680±200 years.

The sample of old wood (54–CS–11) came from an exposure of bedded carbonaceous silt, sand, and clay, 7 feet thick, that overlies a 4-inch layer of gravel which rests on pegmatitic saprolite. The piece of wood was in black peaty clay 4–16 inches above the top of the gravel. The upper surface of this well-bedded carbonaceous sediment has been eroded, and an unknown thickness of sediment has been removed. Because the carbonaceous sediment is well bedded, it is interpreted by us to be part of a fluviatile sequence probably deposited in a ponded part of the stream. In carbon-14 age, the wood

TABLE 14.—*Plant microfossils from flood-plain deposits in the Inner Piedmont belt, North Carolina and South Carolina*

[Pollen analyses by Professor E. S. Barghoorn, Harvard University, 1952]

Sample	Percentage of total arboreal pollen in—												Percentage of total pollen and spores in—					
	Pinus	Picea	Abies	Tsuga	Quercus	Carya	Castanea	Fagus	Betulaceae	Liquidambar	Nyssa	Ilex	Arboreal pollen	Ericaceae	Herbaceous	Fern spores	Lycopod spores	Nonarboreal pollen and spores
52-CS-417 [1]	26.0	52.0	18.0						4.0				90.0	1.3	6.6	2.0		10.0
419	94.0	2.0	5.5						.5				97.5		1.1	.8	0.4	2.5
420	81.5				1.0	2.0			11.0	1.0	3.0		66.6	2.1	6.9	24.3		33.3
424	67.3				10.7	2.0		2.0	10.5	4.0	1.0	3.0	81.0		11.0	4.0		19.0
422	84.0				8.0	1.0			5.3	1.0			91.8	.5	5.3	2.9		8.2
426	95.0	1.5			2.0				1.5				90.1		8.3	1.2		9.9
52-PK-105	55.5				14.0				30.5				79.3	13.0		8.7		21.7
107	89.4			0.6	5.9	1.2	1.7			.6			94.8	.5	3.6	6.3		5.2
109	77.0				4.0				16.2		2.7		91.4		4.9	7.6		8.6
111	83.3				7.4	1.8			3.7	2.4	.6		93.9	.9	1.7	3.5		6.1
113	97.0				1.5						1.5		68.0		12.0	20.0		32.0
114	81.5	2.3		.7	8.4	.7			4.1	2.3			81.3		3.1	15.6		18.7
52-WE-386	83.3				5.0	5.0			6.7				95.3		3.3	1.6		4.7
392	92.0	2.4			.8	.8			1.6		.8	.8	90.0		1.4	8.6		10.0
390	97.6	.6									1.8		91.4		3.6	5.0		8.6
388 [2]	82.0	2.5			2.5	2.5			10.2				78.0		8.0	14.0		22.0
393	85.1	.7	.7			.7			5.1				90.0		4.7	5.3		10.0
394	90.0					5.0			5.0				50.0		30.0	20.0		50.0
52-DC-496	88.5				5.7					2.8	2.8		62.5		16.0	1.8	3.6	37.5

[1] Location of wood specimen 54-CS-11 (lab. No. W-308), dated as older than 34,000 yr by carbon-14 analysis by Meyer Rubin, U.S. Geol. Survey.

[2] Location of wood specimen 52-WE-406 (lab. No. W7) dated as 2,370±200 yr by carbon-14 analysis by H. E. Suess, U.S. Geol. Survey.

from this locality resembles wood from colluvium in the North Gully on the Lattimore farm, Cleveland County, N.C., and the pollen spectra, though not identical, resemble each other more closely than they do the spectra of the 18 samples of Recent preagricultural flood-plain sediments. From these data it appears that relicts of flood-plain deposits of Pleistocene age are preserved in the extreme headwater parts of some, possibly many, streams.

The sample of wood (52–WE–406) from about 2 miles downstream from headwaters of a tributary to North Muddy Creek, McDowell County, N.C., is a fragment of log that lies near the base of a unit of peaty blue-gray sandy clay 3 feet thick. The flood plain at this point is barren of older carbonaceous deposits. However, apparently older carbonaceous beds have been described in the same general area (Kerr, 1875, p. 332). At the sample locality the peaty clay overlies gravel that rests on saprolite. Overlying the carbonaceous clay is a layer of brown sandy silt, 2 feet thick, which is overlain by reddish-brown sandy silt 3 feet thick. Contacts between the units are sharp, but they do not display scoured surfaces or channels. Zonal soil profiles have not formed in the units. The upper unit of reddish-brown sandy silt is a good example of the agricultural sequence, and the unit of brown sandy silt possibly may be part of the preagricultural sequence; thus, a time break of several thousand years exists between the blue-gray sandy clay and the reddish-brown sandy silt. At least the upper 3 feet of sediment was deposited at this locality in the last 150 years, and a minimum of 8 feet of sediment was deposited in the last 2,400 years. Most likely the section has been shortened by erosion of sediment from above the clay before deposition of the presently overlying silts. The presence of older carbonaceous sediment in the same general area, as reported by Kerr (1875, p. 332), means that a stratigraphic succession for transported surficial deposits can possibly be worked out in the McDowell County area also.

Several examples of artifacts in flood-plain sediments were cited previously to show that large thicknesses of agricultural-age sediments have been deposited in the monazite-bearing parts of the Inner Piedmont belt. Indirect evidence supporting this contention is provided by examples of the rapid rate at which the cultivated surfaces of the valley walls have been lowered by accelerated erosion since agriculture was introduced into the region. The general lowering on farmed upper slopes has been on the order of about a foot since the advent of cultivation. Some of the eroded surficial material has been deposited as coluvium on the lower slopes; the rest has entered streams. Frequently observed is the preservation under houses of earth pediments 6 inches to 1 foot higher than the surrounding yard. Their presence suggests removal of 6 inches to 1 foot of soil from the yard around the house-protected area. Most such houses are reported to have been built between 1870 and 1900; many were constructed about 1880. In many cemeteries erosion has lowered the land surface by 4–10 inches from the original finish line of plinths set under headstones dated in the 1880's.

Some roads shown on topographic maps dating from 1900 to 1910 became badly eroded and were abandoned between the date of the surveys and the time fieldwork was done in 1952. Most damage was caused by gullying along the side ditches of the roads. In observed examples the gullies reached a depth of 20 or 30 feet and had opened out from either side toward the centerline of the road, with the result that the old roadbed, if preserved at all, formed a narrow crest on a ridge down the center between parallel gullies.

The many evidences of accelerated erosion related to the advent of agriculture and construction complement the evidence of increased deposition of sediment on flood plains since agriculture was introduced and give a firm idea of the age of the youngest sediments in the flood-plain sequence. In general, the greatest acreage was cleared and cultivated about 1910, and intensive efforts to control erosion were begun in the early 1930's. Owing to the slow growth of population and agriculture in the late 1700's, it seems probable that accelerated sheet wash and gullying was not an important factor in the flood-plain regimen in the Inner Piedmont belt until the early 1800's. Reports cited by Happ, Rittenhouse, and Dobson (1940, p. 4) show that the damaging effects of sedimentation related to agriculturally accelerated erosion were recognized in the Southeastern States as early as 1801. These effects were probably general in the Inner Piedmont by about 1840, and the agricultural sediments in the flood plains probably date mainly from that time onwards.

The age of the Recent but preagricultural sediments is doubtless highly variable from place to place in the basins of streams in the Inner Piedmont belt. At best, the flood-plain deposits are impermanent, being subject to scour and redeposition. Lack of zonal soils in most flood-plain sediments attests to their impermanence and comparative youth. Pollen spectra and carbon-14 analysis also show the preagricultural sediments to be relatively young, probably generally no more than a few thousand years old at most sites of deposition.

SIZE

The size of the flood-plain deposits in the monazite-bearing parts of the Inner Piedmont belt is governed by the dimensions of the valleys in which the deposits occur. These, in turn, appear to be related to the general position of the valley in the river system, by the distribution of saprolite and unweathered rock, and, to a lesser degree, by the kind of rock on which saprolite is formed.

The headwaters of most of the major rivers in the Piedmont are in the Blue Ridge and are subsequent to the structure of the Blue Ridge. In their downstream segments on the Piedmont and Atlantic Coastal Plain the major rivers are consequent to the regional slope of the land surface. Streams tributary to the major rivers range in size from small insequent streams a few thousand feet long to large streams having drainage basins 40 miles long. Dendritic stream pattern is dominant in the Inner Piedmont belt, but rectangular pattern and clear structural control of patterns is present in parts of the belt.

Gradients of the major rivers range from 19 feet per mile on the Enoree River, S.C., from its headwaters downstream for 26 miles to 43 feet per mile on the First Broad River, N.C., from its headwaters downstream for 36 miles. On the Piedmont surface downstream from their headwaters these rivers have gradients of 10–15 feet per mile. The longitudinal profile of the rivers is generally even, but it is locally steepened where unweathered bedrock crops out in the stream channel. At these places the streambed is lowered 20–40 feet over a distance of about 1,000 feet. Gradients of the headwater tributaries to major rivers and headwater tributaries to the larger tributary streams range from 30 to 75 feet per mile. Some headwater tributaries draining the mountains and monadnocks in the belt attain a gradient of 155 feet per mile. Commonly, there is a local increase in gradient of tributary streams as they approach major rivers, which is shown by falls or rapids a short distance from the trunk valley. This may represent rejuvenation of the major rivers. Between the rapids and the trunk valley the gradient of the tributary is low and conforms to that of the main stream. Relatively resistant bedrock may cause rapids in a stream near its mouth without rejuvenation. Graded reaches, produced by an outcrop of unweathered bedrock in areas of saprolite, are common at many places along tributary streams. Many of the tributary streams are mature but have youthful areas in their headwaters, in downstream parts of graded reaches, and near their mouths. In the Chattahoochee River and Flint River areas in Georgia the larger streams are approaching old age and have very gentle gradients. In many places along these streams there is little flow of water, and the channel sediments are thick accumulations of mud. For the most part, the size of the valleys and the volumes of the flood-plain deposits increase downstream as the gradient decreases. The largest volumes of flood-plain deposits are in valleys more than 10 miles below the head of the stream where the gradient of the stream in the flood plain is 4–14 feet per mile (table 15).

Wide valleys and flood-plain deposits are underlain by saprolite, whereas narrow valleys and flood-plain deposits, or constricted channels and gorges lacking flood-plain deposits, are underlain by unweathered rocks. Wide valleys on saprolite of granite, biotite schist, or sillimanite schist constrict locally at the contact where the saprolite changes to hornblende gneiss, amphibolite, and hornblende-biotite gneiss. Many instances of this lithologic control can be found along the southeastern edge of the Inner Piedmont belt in South Carolina where conspicuous layers of hornblende gneiss appear.

Valleys of obvious structural control occur in areas underlain by either saprolite or unweathered rocks, and at many places prominent planar features preserved in soft saprolite seem to have guided the formation of the valley. A large arcuate valley formed in saprolite by the First Broad River, Cleveland County, N.C., reflects the downplunge direction of the Mooresboro anticline (Overstreet, Yates, and Griffitts, 1963a). Although the rocks in the area are deeply weathered, the plunge of the structure controlled the course of the river. Control of valley formation by unweathered quartzite is well shown along Mountain Creek, Harris County, Ga. In some valleys structural features appear to have promoted the formation of saprolite and thereby served to guide the formation of valleys and flood plains. On Cane Creek in Rutherford County, N.C., and adjacent streams heading in the South Mountains in McDowell and Burke Counties, N.C., northeast-trending faults seem to have promoted the formation of deep saprolite on rocks in the fault zone, and the streams preferentially carved long straight valleys in this deep saprolite.

Descriptions of the transverse profiles of flood plains in which 219 churn-drill holes were sunk for an aggregate footage of 4,000 feet are given in eight reports (Griffith and Overstreet, 1953a–c; Hansen and Caldwell, 1955; Hansen and Cuppels, 1954, 1955; Hansen and Theobald, 1955; Hansen and White, 1954). The results of this drilling show that the floors of the valleys are generally flat and the flood-plain deposits are shallow. The deposits range in thickness from a few feet to about 35 feet. The average thickness revealed by the holes is 14.6 feet, which is maintained well up toward the heads of the streams.

Some valley floors are deeply channeled locally and have well-developed slip-off slopes leading into the channel (pl. 6 *Z–Z′*), but this is uncommon.

Few continuous flood plains in the monazite-bearing part of the Inner Piedmont belt contain more than 10 million cubic yards of sediment. Most of those that exceed this size are along the southeastern boundary of the belt, and the majority are in South Carolina and Georgia. The greater number of large flood-plain deposits in the southeastern part of the belt reflects lower relief and gentler stream gradients in this area. Most

TABLE 15.—*Physical characteristics of some monazite-bearing flood-plain deposits in North and South Carolina*

[Average width of flood plain is area divided by length. Where two entries are given under length of flood plain, the first entry is the main flood plain and the second is tributary]

Flood plain	Distance from headwaters (miles)	Length of flood plain (thousand feet)	Gradient (feet per mile in flood plain)	Width (feet)			Estimated depth (feet)		Area (thousand square yards)	Estimated volume (thousand cubic yards)
				Minimum	Maximum	Average	Maximum	Average		
North Carolina										
Hinton Creek, Rutherford County	5.0	1.2	35	170	300	185	10.5	10.0	24.7	81
Do	.5	3.0	105	80	340	285	8.0	4.0	95.7	124
Sandy Run Creek, Rutherford County	2.5	10.6 2.6	31	100	650	250	14.5	11.5	370.0	1,400
Buffalo Creek, Cleveland County	8.0	7.5 4.3	12 16	150	1,000	475	14.0	10.0	623.0	2,000
Knob Creek, Cleveland County	2.5	11.3	14	200	750	400	24.0	16.7	497.0	2,800
South Muddy Creek, McDowell County	10.0	20.0	13	120	2,150	915	19.0	16.5	2,033.0	11,200
South Carolina										
Thicketty Creek, Cherokee County	10.0	15.8 14.0	4	110	1,900	630	20.0	15.0	2,800.0	14,000
Tygre River, Spartanburg County	35.0	31.0 18.0	8	180	2,100	730	32.0	12.0	3,990.0	16,000
North Carolina										
Silver Creek, Burke County	12.0	24.0	14	110	2,450	1,140	23.0	17.0	3,050.0	17,200

flood plains in the belt contain about 3–4 million cubic yards of alluvium.

ORIGIN

The monazite-bearing flood-plain sediments in the Inner Piedmont belt were, and are being, formed by streams as overbank deposits and point bars. Overbank materials are deposited from high water standing or flowing outside the channel of the stream, and point bars are sedimentary deposits formed in stream channels at the convex side of a bend (Wolman and Leopold, 1957, p. 91). Overbank deposits have also been called deposits of vertical accretion, and point bars have been called deposits of lateral accretion (Happ and others, 1940, p. 22–31). In the field, distinctions between the two classes of deposits are often difficult to make, because the features diagnostic of the processes are often obscure. The literature reflects this difficulty: Happ, Rittenhouse, and Dobson (1940, p. 26) argue for the dominance of deposits of vertical accretion in flood plains, and Wolman and Leopold (1957, p. 96), in a well-reasoned account, estimate that as much as 80 or 90 percent of a normal flood plain consists of deposits of lateral accretion.

The reddish-brown sandy silt that generally forms the upper unit in flood-plain deposits in valleys in the Inner Piedmont belt was deposited during the 150-year period since agriculture was widely introduced in the region. This silt occurs across the full width of most flood plains and constitutes 16 percent of the aggregate thickness of flood-plain deposits bored by auger. This silt is not likely to have formed by deposition behind point bars, unless the rate of lateral migration of streams in the Inner Piedmont was sufficient to permit the streams to migrate laterally completely across their valleys since about 1800 to 1840. No records of the rates of lateral migration were obtained during the placer appraisal, but possibly significant, though indirect, evidence was given by many landowners who granted permission for project personnel to drill on their property. Property lines along flood plains commonly were reported to be the present channel of the stream. When the owners were asked if shifting of the stream added or subtracted from the size of their fields where the stream was used as a boundary, the common report was that there had been little observable change in the position of the stream since they had owned the land. Most such expressions imply a reasonably stable position for the stream since at least 1900. There is no reason to think that there was any unusual instability in the local rates of lateral migration between the introduction of agriculture and 1900. Thus, it would seem reasonable to infer that most of these streams did not migrate across their valleys during agricultural time. For this reason we think the reddish-brown sandy silt was not deposited in point bars but that it consists of overbank deposits. Thus, about 15 percent of the flood plain deposits can be attributed with some assurance to processes of vertical accretion.

A somewhat smaller percentage of the flood-plain sediment can with some confidence be attributed to processes of lateral accretion than to those of vertical accretion. The gravel at the base of the section of flood-plain deposits was most probably deposited by processes of lateral accretion instead of overbank sedimentation. This gravel composes about 10 percent of the flood-plain deposits in the segment of the Inner Piedmont between the Savannah and Catawba Rivers (Overstreet, Theobald, Whitlow, 1959, p. 710–711).

Observations made during the placer appraisal give little basis for partitioning the remaining 75 percent of the flood-plain deposits between those formed by vertical accretion and those originating by lateral accretion. If the color change used to separate agricultural from preagricultural flood-plain deposits is fallible, and some of the underlying yellow and gray sediments are also of agricultural age, as well they may be, then the percentage of young sediments deposited by vertical accretion would be increased. To this percentage would have to be added the unknown percentage of vertical accretion deposits present in the preagricultural sediments. From these minimum requirements it would seem that the estimate of Wolman and Leopold (1957, p. 96) assigns too small a role to deposits of vertical accretion, and that, instead of composing 10–20 percent of the flood-plain deposits in this region, they compose at least 20 percent and possibly several times that amount.

GEOLOGIC CONTROL OF MONAZITE PLACERS

The term "monazite placer" as here used means a mechanical concentration of monazite in alluvial or colluvial sediments in which the amount of monazite in a unit volume of the sediment is greater than the average amount of monazite in a unit volume of crystalline rocks. The threshold amount of monazite in sediments needed to meet this criterion is about 0.05 pound per cubic yard in the Inner Piedmont belt, where the average amount of monazite in crystalline rocks is about 0.002 percent. The term is used without economic implication.

Placers may contain as much as 50 pounds or more of monazite per cubic yard, but the average tenor is 0.8 pound of monazite per cubic yard in segments of the Inner Piedmont belt between the Savannah and Catawba Rivers, SC.–NC., and the Oconee River, Ga.

Elsewhere, the average tenor is less. Throughout the belt the tenor is in inverse ratio to the size of the flood plain and the thickness of fine-grained sediment.

Placers formed in stream sediments near the source rocks are individually not a significant part of the total monazite resources in the area, but they are very numerous; hence, they collectively contain about one-third as much monazite as large placers farther downstream (Overstreet, Theobald, and Whitlow, 1959, p. 714). In the headwater areas the streams have gradients of 30–155 feet per mile. Valleys are V-shaped or narrow U-shaped, and streams flow on bedrock or coarse gravel. A rapids-pool type of stream bed commonly forms where bedrock is differentially resistant to erosion. Flood plains are absent or imperfect and discontinuous. Where present, they are seldom greater than 200,000 square yards in area, or 1 million cubic yards in volume. Their distribution serves as a valuable guide to the location of larger downstream placers.

Downstream placers are inferior to the headwater placers in tenor in monazite, but because they contain from several to 20 million cubic yards of ground in broad shallow U-shaped valleys, they represent possible sites for large-scale low-unit-cost mining operations should the need arise and the price of monazite justify their exploitation. They contain about three-quarters of the placer-monazite resources in the region (Overstreet, Theobald, and Whitlow, 1959, p. 714).

Placers at the sources of the streams were formerly mined, but the downstream placers have not been mined.

SOURCE ROCKS AND STREAM GRADIENT

Monazite placers are irregularly distributed in the Inner Piedmont belt. Their frequency distribution varies not only among major drainage systems, but also among tributaries in a given system and along reaches of the same tributary. Sediments of similar lithology and texture contain variable amounts of monazite for short distances along streams, and they do not display the logarithmic pattern in the distribution of tenors experimentally obtained by Wertz (1949). Some of this distributive irregularity can be attributed to variable local conditions of sedimentation, but the principal factors are the occurrence of monazite in crystalline rocks (Overstreet, Yates, and Griffitts, 1963a, 1963b) and downstream decrease in stream gradient.

The drop in tenor of fluvial sediments between headwaters and trunk drainage shows that, in the present cycle of stream activity, monazite is subject to dilutive and dispersive influences from areas of monazite-rich source rocks into areas of monazite-lean or monazite-free rocks. Dilutive influences are caused by a lessening of the amount of monazite in the source materials, but the dispersive influences are related to the decrease in gradient of the streams and to the physical properties of monazite.

The highest concentrations of monazite are in thousands of small placers at the extreme headwaters of streams rising in the high-rank metamorphic core of the Inner Piedmont belt where monazite-rich rocks are present (Overstreet, Yates, and Griffitts, 1963b). These placers were reported by J. B. Mertie, Jr. (1953, p. 10), to average 8.4 pounds of monazite per cubic yard in the part of the belt which formerly was most widely mined for monazite; they were found by us to average 4 pounds of monazite per cubic yard in the segment of the belt between the Savannah and Catawba Rivers (Overstreet, Theobald, and Whitlow, 1959, p. 714). The concentration of monazite in flood-plain sediments drops off abruptly to about 1.5 pounds per cubic yard where flood plains larger than 1 million cubic yards in volume are found a few miles downstream from headwaters. Farther downstream the decline reaches 0.4 pound of monazite per cubic yard or less. This abrupt decrease in tenor is caused principally by the lowering of the gradient of the stream, to which is related a possible increase in relative volume of deposits formed by vertical accretion, giving rise to thick sequences of fine-grained sediments. Comminution of monazite during stream transport, owing to its brittleness, may result in the fine-grained monazite being transported out of the flood-plain section and dispersed downstream with other fine-grained particles, but data on grain size of monazite downstream from the Inner Piedmont belt are lacking.

Influx of monazite-poor sediments from different distributive provinces is a minor factor in the decrease in tenor in the core of the belt, but it is an important factor on the flanks of the belt and is the dominant factor downstream from the belt. Following the abrupt reduction in tenor near headwaters, the average tenor of flood-plain deposits in large streams gradually diminishes toward the mouth. For example, on Buffalo Creek, Cleveland County, N.C., and Cherokee County, S.C., the tenor diminishes from 1.2 pounds to 0.3 pound per cubic yard over a distance of 30 miles (Griffith and Overstreet, 1953b, p. 15; Hansen and Theobald, 1955, p. 25). At its head the stream is in the core of the belt, but at its mouth it is on the southeast edge of the belt. In trunk drainage, as the size and number of tributaries increase, adulteration by suites of heavy minerals from monazite-free areas becomes dominant. Thus, the larger the flood plain and the farther downstream it lies from the monazite-rich rocks in the core of the Inner Piedmont belt, the lower is its average tenor in monazite. These relations are clearly seen if the map showing tenor and size of flood-plain deposits in the area between the Savannah and Catawba Rivers (pl. 7) is compared with maps showing isograms for sillimanite (pl. 2), garnet (pl. 2), and monazite (pl. 3). Placers with tenors of 3 pounds of monazite per cubic yard or greater are restricted to the headwater parts of streams in the core of the belt where concentrates contain more than 1 percent sillimanite, more than 5 percent garnet, and more than 20 percent monazite. The lowest tenor deposits are on the flanks of the belt and in large valleys with gentle gradients of a few feet per mile. The average regional slope of the land is but 4 feet per mile. Stream energy on this low slope has been too small to favor the formation of rich placers in large flood plains in the short time during which the Recent sediments have been deposited.

ROLE OF COLLUVIUM AND RESIDUAL SOILS

The processes forming colluvium and residual soils cause a concentration of monazite greater than that in bedrock. Locally, these materials are rich enough in monazite to have been mined, but their principal role is as an intermediate host for monazite between bedrock and the fluviatile sediments. Colluvium and residual soil in the drainage basin of Knob Creek, Cleveland County, N.C., generally contain two to five times as much monazite as the parent rock and locally contain 100 times as much monazite as the parent rock (tables 16, 17). Colluvial deposits tend to be richer in monazite than residual soils, and the distribution of monazite is more uniform between the top and bottom of colluvial deposits than it is in residual deposits. An example of the rather uniform tenor of colluvium is shown by the data obtained from a churn-drill hole (K26) sunk by the U.S. Bureau of Mines on December 27–28, 1951, on the upper western flank of an interstream area on the Bradshaw farm in the Knob Creek basin, Cleveland County. The hole penetrated 20½ feet of bouldery colluvium that averaged 2.1 pounds of monazite per cubic yard and ranged in tenor from 1.5 to 2.8 pounds of monazite per cubic yard (R. F. Griffith, written commun., 1951).

Many sites formerly mined for monazite are along reaches of streams where most tributaries are gullies incised in colluvium. Some old monazite mines were actually restricted to long narrow gullies that expose only colluvium. Some colluvial deposits, especially sheet-wash sediments, were mined. Of course, not all the monazite in the fluviatile placers passed through colluvium or residual deposits before being released to streams, because erosion exposes saprolite, and monazite enters streams directly from such exposures. However, streams receiving detritus from relatively large areas of colluvium and residual soil and relatively small areas of saprolite are recalled by former miners as being the sites of the richest fluvial placers. Some rich lenses of sediment in intermediate and large-size

TABLE 16.—*Tenor of monazite in saprolite and derived residual topsoil in the drainage basin of Knob Creek, Cleveland County, N.C.*

[Tenors computed from mineral analyses by M. N. Girhard, H. B. Groom, Jr., R. P. Marquiss, C. J. Spengler, Jerome Stone, and E. J. Young, U.S. Geol. Survey]

Saprolite or residual soil derived from—	Sample	Pounds monazite per cubic yard	
		Saprolite	Topsoil
Biotite gneiss	52-JW-75	0.248	
	76		0.416
	81	.131	
	82		.867
	53-JW-89	.047	
	91		.037
	101	.005	
	52-JW-450		.086
	53-JW-106	.028	
	108		.079
	Average	.092	.297
Toluca Quartz Monzonite.	52-JW-364	.158	
	355		.194
	314	.505	
	53-JW-3		1.160
	5	.052	
	7		.311
	15	.127	
	17		.202
	65	.114	
	67		.181
	79	.110	
	81		.553
	85	.100	
	87		.385
	Average	.167	.427
Biotite schist	53-JW-9	.194	
	11		.230
	19	.008	
	21		.229
	23	.006	
	25		.267
	31		
	33		.052
	45	.011	
	47		.040
	Average	.044	.164
Sillimanite schist	53-JW-27	.032	
	29		.241
	37	.002	
	39		.046
	41		
	43		.067
	49	.127	
	51		.248
	53	.050	
	55		.225
	59	.036	
	61		.578
	69	.116	
	71		.266
	75	.239	
	77		.092
	Average	.075	.220

flood plains appear to be fans composed of detritus swept onto the flood plains from gullies that cut colluvium.

TABLE 17.—*Tenor of monazite in residual subsoil and colluvial subsoil in the drainage basin of Knob Creek, Cleveland County, N.C.*

[Tenors computed from mineral analyses by M. N. Girhard, H. B. Groom, Jr., R. P. Marquiss, C. J. Spengler, Jerome Stone, and E. J. Young, U.S. Geol. Survey]

Sample	Pounds monazite per cubic yard	Sample	Pounds monazite per cubic yard
Residual subsoil			
52-JW-37	0.911	52-JW-139	0.333
70	.276	188	.262
77	.290	356	.603
78	.552	357	.198
79	.445	358	.177
80	.168	359	.249
99	----------	452	.125
138	.902		
		Average	.366
Colluvial subsoil			
52-JW-4	1.602	52-JW-141	2.806
123	.269	168	.106
124	.200	169	10.144
140	6.762		
		Average	3.127

RELATION OF MONAZITE TO FLUVIATILE SEDIMENTS

The richest concentrations of monazite are in coarse-grained sediments at the base of the flood-plain sequence and in the present stream channels. Poorest concentrations are in fine-grained sediments throughout the sequence. For the Savannah River-Catawba River segment of the monazite-bearing part of the Inner Piedmont belt, the tenors of three major classes of sediment are (Overstreet, Theobald, and Whitlow, 1959, p. 710–711):

Class of sediment	*Pounds monazite per cubic yard*
Clay	0.2
Silt and sand	.8
Gravel	1.7

The low tenor of the clays, silts, and fine sands explains the low average tenor of large downstream flood-plain deposits where only thin layers of gravel are buried under fine-grained sediment 20 feet or more thick.

It is rare for the full sequence of flood-plain deposits between grass roots and bedrock to average more than 3 pounds of monazite per cubic yard of sediment (pl. 7). Where this average is attained or exceeded, the proportion of coarse clastics to total thickness of alluvium exceeds 15 percent, the coarser sediment averages well over 3 pounds of monazite per cubic yard, and the fine-grained sediment averages about 1 pound per cubic yard.

Fine-grained sediments, whether formed by vertical accretion or lateral accretion, are deposited from suspended load composed chiefly of small particles of low specific gravity. Coarse-grained sediments are deposited from traction load in which active sorting favors concentration of particles in the coarser grades and higher ranges of specific gravity. Coarse monazite and other heavy minerals tend to be trapped among the pebbles and cobbles of the coarse-grained sediment and are not so readily moved downstream as fine-grained monazite in the suspended load. Because such a small proportion of the available detritus is coarse grained, there is little to enter the traction load of the stream, and thick high-tenor deposits have not formed.

INFLUENCE OF AGE

Most sediments in the flood-plain deposits are Recent in age and may be only a few thousand years old, but the valleys themselves are much older. Seemingly, monazite has been transported continuously downvalley with little long-term accumulation. The youth of the sediments and the failure of monazite to lag in the valleys have also operated to prevent large rich placers being formed.

METHODS USED IN RECONNAISSANCE STUDY

The methods used in the reconnaissance study of the monazite placers were devised for a rapid examination of the streams to give a uniform factual base upon which the separate streams could be compared as sources for detrital monazite. The objective of the reconnaissance was a first approximation of the tenors and reserves in the fluvial monazite placers, because the placers occur over thousands of square miles and only a short time was allowed for fieldwork. This first approximation could be made, and the separate streams appraised, by evaluating certain features of the streams: (1) area of flood plains, (2) continuity of flood plains, (3) thickness and composition of the flood-plain sediments, and (4) approximate tenors of the different types of sediments in the separate drainage basins.

In practice, the evaluation of these four features began in the field, continued in the laboratory, and was completed in the office. Accordingly, the methods described below are divided into field, laboratory, and office procedures.

FIELD PROCEDURES

Fieldwork consisted of marking the margins of flood plains on aerial photographs, ground checking to correct any errors, sampling, panning and measuring stratigraphic sections. The work was conducted by teams consisting usually of one geologist and a field assistant. The teams worked from temporary headquarters to cover a radius of 20–30 miles; when they had completed an area defined by the working radius, they moved to another locality.

INTERPRETATION OF AERIAL PHOTOGRAPHS

No uniform topographic or planimetric maps cover the area at a scale adequate to permit defining the narrow flood plains along most of the streams; hence, the margins of the flood plains were plotted on aerial photographs having approximate scales of 1:20,000 and 1:24,000. Courses of the streams and the position of the margins of the flood plains were interpreted and penciled on stereopairs of aerial photographs with the aid of pocket stereoscopes. The penciled interpretations were checked in the field and modified as required. Interpretations were easier and more accurately made on photographs flown after 1945 than on earlier ones. Subsequently, as described in the section on "Office procedures," uncontrolled mosaics were made from the photographs, and from them, planimetric maps were drawn to show the roads, streams, and flood plains.

Several common topographic, cultural, and vegetational features were found to interfere with the interpretation of the photograph. Gentle slopes leading to flood plains, alluvial fans, and accumulated slope wash along the toes of the flood plains resulted in interpreted margins of the flood plains being placed on the actual valley walls. The dredged edges of a few flood plains and fill for highways and railways at the edges of the flood plains resulted in the interpreted margins being placed on the actual flood plains. Some patterns of logging or planting near the margins of the flood plains obscured the actual contacts of the alluvium and resulted in interpretations that were either too wide or too narrow. The reliability of the stereoscopic interpretations is discussed in the section on "Office procedures."

SAMPLING

Many samples were taken from stream sediments and other materials for a wide variety of analyses. The distribution of these samples is shown on plate 8.

By far, the largest group is the 4,245 grab samples of alluvium and colluvium taken for mineral, spectrographic, and chemical analyses and used to compute tenors in the five areas from Virginia through Georgia. Much smaller collections were made of alluvium for paleontologic and carbon-14 analyses and of alluvium, colluvim, and saprolite for mechanical analyses.

SAMPLES FOR MINERAL, SPECTROGRAPHIC, AND CHEMICAL ANALYSES

Grab samples of channel and flood-plain sediments were taken along streams in the monazite belt and on each side of the belt and panned to recover the contained heavy minerals. Mineral analyses (grain counts) of 4,245 heavy-mineral concentrates were made to estimate the tenor in monazite of the alluvium, to show the kinds of associated minerals, and to learn the size distribution among the components of the concentrate. Spectrographic analyses were made on 145 of the concentrates to check for tin, tungsten, tantalum, and niobium in the placer deposits. Chemical analyses for niobium were made on eight ilmenite separates, four rutile separates, and six rutile concentrates prepared from heavy-mineral samples taken at areas recommended for churn drilling to discover whether there was any unusual enrichment in niobium in the associated minerals in the most favorable monazite placers.

Samples were taken at intervals of 1–2 miles along the streams. The first sample collected at a locality was a concentrate panned from riffle gravel or riffle sand forming the bed of the present channel of the stream—these are called "riffle samples" in the text of this report. If the riffle sample was barren of monazite, no further collecting was done at that locality; but if the riffle sample contained monazite, then samples were also taken of the alluvial sediments exposed in the banks of the stream. These are called "bank samples." The riffle samples were the immediate guide to reconnaissance and provided the control used in establishing the distribution of the monazite. A net of barren samples was extended 4–8 miles beyond the northwestern and southeastern margins of the monazite-bearing areas to insure complete coverage.

Where the riffle samples contained monazite and bank samples were taken, the material collected was selected to represent the section of sediment exposed in bank. A face was cleaned on the bank, samples were cut from the dominant classes of sediments, and the vertical heights of the samples above the bed of the stream were recorded. Thus, if a basal layer of gravel was overlain by clay, sand, and sandy silt, one sample of each was taken. Bank sediments are the source of information about the relation of tenor to composition of the sediment and to the vertical interval above the bed of the stream.

Riffle samples were taken upstream from bridges to avoid contamination from sand and gravel used in surfacing roads. It was discovered that the State Highway Departments hauled sand and gravel 5–15 miles from sand pumps or dragline scrapers at one stream for use on dirt roads. After the sand had been placed on the road it would work into streams, as traffic or scraping carried it onto bridges and rain washed it into drainage ditches. Samples from the upstream side were considered to be more representative of the average bedload of the streams.

No system of dry weighing the sample of alluvium was adapted to rapid reconnaissance, and the wet weights of the samples were too variable to be meaningful. Therefore, the volume of the sample was measured after it was dug and before it was screened and panned. Samples of uniform volume and adequate size to give a large enough concentrate for laboratory study were taken. Later the volume was corrected for swell (see the discussion of swell under "Office procedures") to adjust the measured volume of the dug sample to its probable volume in place. The container for measuring the volume of the sample needed to be easily portable and readily replaceable in the field; these requirements are met by the common 10-quart pail. Its volume is 0.34 cubic foot. After screening and removal of clay, a sample originally 0.34 cubic foot in volume would make one to two charges for a standard 16-inch gold pan. This size of sample gives an adequate concentrate.

After the sample was dug from the streambed, or from the cleaned bank of the stream, and measured, it was washed and screened before panning. Clayey samples were slowly kneaded in the gold pan in a protected place in the stream out of the current to remove the clay and to allow sand and the heavy minerals to remain in the pan. Samples of silt, sand, and gravel were passed through two nesting screens made of punch plate perforated with 1/4- and 1/8-inch holes. The −1/8-inch material coarser than silt was caught in a 16-inch pan. Volumes of the sand, following removal of clay, and the volumes of the −1/8-inch material coarser than silt, following screening, were measured and recorded as the "volume panned." The volumes of +1/4-inch and −1/4-inch +1/8-inch debris were measured and recorded as "oversize." For each sample an estimate was made of the shape of the oversize fraction. The degree of rounding—as rounded, subrounded, subangular, and angular (Krynine, 1948, p. 142)—was described, and the maximum intermediate dimension of the largest fragment in the sample was recorded.

Following the selection, screening, and description of the sample, the sized fraction was panned to recover a heavy-mineral concentrate from the alluvium. The recoveries obtained by panning the different sediments are given in a section below. The number of samples collected, described, and panned by a geologist and his assistant in one day depended upon the accessibility of the localities where the samples were collected. Collections ranged in number from 6 to 17 samples and averaged 10 samples a team per day. After the sample was panned, the concentrate was wrapped; later it was dried and bottled. When the samples were bottled, individual 5- by 8-inch cards were filled out with a description of the sample, its location, and number. The number of each sample and its location were plotted on county road maps having a scale of 1 inch = 1 mile.

Groups of concentrates were shipped monthly to the U.S. Geological Survey for mineral and spectrographic analyses.

PANNING

The heavy-mineral concentrates used for estimates of the tenors of monazite in alluvium, colluvium, residual soil, and saprolite were obtained by panning the sample in a standard 16-inch stainless steel pan after screening and removal of clay. Panning techniques have been discussed by Frank Smithson (1930); C. J. C. Ewing (1931); A. P. Sigov (1953(?), p. 3); Robert Peele and J. A. Church (1941, p. 10–537); J. B. Mertie, Jr. (1954, p. 647); and N. R. Junner (1955). A study of the recovery of heavy minerals in panning was made during this investigation, and the results have been published by P. K. Theobald, Jr. (1957). He found that the features of a sample that have the greatest effect upon recoveries of the heavy minerals are the specific gravity and grain size of the minerals and their sorting. He also noted that the greatest losses of wanted minerals occur during the last part of the panning process. The average recoveries of heavy minerals having specific gravities of 4.0 or more at the first panning of riffle samples are (Theobald, 1957, p. 21):

Mineral	*Recovery (percent)*	*Mineral*	*Recovery (percent)*
Monazite	84	Ilmenite	64
Zircon	72	Hematite	62
Rutile	68	Magnetite	59

Recoveries of minerals with specific gravities lower than 4.0 are less than the recoveries for the heavier minerals and range downward to about 25 percent for tourmaline with a specific gravity of 3.1. Recoveries of heavy minerals from clay and silt samples are less than the recoveries from sand and gravel. In some samples of particularly fine-grained material they are as low as half the recovery from riffle samples.

STRATIGRAPHIC DESCRIPTIONS AND MEASUREMENTS

Stratigraphic descriptions and measurements of the flood-plain sediments were made to guide estimates of the thickness and composition of the alluvium. In the office stages of the reconnaissance the stratigraphic measurements were related to the areas of the different flood plains for estimates of the volume and composition of sediment in the flood plains.

Megascopic field descriptions of the alluvium were used throughout the work. A fourfold classification according to grain size was employed in which the major texture of each sedimentary mixture was described as gravel, sand, silt, or clay. Appropriate combinations of these terms were used for the subtextures, which were further modified by adjectives denoting color, varietal minerals, organic components, and size of the grains.

The main classes, clay and silt, were identified in the field by the feel and cohesiveness of the sediment. Various uncohesive, gritty, fine- to coarse-grained sediments were called sand or gravel, depending upon the quantity of material from the original volume (0.34 cu ft) that remained in the pan after washing and screening through a ⅛-inch punch plate. In two-component mixtures of sand and gravel the sediment was called sand if 0.18 cubic foot or more of material passed through the punch plate; the sediment was called gravel if less passed through the plate. Three- or four-component mixtures were classified as gravel or sand depending upon whether the dominant constituent was retained on the punch plate or was recovered in a pan below the plate.

The stratigraphic sequences and thicknesses of the flood-plain deposits were obtained directly by measurement of sections exposed in the banks of streams and by auger-drill holes or approximately by estimate where exposures were lacking and the ground was not drilled.

MEASUREMENT OF EXPOSED SECTIONS

At each place where a sample was taken, the flood-plain sediments exposed in the bank of the stream were measured and described, and other exposures for 200–500 yards upstream and downstream were examined to add supplemental measured sections to the one recorded at the sample locality. Usually, the bank was shoveled clean before the sediments were described. About 4,000 exposures of flood-plain sediments were measured.

MEASUREMENT BY AUGER DRILLING

Two types of auger drills were employed to determine the thickness and composition of the sediments. A hand auger was used to drill 11 holes totaling 90 feet in depth in the drainage basin of Knob Creek, Cleveland County, N.C., and a power auger was used to drill 611 holes totaling 10,054 feet in depth in the five areas from Virginia through Georgia.

The power drill was mounted on a four-wheel-drive truck, and used 4.5-inch augers connecting in 5-foot flights. The auger-drill holes were not cased. In most silt and clay and in some sand and gravel the walls held perfectly, but they caved in loose, wet sand and gravel. Auger drilling was used solely to measure the thickness of alluvial sediments and for descriptions of stratigraphic sequence.

In about 85 percent of the holes the bedrock was saprolite which could be drilled as easily as the alluvium. The characteristic textures and structures of the crystalline rocks are preserved in the saprolite and served to identify the pieces adhering to the auger flights. Also, saprolite usually drilled either faster or slower than the overlying alluvium; thus, the depth at which the power auger entered the saprolite could be determined by the way the drill handled. If the bedrock was unweathered, the auger bit could not penetrate it. Where the auger stopped on an unweathered surface of rock, some doubt lingered about actual depth to bedrock, because an unweathered boulder could have stopped the drill. This doubt was resolved by offsetting a few feet and sinking a second hole or by comparing the stratigraphic sequence in the hole bottoming on unweathered rock with the sequences and depths of holes that penetrated saprolite in the same line.

Sharp changes in lithology were recognized by the cuttings on auger flights and by changes in the sound and rate of advance of the drill. Attention to the behavior of the drill, use of 5-foot advances, examination of the sequence of cuttings from each advance, and test drilling adjacent to exposures in the banks of streams, assured identification of lithologic breaks within a maximum error in depth of 6 inches. Some of the most useful stratigraphic measurements, such as the depth from the collar of the hole to the top and bottom of layers of gravel, are correct to within 1 inch. For uniformity of stratigraphic descriptions among the different areas drilled and to take advantage of accumulated experience in drilling, one member of the project, P. K. Theobald, Jr., did all the drilling and was assisted locally by the personnel of the separate field teams.

ESTIMATES OF DEPTH TO BEDROCK

Estimates of total depth of the alluvium between the top of the flood plain and bedrock were made at all locations where samples were taken and the full sequence of the sediments was not exposed. These estimates were controlled by exposures seen upstream and downstream from a locality, size of the stream, width of the flood plain, angle of the valley walls, probable degree of weathering of the bedrock, and stratigraphic sequence and thicknesses of flood-plain sediments in adjacent drainage basins. Such on-the-spot estimates were subject to later review in the office when fieldwork was completed and all evidence on local thicknesses could be evaluated. At many places the estimates could be compared with subsequent auger or churn drilling. An analysis of the accuracy of estimated depths at 51 localities subsequently drilled is given under "Office procedures" in the discussion of the reliability of estimates of volume.

LABORATORY PROCEDURES

Laboratory work on samples from the monazite reconnaissance included: (1) mineral analyses of all heavy-mineral concentrates; (2) semiquantitative spectrographic analyses of selected concentrates to determine distribution and abundance of tin, tungsten, niobium, and tantalum; and (3) chemical analyses of 18 samples of ilmenite and rutile and rutile concentrate for niobium.

MINERAL ANALYSES

By Jerome Stone

GENERAL FEATURES

Mineral analyses were made on heavy-mineral concentrates shipped from the field to the U.S. Geological Survey in Washington, D.C. Thirteen shipments totaling 4,245 samples were received from August 1951 to August 1953. The analyses were made by R. M. Berman, Jerome Stone, M. N. Girhard, H. B. Groom, Jr., R. P. Marquiss, J. P. Owens, L. A. Weiser, M. E. Morisawa, C. J. Spengler, and E. J. Young. Edward Williams and Paul Benson assisted throughout in the preparation of samples and in the computations.

A method of analysis was soon established, but it became evident that modifications would be necessary to handle the numerous samples that were being submitted. The method of analysis and its modifications are described below. The final method developed, which saved much time and expense, could be used in other projects where many samples are handled.

Preliminary study of prepared mixtures of the heavy minerals was designed to familiarize the mineralogists with the suites of minerals from the southeast and to evaluate each procedure to be used in the analysis. This preliminary work greatly increased the confidence that the mineralogist had in the procedures and in his identifications.

The prepared mixtures were blends of heavy minerals which had been separated from samples and recombined in known amounts. The heavy minerals were separated from the original samples by use of a hand magnet, bromoform, and methylene iodide, the Frantz Isodynamic Separator, and handpicking. To prepare minerals for recombination, the magnetite was first removed from the concentrate by a hand magnet. Then the concentrate was poured into a separatory funnel nearly filled with bromoform (sp gr=2.86) to remove the quartz and feldspar. The minerals heavier than bromoform were washed with acetone and poured into a separatory funnel which contained methylene iodide (sp gr=3.3).

The sink and float (table 18) were separated into magnetic fractions with the Frantz Isodynamic Separator, using a cross tilt of 11°, a vertical angle of 15°, and various currents, and the magnetic fractions were further concentrated by handpicking.

Table 18.—*Magnetic susceptibilities of heavy minerals from the monazite placer area*

Mineral	Current at which mineral becomes magnetic at a cross tilt of 11° and vertical angle of 15° (amperes)
Specific gravity less than 3.3 [The float of methylene iodide]	
Amphibole and pyroxene	0.3–0.4
Biotite	0.3–0.4
Epidote	0.4–0.5
Tourmaline	0.55–0.75
Muscovite	0.7–1.0
Sillimanite	1.0 to nonmagnetic
Specific gravity greater than 3.3 [The sink of methylene iodide]	
Ilmenite	0.1–0.4
Garnet, pink	0.2–0.45
Hematite	0.3–0.4
Xenotime	0.3–0.4
Monazite	0.4–0.7
Staurolite, zircon (metamict), rutile, kyanite, sphene.	1.0
Zircon (pink or colorless), pyrite	Nonmagnetic

Mixtures of minerals were prepared from the separates and were counted under binocular and petrographic microscopes. Evaluation of the two procedures showed that the binocular microscope was more suitable for grain counting than was the petrographic microscope where large numbers of mineralogically similar samples are to be examined. Use of the binocular microscope was found to decrease the time consumed in preparing slides for counting, reduce fatigue, and permit additional examination of any particular grain. As a result of this study about three-fourths of the samples were ultimately counted with the binocular microscope. The petrographic microscope was used periodically to check identifications.

The preliminary studies showed that most of the minerals are readily distinguishable under a binocular microscope, but some of the minerals can be confused. For example, epidote, sphene, and xenotime can be confused with monazite. Table 19 outlines properties useful in distinguishing the minerals in concentrates from the monazite-placer area.

The radioactivity, magnetic susceptibility, discontinuous absorption of visible light, and indices of refraction of monazite were used to check the results of the grain counts on bulk samples and (or) individual grains. The radioactivity of a standard sample of monazite was compared with that of an unknown sample by

TABLE 19.—*Optical and crystallographic properties of heavy minerals from the monazite placer area*

Minerals that may be mistaken for each other when studied with the binocular microscope				Characteristics of minerals immersed in methyline iodide ($n=1.74$) and studied with the petrographic microscope			
Mineral	Color	Luster	Remarks	Relief [1]	Interference figure	Birefringence	Remarks
			Colorless to white				
Quartz	Colorless	Vitreous	Commonly irregularly shaped	Very high (−)	Uniaxial (positive).	Very weak	
Zircon	Colorless to faint pink, brown if metamict, rarely yellow.	Adamantine	Commonly found in −170-mesh fractions as long slender tetragonal prisms; yellow zircon may be confused with monazite.	Very high (+)	do	Very strong	Extinction parallel to elongation.
Sillimanite	Colorless to white	Vitreous	Very perfect cleavage parallel to (010), prismatic crystals are generally striated; also occurs in fibrous form.	Moderate (−)	Biaxial (negative) $2V$ ca. 25°.	Moderate	Do.
Kyanite	Colorless to white or bluish white.	do	Perfect cleavage parallel to (100), prismatic crystals common.	Low (−)	Biaxial (negative) $2V$ ca. 80°.	do	Extinction inclined to elongation.
			Red and orange				
Staurolite	Orange, red	Vitreous to resinous.	May be mistaken for rutile; the luster will often distinguish staurolite from rutile.	Low (+) Moderate (+)	Biaxial $2V$ ca. 80°.	Rather weak	Pleochroism distinct from nearly colorless to yellow brown.
Garnet	Pink to red, orange.	Vitreous	Weathers with red crust; commonly dodecahedral faces can be observed; spessartite is usual variety.	Moderate (+)			Isotropic.
Rutile			See under "Rutile" below				See under "Rutile" below.
			Yellow and green				
Epidote	Various shades of green.	Vitreous	This mineral can be easily mistaken for monazite; the color of epidote is distinctive; epidote is characteristically more angular than monazite.	Low (+) Low (−)	Biaxial $2V$ ca. 80°.	Moderate to strong.	Pleochroism in shades of green noticeably stronger than in monazite; optic axis figure is commonly observed.
Monazite	Yellow, rarely yellowish green, brown.	Resinous	Grains are characteristically round; prismatic crystals are common and some are terminated; radioactive; when viewed with the hand spectroscope either through the binocular or petrographic microscope, a broad absorption band is seen in the yellow and a faint, narrow band is seen in the green if Nd and Pr are present.	Moderate (+) Strong (+)	Biaxial (positive) $2V$ ca. 14°.	Strong	Some disseminated inclusions.
Xenotime	Yellow, rarely yellowish green.	Vitreous, resinous.	Very similar to monazite; bipyramidal crystals common; when viewed through the hand spectroscope, one or two absorption bands can be seen in the green with none in yellow, if Ho and Er are present.	Low (−) Strong (+)	Uniaxial (positive).	do	Square cross sections are common.
Sphene	Yellow, brown	Adamantine, resinous.	Crystals are wedge shaped	Strong (+) Extreme (+)	Biaxial (positive) $2V$ ca. 30°.	Extreme	Acute bisectrix figure is commonly observed.
			Nearly opaque or opaque				
Ilmenite [2]	Black	Submetallic	Most readily distinguished when leucoxene has formed on the grains.	Opaque			
Amphibole, pyroxene.	Colorless, pale green, dark green to black.	Vitreous, pearly on cleavage face.	Most readily distinguished by luster and splintery fracture.	Moderate (−)	Biaxial	Moderate	Extinction inclined to cleavage fragments (amphibole); pleochroism is generally pale green to black.
Tourmaline	Yellow black	Resinous	Grains often have to be rotated in order to observe the light which may be transmitted only through thin edges; hexagonal prism faces with striations parallel to c-axis are common.	Moderate (−)	Uniaxial	do	Extinction parallel to elongation; pleochroism is generally pale black; light is transmitted only through some thin edges.
Rutile	Red, yellow, black.	Adamantine	Grains may have to be rotated in order to observe the transmitted light; tetragonal prisms with striations parallel to c-axis are rarely seen; may be mistaken for staurolite.	Extreme (+)	Uniaxial (positive).	Extreme	Intense light may be necessary to distinguish rutile from an opaque mineral.

[1] The (+) symbol indicates that the mineral has an index of refraction greater than that of methylene iodide. The (−) symbol indicates that the mineral has an index of refraction less than that of methylene iodide.

[2] All black submetallic opaque minerals not removed by a hand magnet were assumed to be ilmenite.

scanning the unknown with a beta-gamma counter. Marked differences in the radioactivity may result from differences in the amount of monazite in the unknown and standard samples; different percentages of thorium and other radioactive elements in the monazite of the unknown and standard samples; the presence of radioactive minerals other than monazite, such as thorite or metamict zircon, in the unknown sample; or misidentification of the monazite in the unknown sample. The magnetic susceptibility of monazite allows most of the monazite to be removed from the concentrate by means of the isodynamic separator set with a cross tilt of 11° and a vertical angle of 15°, and operated at 0.45–0.7 ampere. With the same settings, almost all the xenotime will be removed at 0.4 ampere, and most of the epidote will be removed at 0.45 ampere. The weight of the magnetically separated monazite can be compared with the grain count. Individual grains of monazite can be identified by the discontinuous absorption of visible light by neodymium and praseodymium in the mineral (Wherry, 1915; Mertie, 1953, p. 5). This observation is conveniently made by inserting a hand spectroscope into the tube of either the binocular or petrographic microscope. A broad absorption band in the yellow and a narrow band in the green are characteristic of monazite. Monazite can easily be distinguished from epidote, xenotime, and sphene by its higher indices of refraction. The differences can be observed by petrographic microscope in a concentrate mounted in methylene iodide, $n=1.74$. An oil with $n=1.79$ is also useful in identifying monazite. The alpha (1.787–1.800) and beta (1.788–1.801) indices of monazite are slightly lower or higher than the oil, and the gamma (1.837–1.849) index is moderately higher than the oil. The change in relief of the monazite grain is striking when the stage of the microscope is rotated.

METHOD OF ANALYSIS

The object of the analyses was to determine the mineral composition of shipments of panned concentrates in the shortest possible time after receipt so that the field party could use the analytical data to guide further reconnaisance.

Samples received from the field were concentrates that contained 10–25 percent quartz and feldspar. It was not necessary to remove this quartz and feldspar with heavy liquids, because grain counts could be made on the material as received, counting the quartz and feldspar along with the heavy minerals. To do this, the following routine was established. Magnetite was removed from the sample with a hand magnet and weighed so that the weight percent of the magnetite in the concentrate could be determined directly. The remainder of the sample was sieved into +45-, −45+100-, −100+170-, and −170-mesh fractions in order to count grains of approximately the same diameter and to determine the size distribution of the heavy minerals. Each sieve fraction was weighed and split into portions of 200–300 grains so that a count could be made. The counts were converted to weight percents by specific gravity corrections and tabulated. Simple mineral analysis record sheets and tables were prepared for this purpose (tables 20, 21).

TABLE 20.—*Mineral analysis record sheet of sample JS–1*

[Total weight, 81.8 grams; weight of split 40.9 grams × 2; weight of magnetite 5.1 grams=13 percent]

Sieve fraction	Ilmenite	Quartz	Monazite	Zircon	Staurolite	Tourmaline	Rutile
45-mesh (weight, 7.3 g; weight percentage, 18):							
Grain count	150	15	22	--------	10	38	2
Weight units (total 401)	281	15	44	--------	15	43	3
Weight percent (total 18)	12	1	2	--------	1	2	0
100-mesh (weight, 15.2 g; weight percentage, 37):							
Grain count	140	24	2	8	----------	29	29
Weight units (total 380)	262	24	4	12	----------	33	45
Weight percent (total 37)	26	2	0	1	----------	3	5
170-mesh (weight, 13.2 g; weight percentage, 32):							
Grain count	137	15	4	11	----------	49	17
Weight units (total 380)	256	15	8	18	----------	57	26
Weight percent (total 32)	21	1	1	2	----------	5	2
−170-mesh (weight, 0.1 g; weight percentage, <1 percent):							
Grain count	92	--------	45	75	----------	30	45
Weight units	Tr.	--------	Tr.	Tr.	----------	Tr.	Tr.
Weight percent	Tr.	--------	Tr.	Tr.	----------	Tr.	Tr.

TABLE 21.—*Mineral analysis record of sample JS–1*

[Total sample weight 81.8 grams, total magnetite content, 13 grams. The weight percentage of the sieve fractions plus the weight percentage of magnetite equals 100. A "0" indicates that this mineral is present in an amount less than 1 percent. Results taken from mineral analysis record sheet]

Mineral	Sieve fraction, in weight percent				
	45-mesh	100-mesh	170-mesh	−170-mesh	Total
Ilmenite	12	26	21	0	59
Quartz	1	2	1		4
Monazite	2	0	1	0	3
Zircon		1	2	0	3
Amphibole: pyrozene	1				1
Tourmaline	2	3	5	0	10
Rutile	0	5	2	0	7
Total	18	37	32	0	87

SPLITTING

Splitting each size fraction was necessary to get representative suites of grains suitable for counting under the binocular microscope. The number of grains to be counted in one size fraction of a concentrate depended on the accuracy required and the relative abundance of the different mineral species (Dryden, 1931, p. 233–238). Dryden showed that a count of 200–300 grains would result in a probable error of 3 percent for a mineral calculated as 80 percent of the sample and 20 percent for a mineral calculated as 5 percent of the sample. Reduction of this error by counting more grains in a split requires an impractical increase in the number of grains counted for the small increases in accuracy.

Several methods of splitting were tried and discarded. Hand quartering was tried, and it was accurate enough, but it was too time consuming. Use of the microsplit designed by Otto (1933) also proved to be too time consuming. A method of splitting that was both rapid and accurate enough for the aims of the project was achieved with the multiple-cone sample splitter designed by Richard Kellagher (Kellagher and Flanagan, 1956). This splitter consists of a series of alternating funnels and cones mounted over a circular tray in which are placed several wedge-shaped retainers. A sample poured through the splitter is automatically mixed by the funnels and cones, and a split is captured by the wedge-shaped retainers. The material in each retainer is a representative sample. Two or three passes may be necessary to obtain in one retainer the 200–300 grains desired for counting. Four fractions can be split in 2 minutes.

COUNTING

The four splits are placed in small watch glasses on a record sheet. When the sample is to be counted, the mineralogist takes the record sheet, the splits, and the remainder of the sample. Each split is transferred into a V-shaped groove cut in a black, white, or colorless bakelite or lucite slide designed for counting grains under the binocular microscope. The slide is pushed across the stage of the microscope so that the minerals resting in the groove can be examined. All grains of one mineral are counted at one traverse. The second mineral is counted at a second traverse, and so on, until all mineral species are counted. When the fraction is counted, the grains can be easily transferred into a container so that the entire sample is recovered.

CALCULATIONS

The results of the grain counts were corrected for differences in specific gravity of the grains in order to obtain weight percentages of the minerals in the concentrate. Various assumptions necessarily were made. It was assumed that the specific gravity of a given mineral is constant, but many factors, such as inclusions, weathering, differences in chemical composition, cavities, and metamictization, may cause the specific gravity of the mineral to vary. It was assumed that variations introduced by differences in shape and volume of the different minerals would for the most part be compensated by counting five sieve fractions. Crystal habit, cleavage, roundness, and pitting, however, do cause differences in the shape and volume within a sieve fraction, and some error results from these factors (Chayes, 1946). Detailed study of the variations from the general assumptions caused by differences in specific gravity, shape, and volume were impractical in the time available.

Simplification and speed in the computations were obtained by constructing a "monacus." The name, a combination of the words "monazite" and "abacus," and the idea were suggested by R. M. Garrels. The monacus consists of a 20- by 12-inch rectangular frame with a masonite backing on which are drafted 10 different linear scales for the minerals. The scales are similar to those used by Berman (1953) in the nomogram. Superimposed on each of these scales is a wire containing beads of uniform width. The beads, which represent the grains, are slid along the appropriate wire in order to record the grain count. One bead, which represents one grain, can be translated into "weight units." One "weight unit" equals the weight of one grain of quartz. The width of one bead representing quartz is made to be exactly equal to one division on the linear scales. Inasmuch as the beads are the same width, one bead representing monazite (which has a specific gravity of about 5.2) will be equal to two scale divisions. Thus, 10 grains (beads) of quartz will be equal to 10 weight units and 10 grains (beads) of monazite will be equal to 20 weight units. The weight units, in turn, are converted to weight percent according to the following equation:

$$\frac{WU_l}{WU_n}\times PC_f=PC_m,$$

where

WU_l = weight units of mineral,
WU_n = total weight units of all the minerals in the sieve fraction,
PC_f = weight percent of sieve fraction, and
PC_m = weight percent of mineral in sample.

For example, in a +45 fraction, which is 50 percent of the sample by weight, the following grain counts are recorded: quartz 25, ilmenite 43, monazite 28, and zircon 37. By recording a bead for each mineral grain it is found that the grain count in weight units is: quartz 25, ilmenite 80, monazite 56, and zircon 62. To calculate the weight percentage of the minerals in the sample, two simple operations with a slide rule are necessary:

1. Divide the weight percentage of the fraction by the total weight units and fix the result on the slide rule. It is apparent that this ratio is a constant for this fraction.

2. Multiply the weight units of the different minerals by the ratio.

The example is summarized below:

Mineral	Grain count	Weight units	Weight percentages
Quartz	25	25	$\frac{50}{223}\times 25=$ 5. 6
Ilmenite	43	80	$\frac{50}{223}\times 80=$ 17. 9
Monazite	28	56	$\frac{50}{223}\times 56=$ 12. 6
Zircon	37	62	$\frac{50}{223}\times 62=$ 13. 9
Total		223	50. 0

Conversion tables (table 22) were set up for conversion of grain counts to weight units.

About 20 minutes are required to calculate one sample when a slide rule or calculating machine is used. The use of the conversion tables reduces the time needed to compute one sample to about 6 minutes (Kellagher and Flanagan, 1956a).

In practice, the calculations are made as follows:

1. The weight percentages of the sieve fractions and of the magnetite are calculated by slide rule.
2. The grain counts are converted to weight units by use of the conversion tables, and weight units are totaled by an adding machine.
3. The weight percentage of a sieve fraction is divided by the total weight units of that fraction multiplied by the weight units of each of the different minerals in that fraction.
4. Steps 2 and 3 are repeated for each fraction.

TABLE 22.—*Conversion of grain counts to weight units*

Number of grains of mineral	Weight units [1]					
	Ilmenite	Garnet, staurolite, kyanite	Zircon, xenotime	Amphibole, tourmaline, sillimanite	Epidote	Rutile
1	2	2	2	1	1	2
2	4	3	3	2	3	3
3	6	5	5	3	4	5
4	8	6	7	5	5	7
5	10	8	8	6	6	8
6	12	9	10	7	8	10
7	14	11	11	8	9	11
8	16	12	12	9	10	12
9	18	14	15	10	11	14
10	20	15	17	12	12	16
11	22	17	18	13	14	17
12	24	18	20	14	15	19
13	26	20	22	15	16	20
14	27	21	23	16	17	21
15	28	23	25	17	18	23
16	30	24	26	18	20	24
17	32	26	28	19	21	26
18	34	27	30	20	22	27
19	36	29	31	22	24	29
20	38	30	33	23	25	31
21	40	32	35	24	26	32
22	42	33	36	25	27	33
23	43	35	38	26	29	34
24	45	36	40	27	30	36
25	47	38	41	28	31	38
26	49	39	43	30	32	39
27	51	41	45	31	33	40
28	53	42	46	32	35	42
29	55	44	48	33	36	45
30	57	45	50	34	37	46
31	59	47	51	35	38	48
32	60	48	53	36	40	50
33	62	50	55	37	41	51
34	64	51	57	39	42	52
35	66	53	59	40	43	53
36	68	54	61	41	44	55
37	70	56	62	42	45	57
38	72	57	65	43	47	59
39	74	60	67	44	48	60
40	75	62	68	45	50	61
41	77	63	70	47	51	63
42	79	64	71	48	52	64
43	80	65	73	49	54	66
44	82	66	75	50	55	68
45	84	68	76	52	57	69
46	86	70	78	53	58	70
47	88	71	80	54	59	73
48	90	73	82	56	60	74
49	91	75	83	57	61	75
50	93	76	85	58	62	77

[1] One grain of quartz equals one weight unit by definition, and, for simplification, one grain of monazite equals two weight units. These minerals, therefore, are not in the table.

TEST OF METHOD OF ANALYSIS

To determine the accuracy of the method of analysis, counts were made on three samples of known mineral composition by two mineralogists. The results (table 23) demonstrated that the method was satisfactory for this study. Repeated testing by other mineralogists showed that the results are consistent.

Modifications made on grain-counting techniques to accommodate great numbers of samples resulted in saving time and effort in the splitting and counting of samples and in the calculating of results. These methods have been successfully used in the U.S. Geological Survey. The same methods can be applied to similar projects which require the handling of many samples in a short time.

TABLE 23.—*Determination of weight percent of heavy minerals in three artificially prepared samples*

[A, counted by Jerome Stone; B, counted by C. J. Spengler]

Mineral	1			2			3		
	Determined weight percent		Known weight percent	Determined weight percent		Known weight percent	Determined weight percent		Known weight percent
	A	B		A	B		A	B	
Ilmenite	46	50	46	47	42	45	46	48	53
Quartz	36	39	37	10	13	10	25	25	20
Zircon	3	1	3	2	1	3	6	6	7
Monazite	12	7	10	32	33	29	15	15	13
Epidote	2	2	3	3	5	4	----	----	----
Amphibole	1	1	1	6	6	9	5	2	3
Sillimanite [1]	----	----	----	----	----	----	3	4	4

[1] Not present in samples 1 and 2.

SPECTROGRAPHIC ANALYSES

Semiquantitative spectrographic analyses were made at the U.S. Geological Survey on 145 heavy-mineral concentrates between 1951 and 1953. C. L. Waring directed the work, and the analyses were made by C. S. Annell, Joseph Haffty, K. E. Valentine, and H. W. Worthing.

The analyses were used to determine the abundance of tin, tungsten, niobium, and tantalum in the concentrates, because any of the four elements, if present in recoverable quantities, would add to the value of a placer deposit, and the possible presence of each element needed to be considered in appraisals. Another reason for the analyses was to provide a check on the grain counts. As field and laboratory work progressed, the concentrates were found to be similar in that they lacked tungsten and tantalum in detectable amounts and had traces of tin and niobium. The sample net was opened, and fewer samples were submitted for analyses.

Limits of detection for tungsten, tantalum, and other elements reported are cited by C. L. Waring as—

Element	Percent	Element	Percent	Element	Percent
Ag	0.0001	Ga	0.01	Si	0.0001
Al	.0001	Gd	.01	Sm	.1
B	.001	Ho	.01	Sn	.01
Ba	.0001	La	.01	Sr	.01
Be	.0001	Mg	.0001	Ta	.1
Ca	.001	Mn	.001	Tb	.01
Ce	.1	Mo	.001	Th	.1
Co	.01	Nb	.01	Ti	.001
Cr	.001	Nd	.01	V	.01
Cu	.0001	Ni	.01	W	.1
Dy	.01	P	.1	Y	.001
Er	.01	Pb	.01	Yb	.0001
Eu	.01	Pr	.01	Zn	.01
Fe	.001	Sc	.001	Zr	.001

Note.—It is possible to detect some elements below the sensitivities listed, as standard reference plates were prepared on the basis of 10-percent increments.

Between November 11, 1951, and March 6, 1953, three revisions were made in the standard sensitivities for the elements, but, except for niobium, none of the elements listed above was affected. For the earliest suite of samples submitted, a second analysis for niobium was made so that all analyses could be reported to the same sensitivity.

NIOBIUM DETERMINATIONS

The traces of niobium reported in spectrographic analyses led to chemical determinations for niobium in minerals separated from concentrates selected to represent areas where rutile was unusually common in the streams and areas recommended for churn drilling. Three types of mineral separates were prepared: (1) a handpicked rutile separate; (2) a rutile concentrate made by electromagnetic, electrostatic, and heavy-liquid separation; and (3) an ilmenite separate. The rutile and ilmenite separates were monomineralic, but the rutile concentrate contained 1–5 percent quartz, sillimanite, zircon, and an unidentified black opaque mineral. A total of 18 samples were prepared: 8 ilmenite separates, 4 rutile separates, and 6 rutile concentrates.

The samples were analyzed at the U.S. Geological Survey in Denver, Colo., by A. P. Marranzino under a project directed by Hy Almond. The method of analysis requires a minimum sample weight of 0.2 gram, with 0.5 gram preferred. Sensitivity of niobium is 50 ppm (parts per million), though as little as 10 ppm can be detected under ideal conditions (F. C. Canney, written commun., 1953). Three of the samples, two rutile separates (52–OT–38 and 52–WE–5a) and a rutile concentrate (52–CS–196), weighed less than 0.2 gram; hence, the results may not be comparable with those for which sufficient sample was available (A. P. Marranzino, written commun., 1953).

OFFICE PROCEDURES

The office procedures included compilation of uncontrolled mosaics from aerial photographs of the monazite-bearing streams and drafting the mosaics as planimetric maps, estimating areas and volumes of flood plains, calculating tenors of the grab samples, and calculating tenors and inferred reserves of the flood-plain sediments. Only after these stages of office work were completed could comparisons be made among the different streams, and the placers in the monazite-bearing area be appraised.

UNCONTROLLED MOSAICS AND PLANIMETRIC MAPS

No series of maps covers the region between the Savannah and Catawba Rivers, S.C.–N.C., at a scale adequate to permit measurement of the areas of flood plains. For this reason planimetric maps were drawn by project personnel from uncontrolled mosaics prepared from aerial photographs. The mosaics were compiled and the maps were drafted at approximate scales of 1:20,000 and 1:24,000; the maps were photographically reduced for reproduction at an approximate scale of 1:40,000. Forty-four planimetric maps, which covered areas ranging in size from 26 to 145 square miles, were drawn to show the streams in the monazite belt between the Savannah and Catawba Rivers (W. C. Overstreet, A. M. White, J. W. Whitlow, P. K. Theobald, Jr., D. W. Caldwell, and N. P. Cuppels, unpub. data). No planimetric maps were made for the separate streams examined in the drainage basins of the Yadkin and Dan Rivers, N.C.–Va., and the Oconee, Flint, and Chattahoochee Rivers, Ga.

Stereoscopic interpretation of the aerial photographs to define the margins of flood plains was done in the field. In the office the photographs covering the area to be represented on one planimetric map were assembled, and roads, railroads, streams, towns, locations of samples (stations), lines of auger-drill holes, magnetic north, and margins of the flood plains were traced on individual overlays of the photographs. To eliminate as much distortion as possible, only the central part of each photograph was copied. From the tracings a mosaic was pieced together, and the original uncropped photographs were filed. An ink tracing of the mosaic was reduced photographically to give the planimetric maps.

COMPUTATION OF AREA AND VOLUME OF FLOOD-PLAIN DEPOSITS

AREA

The area of the flood-plain deposits was measured by polar planimeter on the original 1:20,000- and 1:24,000-scale maps. Errors in measuring the outlines of the flood plains were reduced by using the larger scale maps.

For calculations of area, volume, tenor, and reserves, the flood plains shown on each map were divided into blocks. The blocks were selected so that, as nearly as possible, similar parts of a stream were included in one block. Natural features, such as constrictions in the flood plains and the junctions of streams, or culture, such as bridges on main highways and railroads, that would influence mining usually served as upstream and downstream ends of a block.

Square inches of map representing each block of alluvium were converted to square yards of flood-plain surface by one of two constants derived from the same equation:

$$\text{Square yards on ground} = (\text{square inches on map}) \frac{1}{(\text{representative fraction})^2 \times (1296)}.$$

For 1:20,000-scale maps the constant is 308,642, which was rounded to 309,000 in the computations, and for the 1:24,000-scale maps the constant is 440,000. Areas in square yards for each block were rounded to the closest 10,000 square yards.

PRECISION OF ESTIMATES OF AREA

Precision of the estimated area of flood plains is affected by errors introduced in stereoscopic interpretation, by tracing photographs and mosaicking the tracings, by drafting the mosaic in the final form of map, by use of the polar planimeter, and by variations in the scale of the maps from the assumed approximate scales.

Stereoscopic interpretation of the margins of a flood plain introduces errors in the estimates of area of the flood plain within one block, but the error is not consistent in direction or magnitude and tends to be compensating. A comparison of areas outlined by photointerpretation and measured by planetable mapping shows positive and negative errors (assuming the area from the planetable surveys to be the more accurate) in areas developed from photointerpretation that vary from 4.2 to 8.1 percent:

Flood plain	Area estimated from aerial photographs (square yards)	Area determined by planetable (square yards)	Difference assuming planetable survey to be more precise (percent)
Knob Creek	497, 000	541, 000	8. 1
Buffalo Creek	623, 000	584, 000	6. 6
Sandy Run	370, 000	355, 000	4. 2

Other checks made along measured lines of drill holes across flood plains show that the maximum error in interpreted areas of flood plains is 15 percent in either direction. Errors in locating the margins of flood plains by stereoscopic interpretation, which were not corrected by field checks, may locally exceed the 15 percent maximum in embayments where the flood plain is covered by a steep alluvial fan or in areas of extremely low relief where the hillside and flood-plain surface merge with no perceptible break. These features are not common, and the quantitative result of exaggerated errors is not great. For the blocks as individual units the error in estimated area introduced by photointerpretation probably is on the order of ± 10 percent.

Narrow flood plains and small alluvial deposits at the heads of the streams were left off the maps. Their absence from the computations resulted in a small underestimation for the area covered by alluvium in each drainage basin.

In tracing the photographs, preparing the mosaic, and drafting the mosaic, some changes are introduced in the outlines of the flood plains. These result from human error in tracing, the matching of 30–65 photographs to make a map, and the creep of the map with handling and with changes in temperature and humidity.

The polar planimeter used in measuring areas on the maps can be read to 0.01 square inch, which is closer than an operator can reproduce measurements. Three measurements of the area of each block were made with a maximum acceptable deviation of 0.03 square inch. The average of the three measurements was taken as the area of the block. At a scale of 1:20,000 a deviation of 0.03 square inch is equal to a variation of plus or minus 10,000 square yards in the estimated area of the block. Thus, to maintain an accuracy of measurement of 5 percent, the blocks have to contain more than 200,000 square yards of alluvium. Accuracy of planimetry equal to 2 percent and 1 percent of the area of the blocks requires minimum areas of 500,000 square yards and 1 million square yards of alluvium per block. Of the 534 blocks for which estimates of area were made, 42 percent are larger than 1 million square yards; 32 percent have between 500,000 and 990,000 square yards of alluvium; 19 percent have between 200,000 and 490,000 square yards, and the remaining 7 percent have areas of less than 200,000 square yards.

VOLUME

Volumes of the flood-plain sediments were estimated by block. Three assumptions were made: (1) the alluvial fill in each block was treated as a rectilinear solid; (2) the volume of alluvium carved out of the assumed rectilinear solid by the stream (the trench of the present stream channel) was too small, if compared with the total volume of sediment in the block, to warrant extra estimates of its size and their subtraction from the total volume of the block; and (3) the sedimentary units in the flood plains were sheetlike layers. In most blocks the estimates of total volume of alluvium were divided into estimated volumes of clay, silt and sand, and gravel so that tenors in monazite could be applied to the appropriate sediment for estimates of inferred reserves.

The valleys characteristically have steep walls and flat floors, as is shown by diagrams of flood plains given in other parts of the report. The alluvial fill in one block, therefore, closely approaches a rectilinear solid, the volume of which can be estimated from the area of one face and the thickness normal to that face. Thus, the area of the top of the flood plain in one block multiplied by the average thickness of alluvium in the block equals approximately the volume of sediment in the block. In most blocks the exaggeration in the estimates of volume resulting from inclusion of the unfilled volume of the present channel amounts to less than 2 percent of the volume of the block, but in a few long narrow flood plains the exaggeration reaches 30 percent.

A weighted average depth for each block was estimated in the office from stratigraphic measurements recorded in the field by weighting each field measurement on a basis of its estimated area of influence (area factor) in the block. The same area factors used for weighting total depth were applied to the sedimentary units in each stratigraphic section to arrive at a weighted average thickness of clay, of silt and sand, and of gravel in the block.

The types of stratigraphic measurements have already been reviewed, and the reliability of thicknesses determined from direct observation and from auger-drill holes has been discussed. A statement of the precision of field estimates of depth to bedrock, which are the most numerous stratigraphic measurements used, was left to this part of the report so that it could be taken up with other features involved in the reliability of the estimated volumes of alluvium. In a check of 51 flood plains where the geologist estimated depth to bedrock and the ground was subsequently drilled, it was found that two of the estimates of depth were in error by 67 percent; but the average estimate was in error by 24 percent, and the algebraic average error for all checks was less than 10 percent. Thus, the error is compensating, and the greater the number of estimates used for computing the weighted average depth of one block, the more precise is the estimate of the volume of the block.

Greatest accuracy in the estimates of depth to bedrock was obtained where flood-plain sediments are 15 feet deep. This is close to the average depth of alluvium, 14.6 feet, determined from more than 400 holes drilled between the Savannah and Catawba Rivers, S.C.–N.C.

No stratigraphic data were available for some flood plains on the large rivers, but estimates of depth have been given for the alluvium. Checks of the estimates were not made; however, from general considerations of the sizes and shapes of valleys, it is believed that these estimates are conservative by no more than 20 percent.

The errors introduced in estimates of volume by photointerpretation, drafting, planimetry, scale, assumption of rectilinear shape, and estimated depths are in part compensating. Excluding Spartanburg County, the error in estimated volume for a single block is about 15 percent, either too little or too much, and is about 5 percent for volumes composed of more than 10 blocks. In Spartanburg County a single block may be as much as 30 percent in error, but this will reduce to about 10 percent for volumes composed of 10 or more blocks. Should the individual errors be all in the same direction rather than compensating, the total error in the estimate of the volume of one block could conceivably be well above 100 percent. Because of these errors, the depths, area, and volumes entered in the tables have been rounded to three significant figures or to 10,000 cubic yards. It is realized that the second figure may be in some doubt in the single blocks, but the third figure is carried to prevent possible loss in accuracy during rounding. Volumes less than 10,000 cubic yards are dropped because they are inaccurate, and ignoring them will not affect the level of significance of the estimates for drainage basins.

CALCULATION OF TENORS OF GRAB SAMPLES

The relation of the weight percentage of a heavy mineral in a concentrate to the volume of the original sample gives the tenor of the sample in pounds of the mineral per cubic yard of sediment. Only those placer minerals which might have some economic value, such as monazite, ilmenite, rutile, zircon, garnet, kyanite, and sillimanite, were calculated in pounds per cubic yard. Associated minerals, such as magnetite, staurolite, and epidote, were not converted from weight percent to pounds per cubic yard.

The starting point for computing tenors was the weight of the concentrate in grams and the weight percentage of each mineral in the concentrate as reported by the laboratory. The product of these two values was grams of a mineral in the concentrate. From this weight a one-step conversion translated grams in the sample to pounds per cubic yard of sediment in place by converting grams to pounds, correcting for swell, and calculating to a standard volume of 1 cubic yard.

Reduction of the measured volume of the sample to approximate volume in place was done by applying appropriate corrections for swell (Peele and Church, 1941, p. 3–03):

Class of alluvium	*Swell (percent)*
Riffle sand and gravel	14
Bank silt, sand, and loose gravel	20
Clay and compact bank gravel	35

Peele's average figures for swell, rather than locally measured swell factors, were used in calculating the tenors of the thousands of samples collected in the southeast, because Peele's averages are based on more measurements than were made by project personnel. However, to compare the published factors and local ranges in swell, five samples of riffle sand and gravel and of silt, sand, and loose gravel from the banks of streams were measured in the field. All gave swells of 17 percent. Two samples of alluvial clay and of compact bank gravel swelled 34 and 26 percent. Thus, the few locally measured sediments have properties similar to the average.

Saprolite cannot be corrected for swell with the factors used for alluvium. Only the densest saprolite swells like alluvial clay; some porous saprolite actually occupies 10–40 percent more space in place than it does after it has been dug out. Hence, in preparing estimates of the tenors of saprolite, a wider range of swell factors (including both swell and shrinkage) were needed, and the samples were treated as individuals rather than as members of a class.

The conversion from grams of a mineral in the concentrate to pounds of the mineral per cubic yard of sediment in place for alluvial samples of standard size (0.34 cu ft) was made by multiplying grams by the following factors arrived at through the operation:

$$\frac{27 \text{ cu ft} \times 0.002205}{0.34 \text{ cu ft} \times 100} \times (100 + \text{swell}) = \text{Factor},$$

where 0.002205 = conversion gram to pound.

Classes of alluvial sediment	*Factor*
Riffle sand and gravel	0.1996
Bank silt, sand, and loose gravel	.2101
Clay and compact bank gravel	.2363

No adjustment for losses in panning was applied to the estimated tenors of the samples.

The estimated tenors of the grab samples together with descriptive field and laboratory data are entered in sets of tables which have been placed in the open files of the U.S. Geological Survey (Caldwell, 1962; Cuppels, 1962; Theobald, 1962; White, A.M. 1962).

MONAZITE PLACERS

The fieldwork showed that monazite has accumulated as low-grade fluviatile placers along streams draining monazite-bearing rocks, that the average monazite-bearing rock contains 0.06 pound of monazite per cubic yard, and that no crystalline rock is an ore of monazite. Eluvial deposits derived from the crystalline rocks, though widespread in their occurrence, were found to be patchy, small, and impractical as sources of monazite. Ores were found to be confined to fluviatile sand and gravel chiefly in placers between the Savannah River, S.C., and the Catawba River, N.C. None of the monazite-bearing areas in the Inner Piedmont belt beyond these rivers is as satisfactory a source of monazite as selected areas between the rivers. Therefore, most of the following discussion relates to the Savannah River–Catawba River area.

SIZE AND TENOR

Large valleys are common east and west of the monazite-bearing part of the Inner Piedmont belt, but flood plains in the belt typically are small and discontinuous. Northwest of the belt the valleys are virtually barren of monazite, but some to the southeast have collected a part of their fill from the belt and contain a little monazite (see table below). The average tenor of flood-plain deposits is highest in the valley of the Broad River where it is 1.1 pounds of monazite per cubic yard. It is lowest in the basin of the Tyger River.

Drainage basin	*Average tenor of alluvium (pounds of monazite per cubic yard)*
Savannah River	0.5
Saluda River	.6
Enoree River	.7
Tyger River	.4
Pacolet River	.8
Broad River:	
Southern tributaries	.8
Northern tributaries	1.1
Catawba River:	
South Fork	.7
Catawba River	.9
Weighted average	.8

The highest tenor deposits are hundreds of headwater placers having volumes too small to be included in the scope of this study. Commonly, the tenor of the placers drops off abruptly within a few miles of headwaters, but this downstream reduction in grade is accompanied by an increase in the size of the deposit. Most of the 84 deposits classed as placers contain 1–10 million cubic yards of alluvium, the greatest number of deposits averaging about 3.1 million cubic yards.

Placer		Number	Weighted average	
Volume (million cu yd)	Tenor (lb monazite per cu yd)		Volume (cu yd)	Tenor (lb monazite per cu yd)
<1	3.0	[1]8	660,000	4.4
1–2	2.0	15	1,300,000	3.2
2–5	1.5	24	3,100,000	2.4
5–10	1.0	19	6,900,000	1.6
10+	.5	18	18,000,000	.8

[1] Not representative of the frequency distribution because these few were recorded as incidental to the main study.

Deposits in North and South Carolina which the U.S. Bureau of Mines explored by churn drilling (table 24) have a weighted average of 0.5 pound of monazite per cubic yard of sediment and range in tenor from 0.15 to 1.67 pounds of monazite per cubic yard.

The weighted average tenor of all flood-plain sediments between the Savannah and Catawba Rivers is 0.8 pound of monazite per cubic yard, and the weighted average tenor of the 84 placers is 1.3 pounds of monazite per cubic yard.

The sediment is unlikely to carry more than 1 pound of monazite per cubic yard unless the concentrates con-

TABLE 24.—*Monazite in placers explored by churn drilling, 1951–53, North Carolina and South Carolina*

Stream	Placer		References
	Volume (million cu yd)	Tenor (lb monazite per cu yd)	
South Carolina			
Big Generostee Creek	42	0.45	Hansen and Caldwell, 1955, p. 23.
Rabon Creek	52	.41	Do.
North Tyger River	34	.37	Hansen and Cuppels, 1955, p. 16, 22.
Pacolet River	[1]10	.57	Do.
Little Thicketty Creek	5	.47	Hansen and Theobald, 1955, p. 25–26.
Thicketty Creek	16	.39	Do.
Broad River	17	.34	Do.
Buffalo Creek (mouth)	3	.44	Do.
North Carolina			
Buffalo Creek (head)	2	1.25	Griffith and Overstreet, 1953b, p. 16.
Knob Creek	3	1.67	Griffith and Overstreet, 1953a, p. 26.
Wards Creek	3	.72	Hansen and Cuppels, 1954, p. 22.
First Broad River	10	.85	Do.
Hinton Creek	4	.72	Do.
Duncans Creek	2	.74	Do.
Sandy Run	4	1.63	Griffith and Overstreet, 1953c, p. 25–26.
Catheys Creek	[1]10	.53	Griffith, R. F., written commun., 1951–52.
Cane Creek	[1]20	.46	Do.
Silver Creek	20	.63	Hansen and White, 1954, p. 22–23.
Hall Creek	[1]2	1.10	Griffith, R. F., written commun., 1951–52.
South Muddy Creek	19	.61	Hansen and White, 1954, p. 22–23.
Catawba River	[1]10+	.15	Do.
Weighted average		.5	

[1] Estimated.

tain 10 percent or more monazite (pls. 3, 7). The chances are best for a sediment to contain more than 3 pounds of monazite per cubic yard where monazite makes up 30 percent or more of the concentrate. Plate 7 shows that alluvium averaging 3 pounds of monazite or more per cubic yard is rare, that it is restricted to the headward parts of large streams or the full length of short streams, and that it is seldom present to the southwest of the Broad River. However, equal or better tenors do exist in hundreds of small creeks in areas where the alluvium along the larger streams is richer than average in monazite. Sediments in the valleys of the trunk streams have the lowest average tenors in monazite.

The general trend toward low tenors south of the Broad River, as shown on plate 7, is also apparent in the number of placers in each drainage basin that surpass the regional average tenor for placers of the same range in size.

Drainage basin	*Total number of placers*	*Number of placers with tenors greater than the regional average for placers of the same range in size*
Savannah River	9	2
Saluda River	9	5
Enoree River	5	3
Tyger River	5	2
Pacolet River	6	1
Broad River:		
Southern tributaries	8	3
Northern tributaries	31	15
Catawba River:		
South Fork	7	5
Catawba River	4	2

Thus, in the drainage basins of the Broad and Catawba Rivers, 50 percent of the placers have tenors greater than the regional average tenors for deposits of similar size, but between the Broad and Savannah Rivers only 38 percent of the placers are richer than average. Many of the better deposits southwest of the Broad River are isolated from similar placers and in themselves are inadequate to support a local monazite mining industry.

Rivers in the Piedmont downstream from the southeastern edge of the monazite belt are unlikely to have monazite placers. Alluvium deposited along the valleys of large rivers in the core of the monazite belt contains only 0.5–0.8 pound of monazite per cubic yard. A few miles downstream from the southeastern edge of the belt the sediments in the trunk streams have about half that tenor in monazite. It appears that too little monazite enters the large rivers to overcome the dilutive effect of monazite-free suites either transported westward into the belt or contributed by streams entering southeast of the belt. Reduction in the proportion of monazite to other heavy minerals and its dispersal in increasingly larger volumes of alluvium result in progressively lower tenors in the flood-plain sediments accumulated downstream toward the Atlantic Ocean. The area of confluence of the Broad River and Saluda River northwest of Columbia, S.C., and the junction of the Congaree River with the Wateree River southeast of Columbia bring together streams having the largest drainage basins in monazite-bearing crystalline rocks in the Southeastern States. Gravel deposits formed during earlier phases of the present cycle of erosion in the valleys of these streams, or in earlier cycles of erosion, might possibly be monazite placers.

COPRODUCTS AND BYPRODUCTS

A commercial venture based on monazite alone would be impractical in the area described in this report, and it is unlikely that the deposits could be profitably mined at the prices existing in the 1950's and 1960's, even where augmented by the sale of coproducts and byproducts.

The most likely coproducts from the monazite placers are screened sand and gravel, ilmenite, rutile, and gold. Some market might be found for such byproducts as the high-alumina minerals and zircon, but they could not be expected to add greatly to the income. Garnet would be the most valuable product from some of the placers if it could be used industrially, but in the past, garnet from these placers was found to be unsuited in size and shape to industrial requirements (Pratt, 1908, p. 66; Keith and Sterrett, 1931, p. 13). The average concentrate from alluvial deposits containing 2 million cubic yards or more of sediment is lean in salable minerals (table 25).

SAND AND GRAVEL

Sand and gravel for use in construction and on roads is mined from streams along the monazite belt in the Carolinas. Suction dredges, draglines, or clamshell buckets are used to take sand from the flood plains, banks, and bottoms of the streams and to get gravel from the beds of the streams. Several plants produce about 100 tons of sand and gravel daily, but most of them ship only a few truckloads in a day. Many of the plants are mobile and are operated by the highway departments of the respective States.

Prices received for sand and gravel are low. In North Carolina the average price of commercial building and paving sand during 1951 was 61 cents per short ton. Gravel used for the same purposes brought 94 cents per short ton. Statistics given by Chandler and Jensen (1954, p. 1122–1125) for South Carolina are incomplete and show only that for 1951 commercial building and paving sand had an average price of 31 cents per short ton.

TABLE 25.—*Average tenors of industrial minerals associated with monazite in concentrates from placers explored between the Savannah and Catawba Rivers, S.C.-N.C.*

[Determined by U.S. Bur. of Mines for placers containing 2 million cubic yards or more of sediment; Tr., trace; nd, no data]

Stream	Number of drill holes	Average tenor [1] (pounds per cubic yard)					High-alumina minerals [2]	References
		Ilmenite	Rutile	Magnetite	Zircon	Garnet		
South Carolina								
Big Generostee Creek	12	7. 9	0. 3	Tr.	1. 2	0. 1	0. 2	Hansen and Caldwell, 1955, p. 21.
Rabon Creek	19	2. 0	. 2	. 1	. 2	. 1	. 1	Do.
North Tyger River	16	3. 1	. 1	Tr.	1. 0	1. 5	. 3	Hansen and Cuppels, 1955, p. 12, 15, 22.
Pacolet River	4	8. 2	. 5	nd	. 6	nd	nd	Do.
Little Thicketty Creek	3	11. 8	. 5	1. 2	. 3	1. 4	1. 1	Hansen and Theobald, 1955, p. 18, 28.
Thicketty Creek	5	5. 3	. 3	. 2	. 2	. 5	. 4	Do.
Broad River	8	5. 2	. 2	. 3	. 6	. 6	. 5	Do.
Buffalo Creek (mouth)	2	6. 4	. 2	. 1	. 1	1. 8	. 3	Do.
North Carolina								
Buffalo Creek (head)	17	7. 1	1. 0	Tr.	. 2	17. 9	7. 2	Griffith and Overstreet, 1953b, p. 13.
Knob Creek	23	4. 5	Tr.	. 6	. 2	7. 0	nd	Griffith and Overstreet, 1953a, p. 21.
Wards Creek	11	5. 1	. 2	Tr.	. 3	3. 6	1. 2	Hansen and Cuppels, 1954, p. 24.
First Broad River	24	8. 0	. 5	Tr.	. 6	8. 0	2. 6	Do.
Hinton Creek	11	3. 8	. 5	Tr.	. 4	2. 8	1. 4	Do.
Duncans Creek	6	5. 7	. 2	Tr.	Tr.	3. 3	4. 1	Do.
Sandy Run	30	8. 2	1. 3	. 1	. 1	6. 4	3. 8	Griffith and Overstreet, 1953c, p. 22.
Catheys Creek	4	5. 1	nd	. 2	. 6	1. 0	nd	Griffith, R. F., written commun., 1951–52.
Cane Creek	3	8. 0	nd	. 5	. 8	1. 3	nd	Do.
Silver Creek	4	3. 8	. 2	1. 2	. 7	1. 6	. 5	Hansen and White, 1954, p. 19, 27.
Hall Creek	3	13. 3	nd	. 2	1. 2	6. 4	nd	Griffith, R. F., written commun., 1951–52.
South Muddy Creek	11	1. 8	Tr.	. 7	. 6	. 4	Tr.	Hansen and White, 1954, p. 19, 27.
Catawba River	3	6. 5	. 3	. 1	1. 0	. 3	. 1	Do.
Average [3]		5. 3	. 3	. 3	. 6	1. 2	. 5	

[1] Weighted for total depth of all drill holes in the placer.
[2] High-alumina minerals are chiefly sillimanite and kyanite, but they include some andalusite at the head of Buffalo Creek, and staurolite in the Broad and Catawba Rivers, and at the head of Buffalo Creek.
[3] Weighted for total volume of sediment in all deposits in which mineral was determined, including trace amounts.

Half the volume (52 percent) of the alluvium in the streams between the Savannah and Catawba Rivers, S.C.-N.C., is sand and 10 percent of the volume is gravel, but the placers contain somewhat higher proportions of both. Most of it might be recovered in mining, but it is unlikely that more than a small part could be sold. Local demand is inadequate to consume the amount of screened sand and gravel that could be produced at a dredge or dragline operating along one of the large placers. Only 869,291 short tons of commercial sand and 3,695,780 tons of Government-purchased sand (worth about 25 cents per ton) was sold in the entire State of North Carolina in 1951 (Chandler and Jensen, 1954, p. 1122–1125), and 400,790 tons of gravel was used that year.

ILMENITE AND RUTILE

Ilmenite is generally the most abundant heavy mineral in concentrates from the monazite placers, but the average tenor of 5.3 pounds of ilmenite per cubic yard shown in table 25, the averages of samples shown in table 26, and the inferred regional average tenors in ilmenite are low for placer deposits. If mined alone, the ilmenite would be uneconomic at the prices prevailing in 1954 when ilmenite was nominally \$18–\$20 per ton f.o.b., the Atlantic seaboard for concentrates containing 59.5 percent TiO_2 (Tumin, 1958).

The greatest concentration of ilmenite bounded by the 70-percent isogram is in the drainage basins of the Savannah and Saluda Rivers, S.C. (pl. 2), which are among the least likely sources for monazite between the Savannah and Catawba Rivers. The best association of ilmenite with a monazite placer is along east-flowing tributaries to the South Fork Catawba River in Lincoln County, N.C., where a great high appears in the ilmenite isograms—its shape was only incompletely refined by the fieldwork—and the grab samples of alluvium are consistently rich in ilmenite (White, A. M., 1962, table 36.)

Ilmenite concentrates rarely contain the theoretical amount of titanium oxide present in pure ilmenite, 52.7 percent TiO_2, because the composition is altered by weathering and inclusions. Ilmenite concentrates from the Atlantic beaches of North Carolina are practically unweathered—comparing closely in composition and physical characteristics with ilmenite from Adirondack anorthosite and gabbro at the MacIntyre ore body at Tahawus, N.Y.—and contain 49.0 percent TiO_2 (Lynd and others, 1954. Ilmenite from alluvial placers in the monazite belt probably has an average percentage of TiO_2 similar to that of the ilmenite from beach placers on the coast of North Carolina, but no analyses are available. Thus, ilmenite concentrates from streams in the monazite belt are less desirable and would sell for less than the ilmenite concentrates from the Florida beaches, which contain more titanium oxide than theoretical ilmenite.

TABLE 26.—*Average amounts of ilmenite in sediment samples from streams between the Savannah and Catawba Rivers, S.C.–N.C.*

[In pounds per cubic yard. The figures are numerical averages of the quantities listed in mineral tables in reports by D. W. Caldwell (1962, tables 1-15), N. P. Cuppels (1962, tables 16-25), P. K. Theobald, Jr. (1962, tables 26-35), and A. M. White (1962, tables 36-44), except that for a few streams, single extraordinarily rich samples have been omitted from the average. nd, no data]

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Savannah River, S.C.:					
Hogskin Creek	10.5	16.4	1.2	1.1	
Broadway Creek	14.3	11.0	2.4	.3	
Big Beaverdam Creek	19.4	7.3	1.1	nd	
Big Generostee Creek	20.5	13.7	2.0	6.2	
Saddler Creek	19.3	nd	6.9	nd	
Big Beaverdam and Little Beaverdam Creeks	15.5	12.0	.2	2.8	
Average	15.9	11.5	2.5	3.3	11.3
Saluda River, S.C.:					
Rabon Creek	5.8	4.9	.2	1.0	
Walnut Creek	6.2	1.5	.2	.4	
Horse Creek	17.6	11.6	3.0	nd	
Huff Creek	14.8	9.2	.7	.8	
Laurel Creek	12.8	7.2	1.5	.9	
Turkey Creek	9.6	5.3	nd	nd	
Broad Mouth Creek	14.4	3.1	.8	1.3	
Grove Creek	11.9	13.4	1.1	.8	
Big Brushy Creek	10.9	8.6	.3	nd	
Average	12.0	8.1	.9	1.0	7.5
Enoree River, S.C.:					
Durbin Creek	10.7	4.4	.7	.6	
Gilder Creek	14.2	2.6	1.0	nd	
Mountain Creek	5.8	2.9	.8	.8	
Average	11.0	3.7	.8	.7	4.3
Tyger River, S.C.:					
Beaverdan Creek	9.1	7.5	nd	nd	
Ferguson Creek	11.3	6.7	1.8	.9	
Junction of North Tyger and Middle Tyger Rivers	11.2	6.3	.2	nd	
Parts of North Tyger, Middle Tyger, and South Tyger Rivers	8.4	5.2	.5	.6	
Average	10.0	6.2	1.0	.8	5.6
Pacolet River, S.C.:					
Lawson Fork Creek	14.2	6.1	4.3	nd	
Buck Creek	16.2	14.6	.9	nd	
North Pacolet and South Pacolet River	8.3	2.9	3.0	.4	
Average	13.8	6.2	2.5	.4	6.9
Broad River:					
Southern tributaries, South Carolina-North Carolina:					
Thicketty Creek	10.3	7.3	2.3	2.3	
Cherokee Creek	9.9	3.2	.9	1.8	
McKinney Creek	6.6	1.5	1.0	1.1	
Average	9.4	4.1	1.4	1.6	4.7
Northern tributaries, North Carolina:					
Buffalo Creek and Boween River	4.8	3.3	.5	2.1	
Sandy Run	14.4	7.3	2.2	3.0	
Knob Creek	6.3	5.9	1.0	2.5	
Hinton Creek	7.7	7.0	1.8	1.5	
Floyds Creek	10.9	7.9	.7	3.0	
Catheys Creek	7.1	5.3	nd	.1	
Mountain Creek	7.0	5.0	1.3	.9	
Average	8.2	6.0	1.6	2.4	6.8
South Fork Catawba River, N.C.:					
Indian Creek	19.1	7.4	.6	1.4	
Clark Creek	13.3	6.0	.9	.6	
Jacob Fork	8.7	7.4	.5	.6	
Henry Fork	8.2	3.7	.7	.3	
Laurel Creek	4.0	nd	1.2	nd	
Average	12.7	6.5	.7	.9	7.0

See footnote at end of table.

TABLE 26.—*Average amounts of ilmenite in sediment samples from streams between the Savannah and Catawba Rivers, S.C.–N.C.*—Continued

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Catawba River, N.C.:					
Lyle Creek	27.8	2.0	1.3	.7	
Hunting Creek	7.5	2.6	1.0	.3	
Silver Creek	6.2	4.6	.9	.3	
Muddy and Shadrick Creeks	6.7	2.9	1.2	1.5	
Average	12.5	3.3	1.1	.6	4.3
Regional average from the Savannah to the Catawba Rivers, South Carolina-North Carolina	11.2	6.8	1.2	1.6	7.0
Number of samples in regional average	1,707	560	250	97	

[1] Weighted for average proportions of gravel, sand, silt, and clay in separate drainage basins, with a correction of 35 percent added to compensate for losses in panning.

Rutile is generally present as a minor constituent of concentrates from placers in the monazite belt (table 25) where the average amount of rutile in explored placers is 0.3 pound per cubic yard. Its distribution in several thousand grab samples of alluvial gravel, sand, silt, and clay in the same area is shown by minor drainage basins in table 27, as is the inferred average tenor in rutile of fluvial deposits in the major drainage basins. The isogram map for rutile (pl. 2) and table 27 show that alluvium contains the highest tenors in rutile in or just downstream from areas between the 1- and 10-percent isograms for rutile. Some of the streams richest in rutile are also monazite placers. The deposit on Indian Creek and the South Fork Catawba River, which holds the greatest volume of alluvium in the monazite belt, is also notable for its relatively high tenor in ilmenite.

No deposit is known in the monazite belt that can be called a rutile placer under conditions existing at the end of 1954 when rutile concentrates that contained 94 percent TiO_2 reached 7 cents per pound (Tumin, 1958).

NIOBIUM AND TANTALUM

Niobium- and tantalum-bearing minerals were consistently looked for during mineralogic examination of the grab samples, but none was identified. Traces of the elements were sought in semiquantitative spectrographic analyses on 145 concentrates and in chemical analyses of 8 ilmenite separates, 4 rutile separates, and 6 rutile concentrates (pl. 8).

Tantalum was not detected. Niobium was noted in 83 percent of the spectrographically analyzed concentrates from the area between the Savannah and Catawba Rivers, S.C.–N.C. (table 28). In most concentrates the niobium is in the range 0.01 to 0.001 percent. No concentrate contains more than 0.1 percent niobium. Analyses of 15 concentrates from streams emptying into the Dan, Yadkin, Oconee, Flint, and Chattahoochee Rivers in Virginia, North Carolina, and Georgia all show niobium: 12 are in the range 0.1–0.01 percent, and 3 are in the range 0.01–0.001 percent. The slight increase in average amount of niobium in concentrates from these areas probably results from the greater abundance of ilmenite in the concentrates.

TABLE 27.—*Rutile in alluvium samples from the area between the Savannah and Catawba Rivers, S.C.–N.C.*

[In pounds per cubic yard. The figures are numerical averages of the quantities listed in the mineral tables in reports by D. W. Caldwell (1962, tables 1–15), N. P. Cuppels (1962, tables 16–25), P. K. Theobald, Jr. (1962, tables 26–35), and A. M. White (1962, tables 36–44), except that for a few streams, single extraordinarily rich samples have been omitted from the average. Tr., trace; nd, no data]

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Savannah River, S.C.:					
Hogskin Creek	0.05	0.31	0.05	--------	
Broadway Creek	Tr.	--------	Tr.	--------	
Big Beaverdam Creek	--------	Tr.	--------	nd	
Big Generostee Creek	.06	.02	--------	0.15	
Saddler Creek	.09	nd	--------	nd	
Big Beaverdam and Little Beaverdam Creeks	.04	Tr.	--------	--------	
Average	.03	.05	Tr.	.06	0.06
Saluda River, S.C.:					
Rabon Creek	.10	.07	Tr.	Tr.	
Walnut Creek	.10	.02	Tr.	Tr.	
Horse Creek	Tr.	.15	.05	nd	
Huff Creek	.02	.10	.01	--------	
Laurel Creek	.12	.10	.07	.05	
Turkey Creek	.24	.16	nd	nd	
Broad Mouth Creek	.09	Tr.	.01	.01	
Grove Creek	.01	Tr.	.02	--------	
Big Brushy Creek	.03	Tr.	--------	nd	
Average	.07	.06	.02	.01	.05
Enoree River, S.C.:					
Durbin Creek	.27	.10	.03	.02	
Glider Creek	.23	.15	.04	nd	
Mountain Creek	.41	.18	.10	.10	
Average	.29	.12	.06	.07	.2
Tyger River, S.C.:					
Beaverdam Creek	.04	.04	nd	nd	
Ferguson Creek	.02	.03	Tr.	.01	
Junction of the North Tyger and Middle Tyger Rivers	Tr.	Tr.	--------	nd	
Parts of the North Tyger, Middle Tyger, and South Tyger Rivers	.01	.01	.01	.03	
Average	.04	.02	.01	.02	.03
Pacolet River, S.C.:					
Lawson Fork Creek	.23	.02	Tr.	nd	
Buck Creek	.15	.11	Tr.	nd	
North Pacolet and South Pacolet Rivers	.08	.02	--------	.02	
Average	.16	.04	Tr.	.02	.06

See footnote at end of table.

TABLE 27.—*Rutile in alluvium samples from the area between the Savannah and Catawba Rivers, S.C.–N.C.*—Continued

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Broad River:					
Southern tributaries, South Carolina–North Carolina:					
Thichetty Creek	.65	1.00	.20	0.60	
Cherokee Creek	.50	.61	.20	--------	
McKinney Creek	.02	--------	Tr.	Tr.	
Average	.46	.59	.08	.20	.5
Northern tributaries, North Carolina:					
Buffalo Creek and Boween River	.14	.08	.05	.60	
Sandy Run	.30	.26	.14	.14	
Knob Creek	.03	.06	.02	.07	
Hinton Creek	.13	.12	.03	.20	
Floyds Creek	.30	.05	.02	.12	
Catheys Creek	.01	Tr.	nd	--------	
Mountain Creek	.03	.10	--------	Tr.	
Average	.14	.13	.06	.12	.2
South Fork Catawba River, N.C.:					
Indian Creek	.48	.44	.07	.06	
Clark Creek	.11	.06	.01	Tr.	
Jacob Fork	.08	.05	.01	.01	
Henry Fork	.11	.04	.02	.01	
Laurel Creek	.02	nd	Tr.	nd	
Average	.25	.25	.03	.02	.2
Catawba River, N.C.:					
Lyle Creek	.15	.03	.03	Tr.	
Hunting Creek	.03	--------	.01	--------	
Silver Creek	Tr.	--------	Tr.	--------	
Muddy Creek and Shadrick Creek	.03	.07	--------	--------	
Average	.06	.22	.01	Tr.	.2
Regional average from the Savannah to the Catawba Rivers	.16	.11	.04	.07	.1
Number of samples in regional average	1,707	560	250	97	

[1] Weighted for average proportions of gravel, sand, silt, and clay in separate drainage basins, with a correction of 30 percent added to compensate for losses in panning.

TABLE 28.—*Summary of semiquantitative spectrographic analyses for niobium in concentrates from the monazite belt between the Savannah and Catawba Rivers, S.C.–N.C.*

[Analyses by H. W. Worthing, K. E. Valentine, C. S. Annell, and Joseph Haffty, U.S. Geol. Survey]

Drainage basin	Number of samples analyzed	Number of samples with niobium		
		Range 0.01–0.1 percent	Range 0.001–0.01 percent	Less than 0.001 percent
Savannah River, S.C.	14	--------	9	5
Saluda River, S.C.	10	7	2	1
Enoree River, S.C.	5	3	2	------
Tyger River, S.C.	7	--------	7	------
Pacolet River, S.C.	12	3	8	1
Broad River:				
Southern tributaries, South Carolina–North Carolina	9	--------	7	2
Northern tributaries, North Carolina	54	3	43	8
Catawba River, N.C.:				
South Fork	7	5	2	------
Catawba River	7	1	2	4
Total	125	22	82	21

Most of the niobium detected in the concentrates ap-appears to be associated with ilmenite and rutile (Fleischer and others, 1952). Chemical analyses of 17 samples of ilmenite and rutile from monazite placers (table 29, pl. 8) showed that niobium is in both minerals. The results of the analyses also suggest that columbite might be a minor mineral in some placers in Spartanburg County, S.C. (see footnote 4 to table 29). Mineralogists at the U.S. Bureau of Mines identified about 0.1 percent columbite in some concentrates from Rabon Creek (Hansen and Caldwell, 1955, p. 15).

The similarity in the quantity of niobium in ilmenite from placer concentrates with that in ilmenite from saprolite formed from granite is shown by comparison of analyses of ilmenite from placers (table 29) with analyses of ilmenite of known provenance (table 30) kindly supplied by J. B. Mertie, Jr. (written commun., 1955).

Columbite is shown by mineral, chemical, and spectrographic analyses to be practically absent from the concentrates. What niobium is present in the concentrates is mainly associated with the titanium-bearing minerals where it occurs in abundances similar to those noted by Fleischer and others (1952, p. 11–13) for ilmenite and rutile in granitic rocks and in placers derived therefrom. Thus, niobium is not sufficiently abundant in the monazite belt to add to the value of the black sand, unless metallurgic processes should be developed to extract niobium from ilmenite. Then, ilmenite in the monazite belt would be a better source for niobium than ilmenite-magnetite ores from the Adirondacks (Fleischer and others, 1952, p. 12).

GOLD

Placer gold has been mined intermittently since the early 1800's from streams flowing out of the South Mountains at the west edge of the monazite belt in Burke, McDowell, and Rutherford Counties, N.C. By 1831 the local output of gold was enough to support private coinage at a mint established in Rutherfordton, N.C., by C. Bechtler and operated successively by him and his son until 1857 (Pardee and Park, 1948, p. 28).

Gold from the southeastern Piedmont ranges in fineness from 750 to 950 parts per 1,000 and is reported by Pardee and Park (1948, p. 39) to be commonly between 850 and 900 fine. It is assumed that the placer gold

TABLE 29.—*Niobium in ilmenite and rutile from monazite placers between the Savannah and Catawba Rivers, S.C.–N.C.*

[Analyses by A. P. Marranzino, U.S. Geol. Survey]

Sample	Stream	County and State	Niobium (percent)
Ilmenite separates [1]			
52–DC–31	Big Generostee Creek	Anderson, S.C	0.04
649	North Rabon Creek	Laurens, S.C	.11
CS–355	North Tyger River	Spartanburg, S.C	.025
PK–128	Thicketty Creek	Cherokee, S.C	.03
51–KR–93	Buffalo Creek	do	.05
OT–93	Knob Creek	Cleveland, N.C	.05
52–CS–792	First Broad River	do	.045
WE–196	South Muddy Creek	McDowell, N.C	.03
Rutile separates [2]			
52–DC–160	Garvin Creek	Anderson, S.C	0.08
JW–121	Knob Creek	Cleveland, N.C	.40
OT–38 [3]	Hinton Creek	do	.16
WE–5a [3]	Floyds Creek	Rutherford, N.C	.17
Rutile concentrates [4]			
52–DC–95	Twenty Six Mile Creek	Anderson, S.C	0.035
CS–301	Fawn Branch	Spartanburg, S.C	.70
196 [3]	Island Creek	do	.12
111	Barton Creek	do	.65
PK–50	Cherokee Creek	Cherokee, S.C	.22

[1] Monomineralic separate of ilmenite made from concentrate by electromagnetic and electrostatic separation.

[2] Monomineralic separate of rulite made from concentrate by hand picking under binocular microscope.

[3] Determinations made on considerably less than the customary 0.2 g; hence, the results may not be directly comparable with results of other analyses where sufficient material was available.

[4] Rulite concentrated by electromagnetic, electrostatic, and heavy-liquid separation, but the concentrate included from 1 to 5 percent mixed quartz, sillimanite, zircon, and, in samples 52–CS–301, 52–CS–196, and 52–CS–111, an unidentified black opaque mineral that may be columbite.

TABLE 30.—*Niobium in ilmenite from granitic rocks in or near the monazite belt in the western Piedmont of North Carolina and Georgia*

[Samples collected by J. B. Mertie, Jr., U.S. Geol. Survey. Quantitative spectrographic analyses by J. D. Fletcher, U.S. Geol. Survey]

Sample	Source	Niobium (percent)
48-Mt-2	Granitic saprolite exposed in a tributary to Brushy Creek, 4.5 miles northwest of Shelby, Cleveland County, N.C.	0.065
49-Mt-15	Granitic saprolite in roadcut 2.2 miles south-southeast of Zetella, Spalding County, Ga.	.069
52-Mt-154	Granitic saprolite from west side of Liberty quarry, 11.65 miles N. 49½° E. of Lexington, Oglethorpe County, Ga.	.140

averages about 900 fine, because gold from the thoroughly weathered rocks near the surface of the ground is generally finer than that from unweathered rock (Pardee and Park, 1948, p. 39), and practically all the gold in the placers came from weathered rocks.

Gold is a minor mineral in concentrates from most of the southeastern monazite placers. It was discovered in 40 percent of the 219 churn-drill holes bored by the U.S. Bureau of Mines in the Inner Piedmont belt in North and South Carolina (table 31), but the average tenor of the sediment from 73 gold-bearing holes (15 holes along South Muddy and Silver Creeks are excluded because they are not typical of the monazite placers) is only 0.6 milligram of gold per cubic yard. For the 204 holes outside Silver and South Muddy Creeks the average tenor is 0.3 milligram of gold per cubic yard of ground. The tenors recorded in table 31 for the holes drilled on these creeks are similar to the lowest tenors reported by Pardee and Park (1948, p. 52) for alluvial deposits worked along 60 miles of streams in the South Mountains: 57–7,088 milligrams of gold per cubic yard with an average of about 500 milligrams. These estimates for gold refer to placers near the heads of streams, whereas the holes listed in table 31 were placed several miles to scores of miles downstream from the sites of former gold mining, or are on streams east of the zone of gold deposition in the western Piedmont.

The small average tenor in gold found in the monazite placers is similar to that reported by men who used to work in the monazite mines. They have often stated to the writers that in the course of a year they would recover less than a snuffbox full of gold (probably 2–10 oz) from their sluiceboxes. At several properties in or near the gold-bearing area of the South Mountains, local residents recall that about a dollar's worth of gold was recovered daily in headwater monazite placers.

The best associations of gold and monazite are in the

TABLE 31.—*Average quantities of gold recorded in churn-drill holes in monazite placers explored between the Savannah and Catawba Rivers, S.C.–N.C.*

Stream	Number of churn-drill holes	Number of holes having gold	Average amount of gold in gold-bearing holes [1] (milligrams per cubic yard)
South Carolina			
Generostee Creek [2]	12	1	0.3
Rabon Creek [2]	19	5	.2
North Tyger River [2]	16	10	.4
Pacolet River [2]	4	0	----------
Little Thicketty Creek [2]	3	1	.5
Thicketty Creek [2]	5	4	.7
Broad River [2]	8	3	.2
Buffalo Creek (mouth) [2]	2	1	.2
Buffalo Creek (head) [3]	17	6	.5
North Carolina			
Knob Creek [3]	23	14	.4
Wards Creek [2]	11	0	----------
First Broad River [2]	24	15	1.2
Hinton Creek [2]	11	2	.2
Duncans Creek [2]	6	0	----------
Sandy Run [3]	30	1	.1
Catheys Creek [3]	4	4	2.0
Cane Creek [3]	3	3	1.8
Silver Creek [2]	4	4	40.0
Hall Creek [3]	3	3	1.8
South Muddy Creek [2]	11	11	50.0
Catawba River [2]	3	0	----------
Total	219	88	----------
Weighted average excluding Silver and South Muddy Creeks [4]			.3

[1] Quantities less than 1 milligram recalculated from colors on basis of 10 colors per milligram; quantities greater than 2 milligrams recalculated from cents on basis of 900-fine gold worth $0.001 per milligram at $35.00 per Troy ounce.
[2] Hansen, L. A., 1952–53, written communications, giving field estimates by the U.S. Bur. of Mines recorded in the logs of churn-drill holes sunk in 1952–53.
[3] Griffith, R. F., 1951–52, written communications, giving field estimates by the U.S. Bur. of Mines recorded in the logs of churn-drill holes sunk in 1951–52.
[4] Weighted for volume of sediment influenced by gold-bearing holes compared with total volume of sediment in the placers.

upper parts of the First Broad River and Second Broad River, N.C., their upper tributaries, and in the drainage basins of Muddy and Silver Creeks. It is unlikely that any monazite deposit containing more than 2 million cubic yards of alluvium has more than 5 cents' worth of gold per cubic yard of sediment. Most of the monazite placers, other than some small deposits in the heads of streams, contain less than 1 cent in gold per cubic yard of alluvium.

HIGH-ALUMINA MINERALS

The high-alumina minerals used industrially include kyanite, sillimanite, andalusite, dumortierite, topaz, corundum, and staurolite. All have been observed at one place or another in samples from the monazite placers, but only sillimanite is widely distributed. Andalusite, dumortierite, topaz, and corundum display erratic distibution in the monazite belt and are absent from most of the concentrates examined. Staurolite and kyanite are systematically distributed along parts of the margins of the belt (pls. 1, 2) where the placers generally contain scant monazite. Sillimanite appears in the core of the belt and is there associated with the richest monazite deposits (table 32). A list of streams having 0.4 pound or more of high-alumina minerals per cubic yard of gravel would read like a résumé of the most favorable areas for monazite.

The regional distribution of the high-alumina minerals is summarized as inferred average tenors; the highest tenors are in the drainage basins most widely underlain by sillimanite-bearing rocks (pl. 2). The inferred regional average tenor of 0.4 pound per cubic yard is close to the average tenor of the high-alumina minerals (0.5 lb per cub yd in table 25) in samples taken from churn-drill holes. Apparent local discrepancies between tables 25 and 32 reflect the narrowness of the representation of the churn drilling at places where only small areas were explored. Where large areas are represented in the churn drilling, there is reasonable agreement between the tenors estimated from samples taken at the drill and from grab samples.

The placer sillimanite and kyanite is not of strategic grade, nor is it massive; but it does not include any of the sericitized material common in the bedrock. It consists of individual crystals, crystal fragments, or small bundles of crystals which are commonly intergrown with quartz, ilmenite, rutile, and garnet. Hence, it would not command a price similar to the $65 per short ton (3.3 cents per lb) brought by imported kyanite in 1951 (Gunsallus, 1954, p. 1369) or even equal to the $29 per ton (1.4 cents per lb) received in 1951 for domestic kyanite, produced in Virginia and South Carolina. Further benefication, besides removal from the heavy-mineral concentrate, would be required to make an industrially acceptable product of the detrital high-alumina minerals.

TABLE 32.—*High-alumina minerals in alluvium samples from the area between the Savannah and Catawba Rivers, S.C.–N.C.*

[In pounds per cubic yard. High-alumina minerals for which tenors have been calculated include only sillimanite and kyanite, of which the former is by far the dominant mineral. Kyanite, where present, is combined with sillimanite. Such sums are indicated by (k) in the table. The figures are numerical averages of quantities listed in mineral tables in reports by D. W. Caldwell (1962, tables 1–15), N. P. Cuppels (1962, tables 16–25), P. K. Theobald, Jr. (1962, tables 26–35), A. M. White (1962, tables 36–44), except that for a few streams, single extraordinarily rich samples have been omitted from the average. Tr., trace; nd, no data]

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Savannah River, S.C.:					
Hogskin Creek	0.1	0.2	Tr.	Tr.	
Broadway Creek	Tr.	Tr.	Tr.	----	
Big Beaverdam Creek	----	Tr.	----	nd	
Big Generostee Creek	----	----	----	Tr.	
Saddler Creek	Tr.	nd	Tr.	nd	
Big Beaverdam and Little Beaverdam Creeks	Tr.	Tr.	----	----	
Average	Tr.	Tr.	Tr.	Tr.	Tr.
Saluda River, S.C.:					
Rabon Creek	Tr.(k)	Tr.	----	----	
Walnut Creek	Tr.(k)	Tr.(k)	----	Tr.	
Horse Creek	Tr.	----	Tr.	nd	
Huff Creek	.2	.3	0.1	0.2	
Laurel Creek	.3	.6(k)	.1(k)	Tr.	
Turkey Creek	----	Tr.	nd	nd	
Broad Mouth Creek	Tr.	Tr.	Tr.	Tr.	
Grove Creek	.2	.1	Tr.	Tr.	
Big Brushy Creek	.1	.1	Tr.	nd	
Average	.1(k)	.1(k)	Tr.(k)	Tr.	0.1
Enoree River, S.C.:					
Durbin Creek	Tr.	Tr.	Tr.	Tr.	
Gilder Creek	.4(k)	.3	.1	nd	
Mountain Creek	.3(k)	.1	.1	.1	
Average	.3(k)	.1(k)	.1(k)	Tr.	.3
Tyger River, S.C.:					
Beaverdam Creek	.4	.4	nd	nd	
Ferguson Creek	.2	.1(k)	.1	----	
Junction of the North Tyger and Middle Tyger Rivers	.3(k)	Tr.	Tr.	nd	
Parts of the North Tyger, Middle Tyger, and South Tyger Rivers	Tr.	Tr.	Tr.	----	
Average	.2(k)	.1(k)	.1(k)	----	.1
Pacolet River, S.C.					
Lawson Fork Creek	.3	Tr.	.2	nd	
Buck Creek	.5	.5	.3	nd	
North Pacolet and South Pacolet Rivers	.1(k)	Tr.	----	Tr.(k)	
Average	.3(k)	.1	.2	Tr.(k)	.2
Broad River:					
Southern tributaries, South Carolina–North Carolina:					
Thicketty Creek	.6(k)	.9	.3	1.6	
Cherokee Creek	1.0(k)	.6	.6	.2	
McKinney Creek	Tr.	Tr.	Tr.	Tr.	
Average	.6(k)	.6	.2	.4	0.7
Northern tributaries, North Carolina:					
Buffalo Creek and Boween River	.9(k)	.6(k)	.1	.7	
Sandy Run	.8	.8	.7	.8	
Knob Creek	.5	.7	.2	.9	
Hinton Creek	.3(k)	.4	.1	.5	
Floyds Creek	.6	.4	Tr.	.7	
Catheys Creek	Tr.(k)	Tr.	nd	----	
Mountain Creek	Tr.	----	Tr.	.1	
Average	.4(k)	.6(k)	.3	.7	.8
South Fork Catawba River, N.C.:					
Indian Creek	1.0(k)	.6(k)	.1(k)	.4(k)	
Clark Creek	.2(k)	Tr.	Tr.	Tr.	
Jacob Fork	.3(k)	.2	Tr.	Tr.	
Henry Fork	.1	Tr.	Tr.	Tr.	
Laurel Creek	.1	nd	Tr.	nd	
Average	.5(k)	.3	Tr.(k)	.1(k)	.3
Catawba River, N.C.:					
Lyle Creek	.1(k)	.1	Tr.	Tr.	
Hunting Creek	.1	Tr.	.1	----	
Silver Creek	Tr.	Tr.	Tr.	Tr.	
Muddy Creek and Shadrick Creek	.1(k)	.1(k)	Tr.	Tr.	
Average	.1(k)	Tr.(k)	Tr.	Tr.	.1
Regional average from the Savannah to the Catawba Rivers	.3(k)	.3(k)	.1(k)	.3(k)	.4
Number of samples in regional average	1,707	560	250	97	

[1] Weighted for average proportions of gravel, sand, silt, and clay in the separate drainage basins, with a correction of 40 percent added to compensate for losses in panning.

ZIRCON

Zircon has the least regular distributive pattern of the minerals common in concentrates from the monazite belt (pl. 4). Its tenor is generally less than that of monazite (table 33), but in a few areas the tenor in zircon appears to be similar to or exceed that of monazite. These few areas, which are highs on the map of isograms for zircon, are marginal to the core of the monazite belt.

TABLE 33.—*Zircon in alluvium samples from the area between the Savannah and Catawba Rivers, S.C.-N.C.*

[In pounds per cubic yard. Figures are numerical averages of the quantities listed in the mineral tables in reports by D. W. Caldwell (1962, tables 1-15), N. P. Cuppels (1962, tables 16-25), P. K. Theobald, Jr. (1962, tables 26-35), A. M. White (1962, tables 36-44), except that for a few streams, single extraordinarily rich samples have been omitted from the average. nd, no data; Tr., trace]

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Savannah River, S.C.:					
Hogskin Creek	0.29	0.26	0.04	------	
Broadway Creek	.58	.88	.09	0.10	
Big Beaverdam Creek	.57	.03	.03	nd	
Big Generostee Creek	.68	.26	.04	.35	
Saddler Creek	.39	nd	.10	nd	
Big Beaverdam and Little Beaverdam Creeks	.73	.43	.02	.10	
Average	.58	.39	.06	.18	0.04
Saluda River, S.C.:					
Rabon Creek	.07	.11	.01	.02	
Walnut Creek	.04	.02	Tr.	.01	
Horse Creek	.10	.05	Tr.	nd	
Huff Creek	.27	.26	.05	.07	
Laurel Creek	.30	.18	.36	Tr.	
Turkey Creek	.35	Tr.	nd	nd	
Broad Mouth Creek	.38	.04	Tr.	.02	
Grove Creek	.35	.68	.05	.09	
Big Brushy Creek	.78	.46	Tr.	nd	
Average	.30	.26	.08	.03	.2
Enoree River, S.C.:					
Durbin Creek	.13	.09	.02	.01	
Gilder Creek	.17	.02	.02	nd	
Mountain Creek	.21	.05	.04	.02	
Average	.17	.07	.03	.02	.1
Tyger River, S.C.:					
Beaverdam Creek	.33	.15	nd	nd	
Ferguson Creek	.11	.13	.01	.01	
Junction of the North Tyger and Middle Tyger Rivers	1.18	1.48	.04	nd	
Parts of the North Tyger, Middle Tyger, and South Tyger Rivers	.80	1.00	.05	.20	
Average	.65	.74	.03	.10	.6
Pacolet River, S.C.:					
Lawson Fork Creek	.39	.12	.32	nd	
Buck Creek	.24	.40	.01	nd	
North Pacolet and South Pacolet Rivers	.77	.56	.25	.04	
Average	.41	.39	.17	.04	.4
Broad River:					
Southern tributaries, South Carolina-North Carolina:					
Thicketty Creek	.21	.10	.08	.03	
Cherokee Creek	.21	.06	------	.13	
McKinney Creek	.47	.15	.14	.20	
Average	.26	.10	.11	.13	.2
Northern tributaries, North Carolina:					
Buffalo Creek and Boween River	.19	.08	.05	.20	
Sandy Run	.19	.07	.05	.07	
Knob Creek	.18	.16	.06	.06	
Hinton Creek	.24	.74	.07	1.60	
Floyds Creek	.29	.26	.02	.14	
Catheys Creek	1.52	2.07	nd	.01	
Mountain Creek	.70	.82	.08	Tr.	
Average	.49	.40	.06	.12	.4

See footnote at end of table.

TABLE 33.—*Zircon in alluvium in samples from the area between the Savannah and Catawba Rivers, S.C.-N.C.*—Continued

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
South Fork Catawba River, N.C.:					
Indian Creek	.61	.75	.05	.10	
Clark Creek	.87	.26	.04	.02	
Jacob Fork	.22	.20	.02	.03	
Henry Fork	.34	.13	.07	Tr.	
Laurel Creek	.03	nd	.05	nd	
Average	.44	.47	.04	.06	0.4
Catawba River:					
Lyle Creek	.74	.06	.12	.03	
Hunting Creek	.65	.48	.23	.06	
Silver Creek	1.89	.60	.34	.06	
Muddy and Shadrick Creeks	1.42	.38	.16	.04	
Average	1.09	.48	.24	.12	.5
Regional average from the Savannah to the Catawba Rivers	.49	.39	.09	.10	.4
Number of samples in regional average	1,707	560	250	97	

[1] Weighted for average proportions of gravel, sand, silt, and clay in the separate drainage basins, with a correction of 25 percent added to compensate for losses in panning.

The inferred regional average tenor of 0.4 pound of zircon per cubic yard of sediment as estimated from grab samples is similar to the average of 0.6 pound of zircon per cubic yard (table 25) determined by churn drilling in 21 different fields in the monazite belt. Thus, the flood-plain sediments carry about half as much zircon as monazite both on the regional and local scale:

Material	Weighted average tenor (pounds per cubic yard) Zircon	Monazite
All flood-plain sediments	0.4	0.8
All sediment in placers	[1] .6	[2] 1.2

[1] Derived from 21 deposits listed in table 25; hence, less representative of the tenor in the placers than the average given for monazite.
[2] Derived from the 84 deposits classed as placers between the Savannah and Catawba Rivers, S.C.-N.C.

Any of the deposits that might be mined for monazite will provide some zircon as a byproduct. Zircon from the monazite belt should be as marketable as other placer zircon from the southeast, which brought about $50 per ton (2.5 cents per lb) in 1951 (Kauffman, 1954, p. 1347).

GARNET

Garnet from the southeastern placers is reported by Pratt (1904b, p. 1168) to be of good abrasive quality. Later, however, he (Pratt, 1908, p. 66) and Keith and Sterrett (1931, p. 13) stated that an effort was made to sell garnet from the monazite deposits for use as an abrasive, but the material was rejected or brought only small prices because of its small grain size and roundness. No attention seems to have been given the garnet since that time. Because of the large quantities available, an examination of the garnet to determine its current fitness for industrial use would probably be more important to the development of the monazite placers than further exploration for monazite.

Garnet equals the average weight of monazite in concentrates from placers (table 25) and from grab samples (table 34) between the Savannah and Catawba Rivers, S.C.–N.C.:

Material	Weighted average tenor (pounds per cubic yard) Garnet	Monazite
All flood-plain sediments	0.8	0.8
All sediment in placers	[1] 1.2	1.2

[1] From 21 deposits given in table 25; hence, less representative of the tenor in placers than the average given for monazite, which is derived from 84 deposits.

TABLE 34.—*Garnet in alluvium samples from the area between the Savannah and Catawba Rivers, S.C.–N.C.*

[In pounds per cubic yard. The figures are numerical averages of the quantities listed in mineral tables in reports by D. W. Caldwell (1962, tables 1–15); N. P. Cuppels (1962, tables 16–25), P. K. Theobald, Jr (1962, tables 26–35), A. M. White (1962, tables 36–44), except that for a few streams, single extraordinarily rich samples have been omitted from the average. Tr., trace (less than 0.1 lb per cu yd); nd, no data]

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
Savannah River, S.C.:					
Hogskin Creek	0.2	0.1	Tr.	Tr.	
Broadway Creek	1.0	.2	Tr.	Tr.	
Big Beaverdam Creek	.5	.2	.1	nd	
Big Generostee Creek	.2	.1	Tr.	.1	
Saddler Creek	.5	nd	.4	nd	
Big Beaverdam and Little Beaverdam Creeks	.9	.1			
Average	.7	.2	.1	Tr.	0.3
Saluda River, S.C.:					
Rabon Creek	.1	.1	Tr.	.2	
Walnut Creek	.1	.1		Tr.	
Horse Creek	.1	Tr.	Tr.	nd	
Huff Creek	1.5	.8	Tr.		
Laurel Creek	3.0	.2	Tr.		
Turkey Creek	.6	.2	nd	nd	
Broad Mouth Creek	.1	.1	Tr.	Tr.	
Grove Creek	1.0	.3	Tr.	Tr.	
Big Brushy Creek	1.5	.2	Tr.	nd	
Average	.8	.2	Tr.	Tr.	.3
Enoree River, S.C.:					
Durbin Creek	.4	.1	Tr.	Tr.	
Gilder Creek	3.5	1.4	.1	nd	
Mountain Creek	2.2	.2	.1	.1	
Average	2.5	.5	.1	Tr.	.8
Tyger River, S.C.:					
Beaverdam Creek	1.4	1.0	nd	nd	
Ferguson Creek	2.6	.1	.1	Tr.	
Junction of the North Tyger and Middle Tyger Rivers	1.6	.3	Tr.	nd	
Parts of the North Tyger, Middle Tyger, and South Tyger Rivers	3.2	.2	Tr.		
Average	2.1	.3	Tr.	Tr.	.5
Pacolet River, S.C.:					
Lawson Fork Creek	1.0	.5	.2	nd	
Buck Creek	1.9	.8	.2	nd	
North Pacolet and South Pacolet Rivers	.6	.2	.2	Tr.	
Average	1.3	.4	.2	Tr.	.2
Broad River:					
Southern tributaries, South Carolina–North Carolina:					
Thicketty Creek	1.4	.7	.1	Tr.	
Cherokee Creek	1.9	.8	Tr.	.1	
McKinney Creek	.8	.2	Tr.	.1	
Average	1.5	.7	Tr.	.1	.8
Northern tributaries, North Carolina:					
Buffalo Creek and Boween River	1.5	.9	.1	.9	
Sandy Run	1.9	.9	.1	.4	
Knob Creek	1.7	.9	.2	.3	
Hinton Creek	4.1	2.4	.6	.3	
Floyds Creek	1.6	1.3	Tr.	.6	
Catheys Creek	1.0	.2	nd		
Mountain Creek	.6	.2	Tr.	.1	
Average	1.9	.9	.3	.5	1.4

See footnote at end of table.

TABLE 34.—*Garnet in alluvium samples from the area between the Savannah and Catawba Rivers, S.C.–N.C.*—Continued

Tributary streams to—	Gravel	Sand	Silt	Clay	Weighted average [1]
South Fork Catawba River, N.C.:					
Indian Creek	4.2	1.6	.2	.1	
Clarks Creek	.9	.2	Tr.	Tr.	
Jacob Fork	2.3	4.0	.1	Tr.	
Henry Fork	1.2	1.0	Tr.	Tr.	
Laurel Creek	2.5	nd	.1	nd	
Average	2.9	1.3	.1	Tr.	1.6
Catawba River, N.C.:					
Lyle Creek	1.8	.2	Tr.	Tr.	
Hunting Creek	1.0	.2	Tr.	Tr.	
Silver Creek	2.6	1.3	.2	.1	
Muddy and Shadrick Creeks	.9	.4	.1	.1	
Average	1.5	.6	.1	.1	.7
Regional average from the Savannah to the Catawba Rivers	1.7	.6	.1	.2	.8
Number of samples in regional average	1,707	560	250	97	

[1] Weighted for average proportions of gravel, sand, silt, and clay in the separate drainage basins, with a correction of 50 percent added to compensate for losses in panning.

These averages can be misleading. In some of the richer monazite deposits, like the group of streams from the mouth of Buffalo Creek through Sandy Run listed in table 25, the amount of garnet is 2–10 times the amount of monazite in the concentrate. Also, the amount of garnet in concentrates from streams whose distributive provinces correspond to the highs on the map showing isograms for garnet (pl. 2) averages more than the amount of monazite in the same streams:

Drainage basin having greater than average concentrations of garnet	Weighted average tenor (pounds per cubic yard) Garnet	Monazite
Enoree River, S.C	0.8	0.7
Tyger River, S.C	.5	.4
Broad River:		
Southern tributaries, South Carolina–North Carolina	.8	.8
Northern tributaries, North Carolina	1.4	1.1
South Fork Catawba River, N.C	1.6	.8

The most impressive sources of garnet are at the heads of northern tributaries to the Broad River, N.C., and in the upper part of the Enoree River, S.C., where garnet isograms form highs in, and southwest of, the South Mountains and east of Paris Mountain.

Physical and optical properties of the garnets from placers show similar and narrow variations along the whole length of the monazite belt. The common placer garnet is a pyralspite (Winchell, 1933, p. 179) in which spessartite and almandite dominate. The index of refraction of most of the garnet ranges from 1.79 to 1.82, and the specific gravity is between 3.9 and 4.2 (Overstreet, Yates, and Griffitts, 1963b). Their natural crystal outline lends the garnets a subround form, but most of the garnets examined have cracks along which they part into angular or subangular fragments. No rounding of the fragments has been affected by abrasion during transportation, because the detrital grains have not moved far. Garnet is the coarsest grained mineral in the concentrate.

Recovery and sale of the garnet for use as abrasive material may be an avenue toward successful operation of some of the deposits. At a favorable price, some of the deposits listed in table 25 would be substantially increased in value, and the sale of garnet might be more profitable than the sale of monazite from several of the larger placers.

MAGNETITE

Magnetite is one of the least abundant minerals in the black sands from the monazite belt. The maps displaying isograms for magnetite (pl. 1) and monazite (pl. 3) show that magnetite makes up less than 5 percent of the concentrate in the core of the monazite belt. Its weighted average tenor in the 21 streams drilled as representative placers (table 25) is 0.3 pound per cubic yard. This tenor is the same as that found for rutile and is about one-fourth the tenor estimated for monazite in the 84 placers between the Savannah and Catawba Rivers, S.C.–N.C.

Magnetic fractions from plus 1/8-inch sediment at five places in Spartanburg County, S.C., where coarse magnetite is common, was analyzed spectrographically and radiometrically (table 35), and the material was found to have no unusual abundance of rare elements that would increase its value. In another investigation of the chemical properties of detrital magnetite from the monazite-bearing part of the Inner Piedmont belt between the Savannah and Catawba Rivers, S.C.–N.C., variation in the abundance of minor elements in several hundred samples of magnetite was found to relate to the kind of rocks in which the magnetite crystallized (Theobald and Thompson, 1962; Theobald and others, 1967).

Magnetite contributes nothing to the value of the monazite placers.

CASSITERITE, WOLFRAMITE, AND OTHER MINERALS

Mineralogic examination of concentrates from the southeastern placers by personnel of both the U.S. Geological Survey (Caldwell, 1962, tables 1–15; Cuppels, 1962, tables 16–25; Theobald, 1962, tables 26–35; White, A. M., 1962, tables 36–44) and the U.S. Bureau of Mines (Griffith and Overstreet, 1953a–c; Hansen and Caldwell, 1955; Hansen and Cuppels, 1954, 1955; Hansen and Theobald, 1955; Hansen and White, 1954) failed to disclose cassiterite, though deposits lie a few miles east of the monazite belt at the boundary between North and South Carolina (Keith and Sterrett, 1931, p. 10–12). Traces of tin were detected spectrographically in 43 of the 140 concentrates analyzed (table 36) of which 39 tin-bearing concentrates were from the Savannah River-Catawba River area. Some tin was found in one of the five magnetic separates studied (table 35, sample 52–CS–171A), and tin was present in many samples of detrital magnetite from the Savannah River-Catawba River area (Theobald and others, 1967). The source of the tin detected in the 43 concentrates may be mainly magnetite instead of cassiterite, but small amounts of cassiterite are possibly present in concentrates from the central and southeastern part of the Savannah River-Catawba River area, where tin occurs in abundances of 0.0X to 0.X percent (pl. 9). Beryllium is commonly associated with tin in concentrates from streams between the Enoree River, S.C., and the South Fork Catawba River, N.C. (pl. 9), a relation that probably indicates a common source for the tin- and beryllium-bearing minerals in the concentrates. In Cleveland County, N.C., and Cherokee and Spartanburg Counties, S.C., the source is most likely pegmatite related to the Cherryville Quartz Monzonite (Theobald and others, 1967).

The traces of beryllium detected spectrographically, dominantly 0.0001–0.001 percent of the concentrate, are on the order of the distribution of beryllium in the common rock-forming minerals of granite pegmatites

TABLE 35.—*Analyses of coarse-grained magnetic fractions from alluvium in Spartanburg County, S.C.*

Spectrographic analyses by K. E. Valentine and H. W. Worthing, U.S. Geol. Survey. Equivalent uranium (by radioactivity) measured by B. A. McCall, U.S. Geol. Survey]

Sample	Range, in percentage, of elements detected						Equivalent uranium (percent)
	>10	1-10	0.1-1.0	0.01-0.1	0.001-0.01	0.0001-0.001	
52–CS–154A	Fe	Al, Si	Ca, Ti	Cr, Mg	Cu, Pb, Zr	Yb, Be	0.002
165A	Fe	Al, Si	Ca, Ti, Mg	Cr, Na, Mn, B, V	Cu, Ga, Ba, Zr, Ni, Pb, Y, Sc, Sr	Yb, Be	.001
166A	Fe	Al, Si	Ca, Ti, Mg	Na, Cr, Mn, V, Ba	B, Zr, Ga, Cu, Pb, Ni, Sr, Sc, Y	Yb, Be	.002
171A	Fe, Al	Si	Ca, Ti, Mg	Cr, Na, Mn, V, Ba, Zr	Sn, Ga, Cu, Ni, Pb, Sc, Sr, Y	Yb, Be	.002
182A	Fe	Al, Si	Ca, Ti, Na, Mg	Cr, B, Mn, V, Ba	Ga, Cu, Zr, Ni, Pb, Sr, Sc, Y	Yb	.002

in the tin belt (Griffitts, 1954, p. 7–8) and indicate no concentration of beryllium-bearing minerals in the placers.

The low abundances and scattered occurrences of silver shown on plate 9 do not correlate with variations in any mineral in the concentrates; hence, silver must vary in abundance in one or more minerals, possibly even minor minerals, and its variation may be attributed to its variable concentration in its host or hosts, but they are unknown. No relation is known between the distribution of silver in the concentrates and the geology of the crystalline rocks.

Wolframite and scheelite were not detected in mineralogic studies, nor was tungsten identified by spectrographic analysis. Tungsten-bearing minerals are absent from all five areas examined between the Dan and Chattahoochee Rivers.

Chromium generally appears in the spectrographic analyses (table 36), but its low abundance suggests that it is not present as chromite. It is known to be present in magnetite from the Savannah River-Catawba River area (Theobald and others, 1967).

The spectrographic analyses demonstrate that the concentrates lack any economically useful minerals, except those listed in the mineral tables.

VALUE OF THE PRODUCT

A summary of the probable values of the products from the placers, based on prices current in the period 1951–54 and assuming complete marketability, shows an assumed value of 80–90 cents per cubic yard (table 37). Such value is fictional. It would be lowered by 60 cents per cubic yard for every cubic yard of sand and gravel not marketed.

If ilmenite, rutile, zircon, and garnet could be sold, the value of these minerals plus monazite would be between 25 and 33 cents per cubic yard of placer ground.

TABLE 36.—*Summary of results of spectrographic analyses of 140 concentrates from the monazite-bearing part of the Inner Piedmont belt, Virginia through Georgia*

[Compiled from semiquantitative spectrographic analyses made by C. S. Annell, Joseph Haffty, K. E. Valentine, and H. W. Worthing, U.S. Geol. Survey.]

Element	Number of occurrences of each element in each range percent					
	>10.0	1.0–10.0	0.1–1.0	0.01–0.1	0.001–0.01	0.0001–0.001
Iron	122	18				
Titanium	90	50				
Silicon	26	105	9			
Aluminum	15	81	42			
Thorium		40	37	14		
Zirconium	1	27	78	32		
Manganese			132	5		
Chromium		1	5	117	13	
Magnesium		6	121	12		
Gallium				2	59	
Yttrium		1	75	50	8	1
Scandium					136	3
Gadolinium		1	22	47		
Terbium				6		
Dysprosium				28	13	
Holmium			1	4	1	
Erbium				10		
Ytterbium				9	110	19
Cerium	1	22	84	20		
Lanthanum		6	73	47	5	
Praseodymium			32	15		
Neodymium		4	88	40		
Samarium		1	51	49	1	
Europium				3		
Phosphorus	1	15	42			
Vanadium			1	73	60	4
Niobium				35	85	
Molybdenum					3	
Cobalt				109	16	
Nickel				20	39	
Copper				2	138	
Silver						10
Zinc				3		
Tin			2	16	25	
Lead			3	81	40	
Beryllium					5	30
Boron			15	36		
Calcium		24	60	2		
Strontium				20	57	1
Barium			2	1	102	2

TABLE 37.—*Estimated value of products from fluviatile monazite placers, assuming complete marketability*

Product	Price per pound	Regional average for all alluvium between Savannah and Catawba Rivers, South Carolina–North Carolina		Estimated average for 84 placers between Savannah and Catawba Rivers, South Carolina–North Carolina		Weighted average for 21 fields tested by churn drilling	
	Cents	Pounds per cubic yard	Cents per cubic yard	Pounds per cubic yard	Cents per cubic yard	Pounds per cubic yard	Cents per cubic yard
Monazite	16	0.8	12.8	1.2	19.2	0.5	8.0
Sand	.03	1,400	42.0	1,500	45.0	1,500	45.0
Gravel	.05	280	14.0	300	15.0	300	15.0
Ilmenite	1	7.0	7.0	6.0	6.0	5.3	5.3
Rutile	7	.1	.7	.2	1.4	.3	2.1
Gold	[1] .1	[2] .1	.01	[2] .2	.02	[2] .3	.03
Sillimanite-kyanite	1	.4	.4	.5	.5	.5	.5
Zircon	2.5	.4	1.0	.6	1.5	.6	1.5
Garnet	4.7	.8	3.8	1.0	4.7	1.2	5.6
Total			81.71		93.32		83.03

[1] Per milligram.
[2] Milligrams per cubic yard.

Only a slight increase over these values could be realized by attempting to select placers unusually rich in monazite, ilmenite, rutile, or zircon within one category of deposit, because average tenors of these minerals do not vary greatly within each of the categories of flood plain classed as a placer. Greater gains in value per cubic yard would be obtained by changing category and seeking the high-tenor small-volume deposits, but attendant increases in operating costs would offset any gain achieved. Considerable increase in revenue within a category of placer might follow selection of deposits rich in garnet, because some placers contain many times the garnet average, but any increase in revenue would depend on acceptance of the garnet by industry.

Absence of a market for the coproducts and byproducts would prevent development of the placers unless the price of monazite goes up.

SUMMARY

Reconnaissance of the monazite-bearing part of the Inner Piedmont belt is as complete as the results justify. Further work of a similar nature along the monazite belt is not warranted in the absence of development of the explored areas, but some future reconnaissance in connection with any opening of placer mining in the area could be expected.

Future reconnaissance might begin where the present investigation left off and, initially, be guided by the trend of isograms for monazite shown on plate 3 which suggests six places for study. An area might be explored southwestward from Abbeville County, S.C., where monazite-rich concentrates occur between the Little and Rocky Rivers, to the drainage basin of the Oconee River near Athens, Ga. Exploration could follow the monazite highs that lead west toward the Blue Ridge near the Tugaloo River, Oconee County, S.C., and near Paris Mountain, Greenville County, S.C. A similar high appears east of Marion, McDowell County, N.C., and might be followed toward the north across Lake James into the Blue Ridge, possibly in conjunction with exploration for uranium in the Grandfather Mountain window in McDowell and Burke Counties, N.C. In eastern Burke County, N.C., the strong core of the monazite belt might be traced northeastward across the Catawba River into Caldwell County. The broad area in Catawba County, N.C., that lies northeast of Lincolnton at the big bend in the Catawba River from which concentrates containing 1–10 percent monazite came, might be examined for the amount of uranium in the monazite. If the uranium is unusually abundant, then the northeastward projection of the area into Iredell County, N.C., might also be explored for placers.

Additional reconnaissance for monazite along the Inner Piedmont belt farther toward the southwest than the drainage basin of the Oconee River, Ga., or farther northeast than the southern tributaries to the Yadkin River, N.C., cannot be justified. Earlier recommendations (W. C. Overstreet, P. K. Theobald, Jr., A. M. White, N. P. Cuppels, D. W. Caldwell, and J. W. Whitlow, unpub. data, 1953) cannot be continued for the exploration of eluvial deposits in the monazite belt or alluvial deposits on the trunk streams between the belt and the Fall Line at the inner edge of the Atlantic Coastal Plain. Exploration around the Fall Line near Columbia, S.C., however, seems warranted.

In planning the exploratory program we recognized that the hand methods of mining formerly used (successful when labor received $0.50 to $1 per day) are impractical under present economic conditions. We further assumed that mechanization of mining would decrease the cost of producing monazite and thought that somewhere between the trunk streams and the sites of former mines near the heads of tributaries, placers could be found whose tenor and yardage would adequately support mechanical mining. In the first season (1951–52), the placers drilled were of a size (1.5–3.5 million cu yd of alluvium) suitable for mining by dragline, dryland, or suction dredges having a maximum capacity of 2,000 cubic yards per day. However, the tenor in monazite, about 1.6 pounds per cubic yard, proved to be too low for a dragline operation. During the second season (1952–53), attention was given to larger deposits (more than 10 million cu yd) to learn if any of them had an adequate amount of monazite to support bucketline dredges having a daily capacity of 5,000 cubic yards, but no such deposit was found. All the drilled deposits are submarginal monazite placers. No further exploratory drilling can be recommended for the western belt.

Ordinarily, the record of this drilling would be ample for a recommendation against further drilling, but several factors induce a more conditional approach. Reappraisal of the recommendation would be needed if placer garnet became acceptable to the abrasives industry, if the uranium-rich monazite associated with the Cherryville Quartz Monzonite were found to be common, and if an artificially high price for monazite were guaranteed. At the advent of one or a combination of these factors, developmental drilling might commence in some of the areas previously drilled, and additional exploratory drilling might begin on untried flood plains.

The outstanding site among the appraised but undrilled deposits is the large placer area along the South Fork Catawba River and its western tributaries, northwest of Lincolnton, N.C. Reconnaissance beyond the area examined for this report, especially toward the

Blue Ridge, might turn up more sites for local drilling. Some drilling should be accorded the area along the middle Oconee River, Ga.

Monazite had not been mined in the western Piedmont for 34 years when exploration began in 1951, and, except for a few abortive efforts in 1951–54, the industry has not revived. Successful opening of the placers would require either a high price for monazite or establishment of markets for the dominant byproducts. If either condition is met, several of the fields already drilled and the deposits singled out in these appraisals are sites for further exploration leading toward development. If placers are ever opened for mechanical mining by dragline or bucketline dredge and a plant is erected for local separation of the minerals in the concentrate, a favorable environment may be created for the revival of small-scale mining. Custom handling of rough concentrates from small operations, which could be performed at the plant, would provide the only feasible outlet for monazite mined by landowners from streams on their property.

Deposits capable of being worked by earth-moving equipment common to farms in the Southeast are thought to contain about two-thirds as much monazite as the deposits amenable to mining by dragline or bucketline dredge. These small deposits were not much studied during reconnaissance, but the following estimates are made for the core of the monazite belt between the Savannah and Catawba Rivers, S.C.–N.C. There is as least one placer for every six farms; that is, a total of about 5,000 small placers. The average tenor is 5 pounds of monazite per cubic yard, and the average volume is about 20,000 cubic yards. Thus, it appears that half a billion pounds of monazite could be found in the small placers along creeks and branches in the core of the belt. The 84 placers (of which 76 are large enough to be mined by dragline or bucketline dredge) discovered in the same area contain about three-quarters of a billion pounds of monazite (Overstreet, Theobald, and Whitlow, 1959, p. 712).

The resource represented by the small placers is so great that every effort should be made to revive interest in them in conjunction with development of the large deposits. Establishment of local custom plants for beneficiation of concentrates would not be enough to bring the small deposits into production. Fears that mining would disturb the balances now effected in the land would have to be relieved. Fields are stabilized on many of the farms; hence, the possible destruction of the equilibrium achieved after years of contour plowing, systematic planting, and the control of gullies would generally appear to be too great a penalty for the income from a brief scalping of the monazite.

Development of monazite mining at the household level would require a plan to advise and demonstrate safe methods of mining and ways to adapt common farm machinery for mining. No well-organized plan could be introduced without prior study of the problems (W. C. Overstreet and P. K. Theobald, Jr., unpub. data, 1952; Griffith and Overstreet, 1953a, p. 8, 27–29; W. C. Overstreet, P. K. Theobald, Jr., A. M. White, N. P. Cuppels, D. W. Caldwell, and J. W. Whitlow, unpub. data, 1953). Mining practice, whether by dredge or at the household level, would have to provide for leveling and smoothing the tailings to reclaim the flood plains for pasture or crops, and local base levels of erosion should not be lowered. Monazite mining as a household industry would have to be introduced as an annual cropping program harmonious with other aspects of modern husbandry, as the monazite-bearing part of the Inner Piedmont belt is an agricultural community and not a mining district.

The methods of heavy-mineral prospecting (Overstreet, Theobald, Whitlow, and Stone, 1955) developed during reconnaissance in the monazite belt in the southeastern United States can be applied elsewhere in the world to studies of the distribution of a wide variety of economic minerals (Overstreet, 1962, 1963). Modifications of the system to suit diverse conditions are apparent, and the methods can be introduced wherever the stream density is adequate and the region is unglaciated. Although the information must embrace several thousand square miles to be useful, concentrations of ore minerals—or of minerals indirectly indicative of ore deposits—shown by the contours, become foci for normal geologic search.

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